**Species Status Assessment Report for the**
**Southern White-tailed Ptarmigan**
**(*Lagopus leucura altipetens*)**

Prepared by the Montana Ecological Services Field Office
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**Southern White-tailed Ptarmigan Species Status Assessment**

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## Executive Summary

This species status assessment (SSA) report documents the results of the comprehensive review of the biological status for the southern white-tailed ptarmigan (*Lagopus leucura altipetens*), a small grouse found in alpine habitats of Colorado, northern New Mexico, and historically in southern Wyoming. This SSA report summarizes a thorough analysis of the subspecies' overall viability, or ability to maintain a population in the wild, and thus extinction risk, using the SSA framework (Smith et al. 2018). This SSA report is intended to provide the best available biological information to inform the U.S. Fish and Wildlife Service's (Service's) decision on whether or not the southern white-tailed ptarmigan is warranted for listing under the Endangered Species Act (Act), and if so, whether, and where, to propose critical habitat.

The southern white-tailed ptarmigan historically inhabited alpine areas in the Rocky Mountains from the Snowy Range in southern Wyoming south through alpine habitats of Colorado and into northern New Mexico south to near Santa Fe, New Mexico. The distribution of southern white-tailed ptarmigan is largely unchanged from historical levels with some exceptions. The lack of recent observations in the Snowy Range suggests that ptarmigan populations no longer persist in Wyoming.

The southern white-tailed ptarmigan primarily inhabits alpine ecosystems at or above treeline year-round, although areas below treeline are also used in winter. White-tailed ptarmigan experience extreme variability in temperature, precipitation, wind, and snow cover and exhibit a high level of plasticity and adaptability to these conditions.

For this SSA, we first identified the individual needs of the subspecies, including winter snow conditions, the availability of late-lying snowfields, summer precipitation/monsoonal moisture, brood-rearing habitat, and willow availability. We also identified population needs that are most influential to resiliency, including external recruitment of immigrants, breeding dispersal, adult female survival, and population growth. At the subspecies level, the southern white-tailed ptarmigan needs a certain number of populations (redundancy) with genetic and ecological diversity across the populations (representation).

We first evaluated current condition for the subspecies by evaluating the resiliency of populations across the overall range. To roll up our analysis, we identified 3 representative units and 19 analytical units (AUs) to evaluate resiliency. Then using a calibrated condition category table, we systematically evaluated the current condition for each of the habitat and demographic factors identified as needs across all 19 analytical units and averaged these for an overall score of resiliency, either High, Medium, Low, or Very Low conditions. Our analysis of current conditions for the southern white-tailed ptarmigan revealed that 14 AUs are in High condition, 3 AUs are in Medium condition, 1 AU is in Very Low condition, and 1 AU is presumed extirpated (Table 1). Redundancy and representation are characterized by these 18 AUs distributed across Colorado and a small portion of northern New Mexico across 3 representative units.

Table 1. Summary of current conditions for southern white-tailed ptarmigan analytical units. For the Snowy Range AU in Wyoming, we evaluated condition for the habitat factors but assigned an "X" to the demographic factors, as this AU is presumed extirpated.

| **Analytical Unit (Shading identifies the representative unit: green = northern; tan = southern; blue = New Mexico)** | **Winter snow conditions** | **Late-lying snowfields** | **Summer precipitation/ monsoonal moisture** | **Brood-rearing habitat (insects/forbs)** | **Willow availability** | **External recruitment of immigrants/ Breeding dispersal** | **Adult female survival** | **Population growth** | **Overall Current Condition Score** | **Overall Current Condition** |
|---|---|---|---|---|---|---|---|---|---|---|
| Crown Point | High | Unknown | Medium | Medium | High | High | Unknown | Unknown | 5.8 | High |
| Mt. Evans | High | Medium | Medium | High | High | High | High | High | 6.5 | High |
| RMNP/Trail Ridge | High | Medium | Medium | High | Low | High | High | Low | 5.7 | High |
| Niwot Ridge | High | High | Medium | Medium | High | High | Unknown | Unknown | 5.8 | High |
| Independence Pass | High | High | High | High | High | High | High | High | 6.7 | High |
| Square Top | High | Unknown | Medium | Unknown | High | High | Medium | Medium | 5.9 | High |
| Guanella Pass | High | Unknown | Medium | Unknown | High | High | Medium | Medium | 5.9 | High |
| Loveland Pass | High | Unknown | Medium | Unknown | Medium | High | Medium | Medium | 5.8 | High |
| Byers Peak | High | High | High | High | High | High | High | High | 6.7 | High |
| Flat Tops | High | High | Unknown | High | High | Medium | Unknown | Unknown | 5.0 | Medium |
| Mt. Yale | High | High | High | High | High | High | High | High | 6.7 | High |
| Mt. Zirkel | High | Medium | High | Medium | Medium | Medium | Unknown | Unknown | 4.7 | Medium |
| Sangre de Cristos | Medium | Low | Medium | Medium | Medium | Medium | Unknown | Unknown | 4.4 | Medium |
| Snowy Range, Wyoming-Presumed Extirpated | Medium | Unknown | Unknown | Medium | Medium | X | X | X | **X** | **X** |
| Mesa Seco | High | Low | High | High | High | High | High | High | 6.5 | High |
| Emerald Lake | High | High | High | High | High | High | High | High | 6.7 | High |
| Ophir | High | High | High | High | High | High | High | Low | 6.0 | High |
| Southern San Juans | High | Medium | High | High | High | High | Unknown | High | 6.6 | High |
| New Mexico (Culebra, Wheeler Peak, Northern Pecos) | Unknown | Very Low | Medium | Medium | Low | Very Low | Very Low | Very Low | 2.1 | Very Low |

To evaluate future condition, we used scenario planning to project a range of plausible futures using the same methodology we used to evaluate current condition. We evaluated the range of expected future conditions for southern white-tailed ptarmigan by 2050. We selected 2050 because we had localized climate models available for this timeframe. This timeframe also represents approximately 10 generations of southern white-tailed ptarmigan. The viability of southern white-tailed ptarmigan is dependent upon maintaining demographic connectivity across suitable alpine habitat. Future change in climate is the primary factor expected to influence future conditions for southern white-tailed ptarmigan, specifically changes in projected temperature and precipitation.

We considered three plausible future scenarios based on projected changes in climate. We considered three climate scenarios: Very Hot and Dry, Hot, and Hot and Very Wet, using downscaled and consolidated climatic data. We evaluated each of these scenarios in terms of how it would influence resiliency, redundancy, and representation of southern white-tailed ptarmigan by the year 2050.

Currently, 14 of 19 AUs are in High condition, 3 AUs are in Medium condition, 1 AU is in Very Low condition, and 1 AU is presumed extirpated. We anticipate that of the 18 extant AUs, 17 will remain occupied under all scenarios, and 18 will remain occupied under Future Scenarios 2 and 3. In this analysis, resiliency for all of the AUs is expected to decrease under Future Scenario 1 due to substantially hotter and drier climate conditions. We also expect a decrease in redundancy and representation under Future Scenario 1 due to the loss of the New Mexico representative unit, which represents an increased risk to the subspecies under Scenario 1. Under Future Scenario 2, we expect that resiliency will be maintained similar to current conditions for all AUs with the exception of the Ophir AU, which declines under this scenario due to reductions in winter snow conditions, availability of late-lying snowfields, and brood-rearing habitats. Under Future Scenario 3, we anticipate reductions in resiliency across 5 AUs due to reductions in several habitat and demographic factors as a result of reductions in snowpack leading to reductions in brood-rearing habitat and subsequent impacts to both adult female survival and chick survival influencing population growth. Redundancy and representation are expected to be maintained under Future Scenarios 2 and 3. Therefore, risk to the subspecies generally stays the same as current condition by year 2050 under Future Scenarios 2 and 3 (Tables 2 and 3).

Table 2. Summary of overall condition scores for current condition and three future scenarios by year 2050 by analytical unit. Analytical units assigned an "X" are considered extirpated.

| **Analytical Unit** **(Shading identifies the representative unit: green = northern; tan = southern; blue = New Mexico)** | **Overall Current Condition Score** | **Future Scenario 1: Very Hot and Dry** | **Future Scenario 2: Hot** | **Future Scenario 3: Hot and Very Wet** |
|---|---|---|---|---|
| Crown Point | High | Medium | High | High |
| Mt. Evans | High | Medium | High | High |
| RMNP/Trail Ridge | High | Medium | High | Medium |
| Niwot Ridge | High | Medium | High | High |
| Independence Pass | High | Medium | High | High |
| Square Top | High | Medium | High | Medium |
| Guanella Pass | High | Medium | High | Medium |
| Loveland Pass | High | Low | High | Medium |
| Byers Peak | High | Medium | High | High |
| Flat Tops | Medium | Low | Medium | Medium |
| Mt. Yale | High | Medium | High | High |
| Mt. Zirkel | Medium | Low | Medium | Medium |
| Sangre de Cristos | Medium | Low | Medium | Medium |
| Snowy Range, Wyoming-Presumed Extirpated | **X** | **X** | **X** | **X** |
| Mesa Seco | High | Medium | High | High |
| Emerald Lake | High | Medium | High | High |
| Ophir | High | Low | Medium | Medium |
| Southern San Juans | High | Low | Medium | High |
| New Mexico (Culebra, Wheeler Peak, Northern Pecos) | Very Low | **X** | Very Low | Very Low |

Table 3. Summary of the current and future condition for the southern white-tailed ptarmigan in terms of the resiliency of analytical units (AUs), and redundancy and representation of the subspecies.

| 3Rs | Current Condition | Future Condition by year 2050 | | |
|---|---|---|---|---|
| | | Very Hot and Dry Scenario | Hot Scenario | Hot and Very Wet Scenario |
| **Resiliency** | •14 out of 19 AUs are currently in high condition.<br>•3 AUs are in medium condition.<br>•1 AU is in very low condition.<br>•1 AU is presumed extirpated (Snowy Range in Wyoming). | All AUs have reduced resiliency from current conditions<br>•11 AUs currently in high conditon will decline to Medium<br>•3 AUs currently in high condition will decline to Low<br>•3 AUs currently in medium condition will decline to Low<br>•New Mexico expected to be extirpated from very low condition currently. | Resiliency maintained for all AUs at current condition levels, with exception of Ophir which declines from high to medium condition, due to decrease in late-lying snow. | • 9 AUs remain in High condition; 5 AUs decline from High to Medium condition<br>•3 AUs remain in Medium condition<br>•1 AU remains in Very Low condition |
| **Redundancy** | Number and distribution of AUs largely unchanged from historical levels except for the loss of Snowy Range AU. | 17 of 18 AUs remain, with the same distribution. | Continue to have 18 AUs, with the same distribution | Continue to have 18 AUs, with the same distribution |
| **Representation** | 18 out of 19 AUs occupied across three representative units | Ecological and possibly genetic diversity decline due to loss of New Mexico | Expect ecological and genetic diversity to be maintained | Expect ecological and genetic diversity to be maintained |

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# Chapter 1: Introduction and Analytical Framework

This report summarizes the results of a species status assessment (SSA) conducted for the southern white-tailed ptarmigan (*Lagopus leucura altipetens*). In 2010, the U.S. Fish and Wildlife Service (Service) received a petition to list either the U.S. population or the Rocky Mountain population of the white-tailed ptarmigan (*L. leucura*) as threatened, distinct population segments (DPSs) and to designate critical habitat. Following correspondence with the Service regarding the accepted taxonomy of the white-tailed ptarmigan and our DPS policy, the petitioner revised its petition in October 2011. The revised petition requested that we list the southern white-tailed ptarmigan and the Mt. Rainier white-tailed ptarmigan (*L. l. rainierensis*) as a threatened species under the Endangered Species Act of 1973, as amended (Act). In June 2012, the Service found that the petition presented substantial scientific or commercial information indicating that the listing of the southern white-tailed ptarmigan and Mt. Rainier ptarmigan may be warranted (77 FR 33143). This SSA report applies only to the southern white-tailed ptarmigan; the SSA for Mt. Rainier ptarmigan will be presented in a separate report.

## 1.1. Analytical Framework for the Species Status Assessment

This SSA report for the southern white-tailed ptarmigan is intended to provide the biological support for the decision on whether or not to propose to list the subspecies as threatened or endangered under the Act and, if applicable, where to propose designating critical habitat. This SSA report does not result in a decision by the Service on whether this subspecies should be proposed for listing as threatened or endangered under the Act. Instead, this SSA report provides a review of the best available scientific and commercial information regarding the biological status of the southern white-tailed ptarmigan. The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the Federal Register, with opportunities for public input, if appropriate.

This report summarizes the subspecies' biology (taxonomy, life history, and habitat); its ecological needs at the individual, population (analytical unit), and/or subspecies levels; the current condition of the subspecies' habitat and demographics, and the probable explanations for historical and current changes in abundance and distribution across the range of the subspecies; and the subspecies' response to probable future scenarios of environmental conditions and conservation efforts. The SSA report is intended to be easily updated as new information becomes available, and to support all functions of the Endangered Species Program. As such, the SSA report will be a living document upon which other documents, such as listing rules, recovery plans, and 5-year reviews, would be based if the species warrants listing under the Act.

Using the SSA framework, we consider what the southern white-tailed ptarmigan needs to maintain viability by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation, collectively known as the 3Rs (Shaffer et al. 2002, pp. 139-140; Wolf et al. 2015; Smith et al. 2018). For the purpose of this assessment, we define viability as the ability of the species to sustain populations in natural ecosystems over a biologically meaningful timeframe, in this case, by middle of the 21$^{st}$ century (2050). This timeframe is a period that allows us to reasonably project the potential effects of various stressors within the

range of the species and also accounts for approximately 10 generations of southern white-tailed ptarmigan. This is also consistent with the time scale for which we have data available on the subspecies.

The 3Rs are defined as follows:

**Resiliency** is the ability of a species to withstand stochastic disturbance by having sufficiently large populations for the species to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health, such as population size, growth rate, and habitat connectivity. Resilient populations are better able to withstand disturbances that contribute to random fluctuations in birth rates (demographic stochasticity), variations in weather events (environmental stochasticity), or the effects of human activities.

**Redundancy** is the ability of a species to withstand catastrophic events by spreading risk among multiple populations or across a large area by having a sufficient number of populations for the species to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy can be measured through the duplication and distribution of populations across the range of the species. Generally, the greater the number of populations a species has distributed over a larger landscape, the better it can withstand catastrophic events.

**Representation** is the ability of a species to adapt to changing environmental conditions over time as characterized by the breadth of genetic and environmental diversity within and among populations. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human-caused) in its environment.

The decision to list a species or subspecies is based upon an assessment of the species' or subspecies' risk of extinction. This SSA report is intended to inform this assessment of extinction risk by describing the subspecies' current biological status and assess how this status may change in the future under a range of scenarios. We evaluate the current biological status of the southern white-tailed ptarmigan by assessing the factors positively and negatively affecting the subspecies and describe current condition of the subspecies in terms of the 3Rs. We then evaluate the future biological status by describing a range of plausible future scenarios representing a range of conditions for the primary factors affecting the subspecies and forecasting the most likely future condition for each scenario in terms of the 3Rs.

## Chapter 2: Subspecies Description, Distribution, and Ecology

In this chapter, we describe the southern white-tailed ptarmigan, as well as its taxonomy, distribution and life history. We also provide a summary of the relevant ecological requirements of the southern white-tailed ptarmigan at the individual, population, and subspecies levels. These ecological requirements form the basis of our analyses conducted in Chapters 3 and 4.

## 2.1. Species Taxonomy and Description

The white-tailed ptarmigan is the smallest grouse in North America, occurring in the taxonomic order Galliformes, family Phasianidae, and the subfamily Tetraoninae (Dimcheff et al. 2002, p. 203; Martin et al. 2015, unpaginated). It inhabits alpine areas (above treeline) in mountainous areas from Alaska to northern New Mexico (Figure 1). The white-tailed ptarmigan does not hybridize (interbreed) with either the rock (*L. muta*) or willow ptarmigan (*L. lagopus*) where ranges overlap in the northern part of the range (Short 1967, p. 17; Johnsgard 1973, p. 252; Hoffman 2006, pp. 11, 36). Brood-rearing habitat may overlap with dusky grouse (*Dendragapus obscurus*) (Zwickel and Bendell 2018, unpaginated); however, the two species typically use different portions of the alpine for foraging and cover (Hoffman 2006, p. 36).

Figure 1. Distribution of white-tailed ptarmigan. Black points indicate successful population introductions. Red dot in New Mexico indicates a translocation/reintroduction. Modified from Martin et al. 2015.

Five subspecies of white-tailed ptarmigan are currently recognized based largely on phenotypic differences (American Ornithological Union (AOU) 1957, p. 135). Since 1957, the AOU has not conducted a review of its subspecific distinction and no longer lists subspecies as of the 6th edition (AOU 1983). However, the AOU recommends the continued use of its 5th edition for

taxonomy at the subspecific level (1998, p. xii). Based on their 1957 consideration of the taxon, the AOU recognizes the southern white-tailed ptarmigan as a valid subspecies.

Two subspecies, the southern white-tailed ptarmigan and the Vancouver Island white-tailed ptarmigan (*L. l. saxatilis*), are somewhat geographically isolated. The southern white-tailed ptarmigan occupies the Rocky Mountains in Colorado, New Mexico, and historically in southern Wyoming. The Vancouver Island white-tailed ptarmigan is restricted to Vancouver Island, British Columbia (Martin et al. 2015, unpaginated). Recent genomic work (Langin et al. 2018) provides evidence that *L.l. altipetens* and *L.l. saxatilis* display substantial genetic divergence from each other and from the other three currently recognized subspecies (Langin et al. 2018, p. 1480).

The level of divergence is more subtle among the other three subspecies (Langin et al. 2018, p. 1480), with some evidence to support the currently recognized subspecies (Langin et al. 2018, pp. 1478-1479). However, additional sampling will be needed to determine the validity of these three subspecies and the location of their respective geographic boundaries (Langin et al. 2018, p. 1482). The Kenai white-tailed ptarmigan (*L. l. peninsularis*) occurs from southern Alaska east to the northern Rocky Mountains of the Yukon and Northwest Territories and south to Glacier Bay, Alaska (Aldrich 1963, p. 543). The northern white-tailed ptarmigan (*L. l. leucura*) occurs from British Columbia and southwest Alberta south into Montana (Aldrich 1963, p. 542; Langin et al. 2018, pp. 1481-1482). The Mt. Rainier white-tailed ptarmigan (*L. l. rainierensis*) occupies the Cascade Range of Washington., and likely extends into southwestern British Columbia (Langin et al. 2018, Suppl. Materials, Figure S10).

Within *L.l. altipetens*, genetic analysis revealed two distinct clusters, separating southern Colorado from other *L.l. altipetens*. Further genomic analysis detected finer-scale levels of population structure and identified three clusters: (1) New Mexico; (2) southern Colorado; and (3) central and northern Colorado (Langin et al. 2018, p. 1478, Suppl. Materials, Figure S8; Zimmerman et al. 2020). The results of additional genomic analysis suggest that individuals in southern Colorado and New Mexico may be locally adapted to climatic conditions found in the southern part of the subspecies range, specifically warmer summer temperatures and higher summer precipitation (Zimmerman et al. 2020).

At the time of this assessment, the best available scientific and commercial information suggests that the five subspecies identified by the AOU are valid, including strong genetic evidence for the designation of the *L.l. altipetens* subspecies (Langin et al. 2018). Therefore, we accept the taxonomic characterization of the southern white-tailed ptarmigan as a recognized subspecies and as a subject of this Species Status Assessment.

All subspecies of white-tailed ptarmigan have plumage that changes annually from white in winter to grayish brown in summer to match the coloration and patterns in their alpine habitat (Martin *et al.* 2015, unpaginated). Ptarmigan have complex molts and plumages (Martin et al. 2015, unpaginated), and is in a nearly continuous state of molting from April to November (Hoffman 2006, p. 12). Tail feathers (rectrices) remain perpetually white year-round, which distinguishes the species from rock and willow ptarmigan (Martin et al. 2015, unpaginated). Males and females are similar in size, with adult body lengths measuring 11.8 to 13.4 inches (30

to 34 centimeters) and body mass averaging 345 to 410 grams for males and 350 to 425 grams for females (Hoffman 2006, p. 12). During the winter, both males and females are glossy white, except for black eyes, toenails, and beak (Hoffman 2006, p. 12). Summer plumage of males is vermiculated with brownish-gray with black-tipped head and neck feathers, giving a hooded appearance (Johnsgard 1973, p. 242). Summer plumage of females is more regularly barred with black and yellowish markings (Johnsgard 1973, p. 242). Both sexes have eyecombs, but eyecombs of males are more prominent and bright red. Both males and females have heavily feathered feet that act as snowshoes to support them as they walk across the snow (Martin et al. 2015, unpaginated). The southern white-tailed ptarmigan is the largest of the five subspecies (Langin et al. 2018, p. 1482).

### 2.2. Historical and Current Distribution

The southern white-tailed ptarmigan historically inhabited alpine areas in the Rocky Mountains from the Snowy Range in southern Wyoming (Braun and Wann 2017, p. 207) south through alpine habitats of Colorado (Braun and Rogers 1971) and into northern New Mexico south to near Santa Fe, New Mexico (Braun and Williams 2015, p. 236) (Figure 2). The distribution of southern white-tailed ptarmigan is largely unchanged from historical levels with some exceptions (Hoffman 2006, p. 16). In Colorado, the southern white-tailed ptarmigan inhabits nearly all available alpine areas, except the Spanish Peaks and Greenhorn Mountain in the southern part of the state (Hoffman 2006, p. 15). The species was successfully introduced to the isolated Pikes Peak in 1975, over 60 kilometers from the nearest occupied habitat (Hoffman and Giesen 1983, p. 1758). Colorado Parks and Wildlife (CPW) developed a predicted range model for the southern white-tailed ptarmigan in Colorado (Seglund et al. 2018, p. 38). We use this range model in our maps of suitable ptarmigan habitat in Colorado in this report. Nearly all suitable habitat occurs on lands managed by federal land management agencies, with over 85% managed by the U.S. Forest Service, over 5% owned by the National Park Service, 4.5% owned by the Bureau of Land Management. Approximately 6% of suitable habitat is located on privately owned land. Over 55% of suitable habitat occurs in designated wilderness areas, which prohibits use of motorized or mechanized equipment. An additional 22% of suitable habitat is located within inventoried roadless areas.

In Wyoming, credible observational and specimen data exist from only the Snowy Range in southern Wyoming (Braun and Wann 2017, p. 206), with the latest verified observation in the Snowy Range from 1974 (Braun and Wann 2017, p. 209). The Medicine Bow National Forest in southern Wyoming considers the ptarmigan to be present historically but currently extirpated from the Snowy Range (USDA 2003, pp. 3, 154; Hoffman 2006, p. 15). The latest verified observation in Wyoming was of two individual ptarmigan in 2005 approximately 24 km (15 mi) north of the Snowy Range, suggesting movement of birds within Wyoming or possibly between

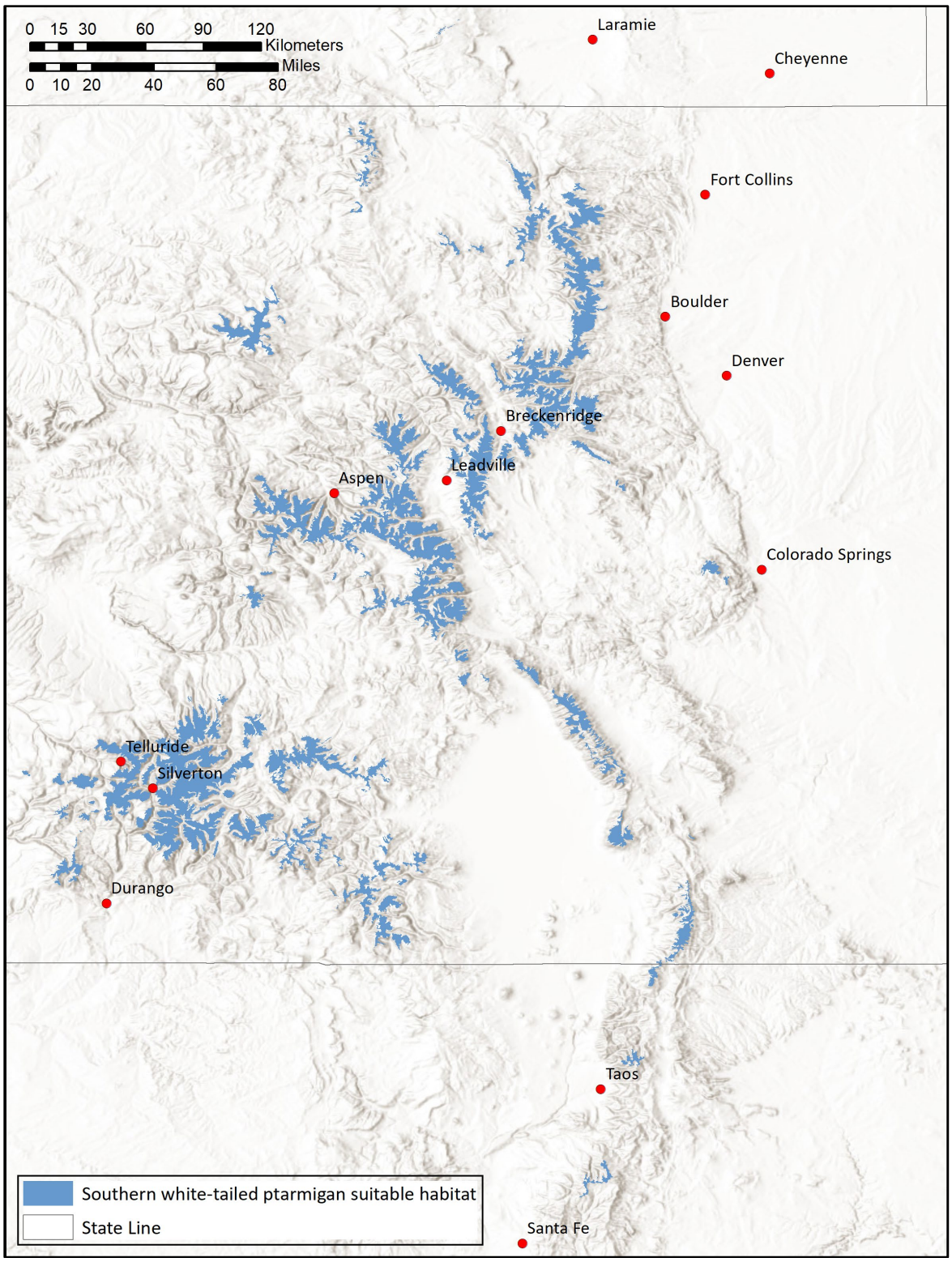


Figure 2. Suitable habitat in Colorado is based on a predicted range model developed by Colorado Parks and Wildlife. Suitable habitat in New Mexico was provided by John Bulger with New Mexico Department of Game and Fish. Habitat representing the Snowy Range in Wyoming was developed using GAP/LANDFIRE 2011 and pixels classified as "alpine" ecological systems (U.S. Geological Survey Gap Analysis Program 2011).

Wyoming and Colorado (Braun and Wann 2017, p. 207); however, the lack of recent observations suggests that ptarmigan no longer persist in Wyoming (Braun and Wann 2017, p. 210). A combination of factors likely contributed to the presumed loss of ptarmigan from the Snowy Range. Currently the area experiences heavy recreational activity, particularly winter snowmobile use (Braun and Wann 2017, p. 209). Additionally, suitable ptarmigan habitat is limited (< 10 $km^2$ [3.9 $mi^2$]) and relatively isolated from the nearest suitable habitat in Colorado (Braun and Wann 2017, p. 204). Dispersal of birds from areas in northern Colorado (e.g., Mt. Zirkel) to the Snowy Range, although possible, is unlikely to occur in sufficient numbers to maintain a breeding population (Hoffman 2006, p. 15), and historical abundance of ptarmigan was likely low (Hoffman 2006, p. 16).

Colorado supports the largest distribution of white-tailed ptarmigan in the United States outside of Alaska (Hoffman 2006, p. 15). Recent surveys conducted by CPW detected ptarmigan at 57 of 59 survey plots (Seglund 2011, p. 7), indicating that the distribution of ptarmigan in Colorado has not changed since earlier mapping of ptarmigan distribution by Braun and Rogers (1971) (Figure 3). Recent statewide estimates of abundance (adults and chicks) provided by CPW varied from a low in 2014 of 147,798 (95% credible intervals 128,289-171,563) to a high in 2013 of 221,555 (95% credible interval 178,615-268,548) (Seglund et al. 2018, p. 72). These estimates are based on extrapolations of abundance from six study sites with relatively high densities throughout the ptarmigan range in Colorado. An estimate of the breeding population in Colorado of 34,800 birds was provided by Hoffman (2006, p. 16) based on an average breeding density of six birds/$km^2$ and 5,800 $km^2$ (2,239 $mi^2$) of suitable breeding habitat.

In New Mexico, the southern white-tailed ptarmigan historically inhabited all the ridges and peaks above treeline within the Sangre de Cristo Mountains from Santa Fe Baldy north to the Colorado border (Ligon 1961, p. 87; Braun and Williams 2015, p. 240; NMDGF 2016, p. 7). By the 1920s, it was presumed extirpated from the southern peaks and found only on the northernmost peaks of its former range (Braun and Williams 2015, p. 235). The northern (e.g., Wheeler Peak) and southern (e.g., Pecos Wilderness) peaks are separated by more than 50 km (31 mi) (NMDGF 2016, p. 7). Following declines and possible extirpation in the southernmost peaks, the NMDGF listed the white-tailed ptarmigan as endangered in the state in 1975 (NMDGF 2016, p. 16). Approximately 43 birds from Colorado were translocated to the southern peaks of the Sangre de Cristo Mountains near the Pecos Wilderness in 1981 (Braun and Williams 2015, p. 238). Recent observations and reports indicate that a small population of ptarmigan remain in this translocation area, and populations continue to persist in the northernmost peaks (Braun and Williams 2015, p. 241). Based on the availability of both mat willow species and taller willow, alpine areas in the Pecos Wilderness, Wheeler Peak Wilderness, and the Culebra Range of the Sangre de Cristo Mountains likely provide year-round habitat for ptarmigan (NMDGF 2016, p. 4; Wolfe and Larsson 2018, pp. 4-5), whereas other areas may provide habitat only seasonally (NMDGF 2016, p. 7; Wolfe and Larsson 2018, p. 5). Alpine areas in New Mexico are relatively small and isolated, often linear, and contain areas of unsuitable habitat for ptarmigan (Braun and Williams 2015, p. 240).

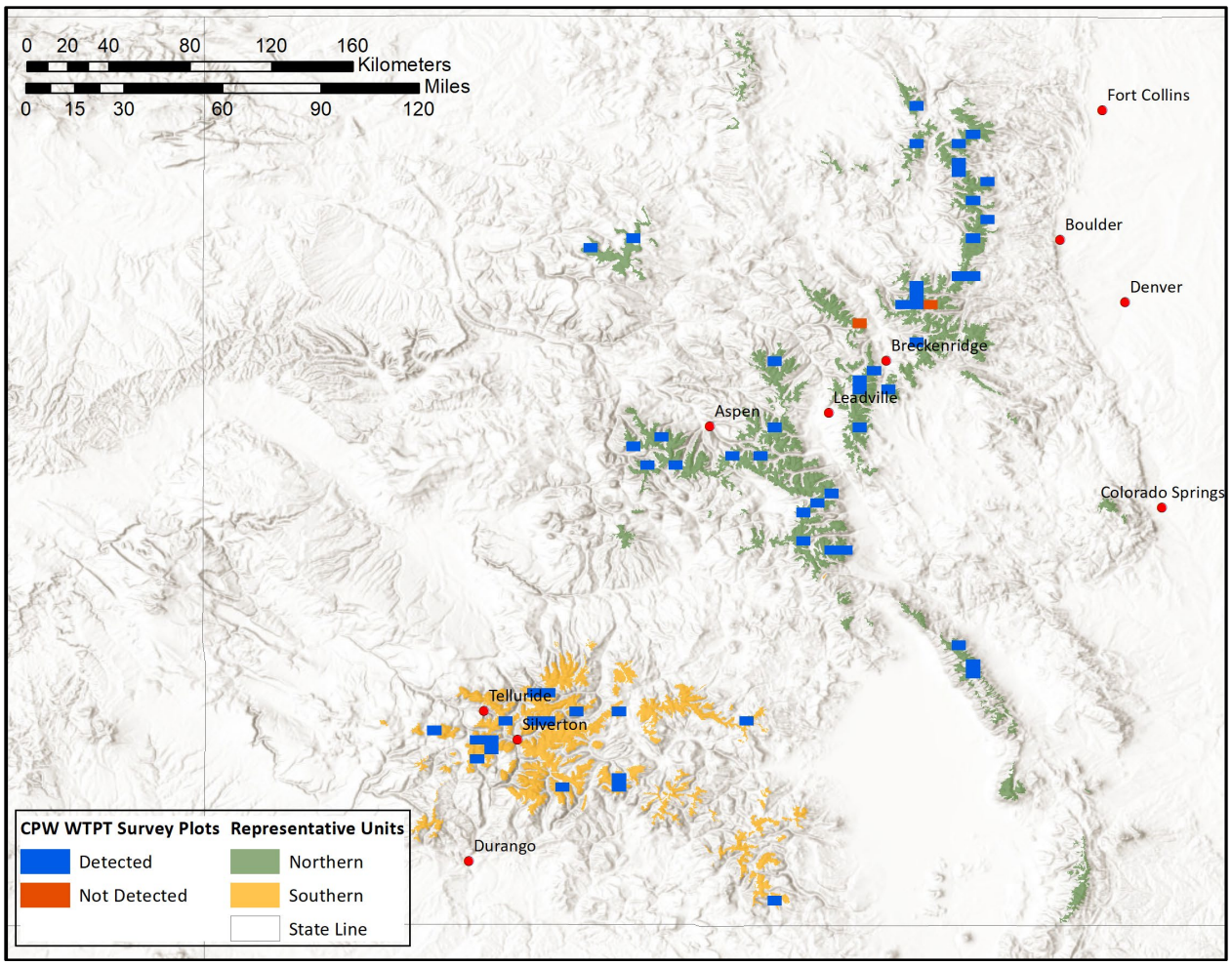

Figure 3. Survey plots where southern white-tailed ptarmigan (WTPT) were detected by Colorado Parks and Wildlife (CPW) during occupancy surveys conducted in 2011 (Seglund 2011).

CPW has worked successfully with multiple wildlife agencies to introduce white-tailed ptarmigan from Colorado to areas outside of the species historical range to provide recreational hunting opportunities, including into the Sierra Nevada Mountains of California, the Uinta Mountains in Utah, and to Pike's Peak in Colorado (Hoffman 2006, p. 13). A translocation attempt in the Wallowa Mountains of northeastern Oregon in the late 1960s was ultimately unsuccessful, as no ptarmigan sightings have been reported since approximately 1990 (Braun et al. 2011, p. 4).

### 2.3 Life History

The white-tailed ptarmigan has five life stages: egg, chick, juvenile, subadult, and adult (Figure 4). Males begin defending breeding territories in mid-April, and females arrive on breeding grounds in late April or early May, depending upon snow conditions (Giesen et al. 1980, pp. 188-189). Females breed in their first year of life and each year thereafter (Sandercock et al. 2005b, p. 2177). Females produce one brood per season but can renest if their first clutch is lost during egg-laying or early incubation (Giesen and Braun 1979, p. 217). Adult females tend to

renest at a higher rate than subadults (Sandercock et al. 2005a, p. 16; Seglund et al. 2018, p. 120). White-tailed ptarmigan are primarily monogamous; polygyny occurs but is uncommon (Hoffman 2006, p. 19, Martin et al. 2015, unpaginated).

The timing of nest building and initiation of egg laying depends on the availability of snow-free areas but typically begins in early to mid-June, with incubation occurring in mid-to late June and hatching in early to mid-July (Hoffman 2006, p. 20; Seglund et al. 2018, p. 105-106). Average clutch size in Colorado was 5.46 eggs (range 4-7 eggs; $n$ = 67 nests) for first nest attempts and all age classes combined (Seglund et al. 2018, p. 3). Adult females tend to have larger clutch sizes (mean = 5.7 eggs, range 3-7 eggs, $n$ = 61 nests) than subadult females (mean = 5.2 eggs, range 3-7 eggs, $n$ = 31 nests; Wann 2017, p. 39). Incubation period, defined as the onset of continuous night-time incubation until the first chick is hatched, ranges from 22-25 days (Martin et al. 2015, unpaginated;). Chicks are able to leave the nest within a few hours after hatching and are capable of flight at 10-12 days old (Martin et al. 2015, unpaginated). Chicks are dependent on hens for thermoregulation, protection from predators, and food selection during the first three weeks of life (Martin et al. 2015, unpaginated) and remain with hens for 8 to 10 weeks (Hoffman 2006, p. 33). Incubation and care of the young are conducted exclusively by females.

Apparent nest success (the proportion of successful nests in a sample) ranged from 25-75% across five study sites and four breeding seasons based on observations of banded birds (Braun and Rogers 1971, p. 42). Recent studies found apparent nest survival of 56% (Wann 2017, p. 39) and 57% (Seglund et al. 2018, p. 122). Mean nest survival (the probability that a nest survived from when the first egg was laid until the nest hatched) was 0.24 (CI 0.19-0.90, $n$ = 253 nests; Wilson and Martin 2011, p. 466) at Mt. Evans, Colorado over a 10-year period (1987-1996). Across six study areas, mean nest survival was 0.393 (SE = 0.07, $n$ = 115 nests) from 2013-2017 (Seglund et al. 2018, p. 108). Nest failure is due primarily to predation of nest contents (Wilson and Martin 2011, p. 468; Seglund et al. 2018, p. 108).

Life span records for wild white-tailed ptarmigan include a female of 12 years and a male of 15 years (Martin et al. 2015, unpaginated). In general, generation time for white-tailed ptarmigan is relatively short at less than three years (Sandercock et al. 2005a, p. 21). Annual survival is highly variable (Wann et al. 2014, p. 560; Seglund et al. 2018, p. 79). Analysis over a 43-year period from 1968-2010 indicates that subadult males have the highest survival, followed by subadult females, adult males, and adult females (Wann et al. 2014, p. 559; Table 1). Adult female survival varies seasonally, with survival estimates lowest in May and June and highest during July and August (Seglund et al. 2018, p. 82). Mean daily chick survival increases with age (Seglund et al. 2018, p. 117; Wann et al. 2019, p. 7208). During a four-year study across the ptarmigan range of Colorado, the probability of a chick surviving to 49 days varied by year and population, ranging from 0.781 (SE = 0.101) in the northern population in 2015 to 0.047 (SE = 0.034) in the southern population in 2013 (Seglund et al. 2018, p. 117).

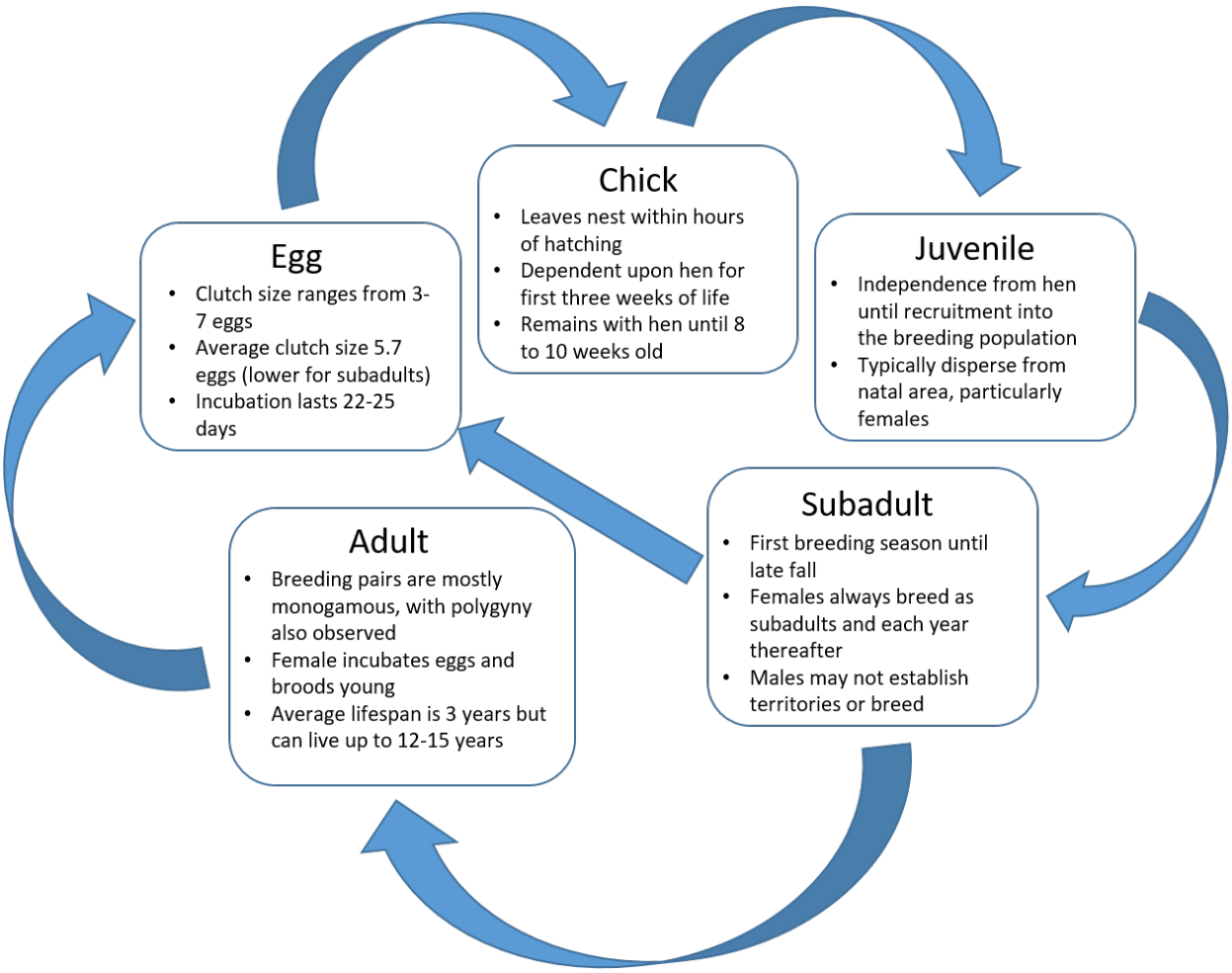


Figure 4. Life cycle diagram of the southern white-tailed ptarmigan.

Table 1. Annual survival estimates, followed by standard error (SE) and lower and upper 95% confidence intervals (CI), by age and sex for southern white-tailed ptarmigan at Mt. Evans from 1968-2010 (Wann et al. 2014, p. 560).

| | Survival | SE | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| Adult males | 0.610 | 0.030 | 0.552 | 0.668 |
| Subadult males | 0.717 | 0.033 | 0.653 | 0.780 |
| Adult females | 0.502 | 0.032 | 0.439 | 0.564 |
| Subadult females | 0.612 | 0.035 | 0.543 | 0.680 |

## 2.4 Individual-Level Ecology and Habitat Requirements

Individual resource needs of southern white-tailed ptarmigan are summarized by life stage and season in Table 2, below. The southern white-tailed ptarmigan primarily inhabits alpine ecosystems at or above treeline year-round (Hoffman 2006, p. 12), although areas below treeline are also used in winter (Braun et al. 1976, p. 4; Seglund et al. 2018, p. 130). White-tailed ptarmigan, along with other alpine species, experience extreme variability in temperature, precipitation, wind, and snow cover (Martin and Wiebe 2004, p. 177). Ptarmigan exhibit a high level of plasticity and adaptability to these conditions (Martin and Wiebe 2004, p. 177; Wann 2017, p. 5).

In Colorado, ptarmigan occupy habitats between 3,353-4,114 meters (11,000-13,500 feet; Seglund et al. 2018, p. 130). Treeline elevations vary with aspect but generally occur at elevations around 3,800 meters (12,467 feet) in the Sangre de Cristo Mountains of northern New Mexico (Elliott and Kipfmueller 2011, p. 1184) and at 3,500-3,600 meters (11,500-11,800 feet) in the Front Range of northern Colorado (Elliott and Kipfmueller 2011, p. 1183) and the San Juan Mountains of southwest Colorado (Rondeau et al. 2012, p. 4), respectively. The alpine is characterized by high winds, cold temperatures, short growing seasons, low atmospheric oxygen concentrations, and intense solar radiation (Martin and Wiebe 2004, p. 177; Sandercock et al. 2005a, p. 13). White-tailed ptarmigan initiate movements to wintering areas with the arrival of the first severe snowstorms (Braun et al. 1976, p. 4), although timing of these movements depends on weather and snow conditions (Hoffman and Braun 1977, p. 108). Movements to wintering areas are not simultaneous and can be delayed due to prolonged mild fall weather (Hoffman and Braun 1977, p. 108). Winter flocks are typically segregated by gender, with males wintering at slightly higher elevations closer to breeding areas and females and juveniles moving greater distances to seek out suitable winter habitat (Hoffman and Braun 1977, p. 110; Seglund et al. 2018, p. 93). Willow buds and twigs provide the primary food source for ptarmigan from late fall through spring (May and Braun 1972, p. 1182), and the presence of willow may have the greatest influence on the distribution of white-tailed ptarmigan during this period (Braun et al. 1976, p. 10; Hoffman 2006, p. 23). During winter (November to April), ptarmigan often use windswept areas at the upper reaches of drainage basins that provide abundant willow growth above the snow and areas where soft snow accumulates (Braun et al. 1976, p. 2-4). Wind-blown areas above treeline provide access to short-statured willow, such as snow willow (*Salix nivalis*), whereas riparian areas and swales support taller willow species, such as planeleaf willow (*S. planifolia*). During winter, ptarmigan burrow in soft snow for roosting during the night and occasionally during the day if weather conditions are unfavorable (Braun et al. 1976, p. 7). Daytime snow roosts are shallower (average < 120 millimeters; 4.7 inches) than night snow roosts (average 160 millimeters; 6.3 inches), with night roosts occurring in soft snow 300 millimeters (11.8 inches) in depth or greater (Braun and Schmidt 1971, p. 244).

As alpine winter transitions to spring, both males and females migrate upward in elevation to areas that are free of snow with access to willows by mid-May (May and Braun 1972, p. 1183; Hoffman and Braun 1975, p. 486). Pair formation is typically complete by late May and breeding territories expand with snowmelt and vegetation green up (May and Braun 1972, p. 1182-1183). Females require snow-free areas to place their nests (Martin and Wiebe 2004, p. 182), and late snowmelt can negatively impact breeding success and productivity (Martin and

Wiebe 2004, p. 183). Additionally, females delay egg laying until they have undergone molt into their cryptic breeding plumage, the onset of which is tied to the amount of snow cover as well as photoperiod (Braun and Rogers 1971, p. 36). Spring snowstorms can delay nesting (Martin and Wiebe 2004, p. 182; Wann et al., 2016, p. 10), and females must be flexible in the timing of reproduction (Martin and Wiebe 2004, p. 182).

Suitable nest sites often have some type of cover (e.g., boulders, willows) adjacent to the nest, which serves largely as protection against the elements (Giesen et al. 1980, p. 194, p. 196; Wiebe and Martin 1998, p. 1142, Seglund et al. 2018, p. 109; Spear et al. 2020, p. 181), although females will also place nests in open areas of low-statured alpine vegetation (Giesen et al. 1980, p. 195, Wiebe and Martin 1998, p. 1142, Seglund et al. 2018, p. 109). Boulders (large rocks > 30 cm [12 in]; Frederick and Gutierrez 1992, p. 899) may provide better protective and thermal cover for nests than vegetation (Wiebe and Martin 1998, p. 1143), and females may preferentially place nests adjacent to boulders (Wiebe and Martin 1998, p. 1142). Incubating females display high nest attentiveness, which may serve to reduce the likelihood of predation (Giesen and Braun 1979, p. 216, Wiebe and Martin 1997, p. 221). Suitable feeding sites for incubating females are typically in close proximity to the nest (50-800 meters [164-2,625 feet]) (Wiebe and Martin 1997, p. 222; Spear et al. 2020, p. 181). Females select nest sites with greater cover of desirable forage forbs at the scale of the nest patch (200 $m^2$; Spear et al. 2020, p. 178).

After hatching, hens with chicks typically remain within several hundred meters of the nest for up to a week after hatching (May and Braun 1972, p. 1183), although hens nesting near treeline may move farther with their broods to habitats at higher elevations (Rick Hoffman 2020, pers. comm.). Prolonged cool and wet weather conditions during the early brood-rearing period can have a negative impact on chick survival, as young chicks are unable to thermoregulate independently during their first weeks of life (Wann et al. 2016, p. 12).

Invertebrates are an important food source for chicks less than three weeks old (May 1975 *in* Martin et al. 2015, unpaginated), and females may select brood sites with abundant invertebrates during this period (Spear et al. 2020, p. 180). Females provide cues to chicks for the selection of protein-rich forage items (Allen and Clarke 2005, p.308) and select foraging sites with abundant low-growing forbs such as American bistort (*Polygonum bistortoides*), alpine bistort (*P. viviparum*), Ross' avens (*Geum rossii*), and clover (*Trifolium* spp.) and low-growing snow willow (May and Braun 1972, p. 1183; Allen and Clarke 2005, p. 308; Clarke and Johnson 2005, p. 172). Brood-rearing habitat for females, and summer areas for post-territorial males and unsuccessful females, occur at higher elevations than breeding territories (Hoffman 2006, p. 26). These late summer habitats tend to occur on high, rocky, windswept areas near late-lying snowfields or other moist sites. Drier alpine fellfields adjacent to these moist sites are also important summer use areas (Hoffman 2006, p. 26) that support key forage species such as mountain avens (*Dryas octopetala*) (Clarke and Johnson 2005, p. 172). Late summer diets differ between male and female ptarmigan.

White-tailed ptarmigan have several adaptations to cold, snowy conditions. Birds are fairly sedentary during winter and limit movements to conserve energy (Braun and Schmidt 1971, p. 243). Legs and feet are heavily feathered, creating a snowshoe effect that allows ptarmigan to

save energy by walking on top of snow rather than flying (Hohn 1977, p. 382). Metabolic rates are low, allowing the white-tailed ptarmigan to gain weight during the winter (May 1975 *in* Hoffman 2006, p. 31). Ptarmigan plumage is highly insulative (Johnson 1968, p. 1010), and low evaporative efficiencies prevent the loss of body heat (Johnson 1968, p. 1010). As a result, ptarmigan are highly susceptible to heat stress (Johnson 1968, p. 1011), exhibiting signs of stress (e.g., panting, snow bathing) at ambient air temperatures over 21°C (70°F; Johnson 1968, p. 1003). In summer, birds select microsites such as late-lying snowfields or the shade of boulders or willows as thermal refugia (Johnson 1968, p. 1003; Wiebe and Martin 1998, p. 1143). In the southern portion of the southern white-tailed ptarmigan range, afternoon precipitation associated with monsoonal thunderstorms can provide substantial added moisture along with cooler temperatures during the warm summer months (mid-July through August; Steenburgh et al. 2013, p. 61).

Table 2. Habitat metric/resource need and applicable life stage, resource function, and season for southern white-tailed ptarmigan.

| Habitat Metric/Resource Need | Life Stage[1] | Resource Function[2] | Season[3] | Notes/Citations |
|---|---|---|---|---|
| Willow abundance and distribution | E, C, J, S, A | B, F, S, M, D | F, W, Sp, Su | Primarily Oct-June but some summer use as food; some importance for nest site selection; in winter must be accessible (e.g., exposed above snow or on windswept ridges) (May and Braun 1972, p. 1182-1183, Clarke and Johnson 2005, p. 172). |
| Forbs | E, C, J, S, A | F, M, D | Su, F | May and Braun 1972, p. 1183-1184. |
| Boulders/Rocky Areas | E, C, J, S, A | B, S, M, D | Sp, Su, F | Choate 1963, p. 686; Braun et al. 1976, p. 4; litt in Hoffman 2006, p. 25-26. |
| Invertebrates (consumed by chicks typically ≤ 3 weeks old) | C | F | Su | May 1975 in Hoffman 2006, p. 27, 30; leafhoppers (Spear et al. 2020, p. 180). |
| Late-lying snowfields and moist areas | E, C, J, S A | S, F, B | Su, F | Hoffman 2006, p. 23, 46; Seglund et al. 2018, p. 133, 138. |
| Availability and distribution of soft snow for winter roosting | J, S, A | S | W | Braun and Schmidt 1971, p. 244; Braun et al. 1976, p. 2-at least 300 mm deep snow-Braun and Schmidt 1971, p. 244 |
| Snow-free areas by early June | E, S, A | B, F, S | Sp, Su | Adult females initiate molt based on amount of snow cover and light intensity (Hoffman 2006, p. 20). Females will not initiate nesting activities until completely in cryptic, alternate plumage (Giesen and Braun 1979, p. 216). Snow-free sites required for nesting (Martin and Wiebe 2004, p. 182; Wann et al. 2014, p. 557). |
| Ambient temperatures <21°C (70°F) (exhibit gular flutter and panting) | C, J, S, A | S | Su, F | Johnson 1968, p. 1003, 1011. |
| Timing of precipitation falling as snow | E, C, J, S, A | B, S, M | Sp, F | Delays in snowfall can increase predation risk in the fall (Henden et al. 2017, p. 5), as the onset of molt is regulated, in part,by photoperiod (Zimova et al. 2018, p. 1489). Spring snowstorms can delay nesting (Wann et al. 2016, p. 10). |
| Timing of snowmelt | E, S, A | B, F, M | Sp, Su | Late snowmelt can negatively impact breeding success and productivity (Clarke and Johnson 1992, p. 623-624; Martin and Wiebe 2004, p. 183). |
| Summer precipitation/monsoonal moisture | C, J, S, A | S, F | Su | Precipitation associated with thunderstorms and/or monsoonal moisture provides moisture and cooler temperatures (Seglund et al. 2018, p. 137). |

[1] E=egg, C=chick (hatching to 8-10 weeks old; Hoffman 2006, p. 33), J=juvenile (10 weeks to approximately 9 months [onset of first breeding season], Sandercock et al. 2005b, p. 2180; Wann et al. 2014, p. 563), S=subadult (9 to 14 months, Wann 2017, p. 87; Braun and Rogers 1971, p. 19), A=adult (>14 months; Braun and Rogers 1971, p. 19); [2] B=breeding, F=foraging, S=sheltering, M=migration, D=dispersal; [3] F=fall, W=winter, Sp=spring, Su=summer.

## 2.5 Population-level Ecology and Habitat Requirements

Population resiliency of the southern white-tailed ptarmigan is dependent upon several demographic factors, including annual adult survival, juvenile survival, external recruitment, natal and breeding dispersal, and connectivity of suitable habitats (Figure 5). Survival and productivity are highly variable across populations of southern white-tailed ptarmigan due largely to variability in climate and predation (Martin et al. 2000, p. 504, Seglund et al. 2018, p. 3), yet ptarmigan populations continue to persist throughout most of the historical range (Martin et al. 2000, p. 512; Martin et al. 2015, unpaginated, Seglund et al. 2018, p. 138). In Colorado, the survival of adult females has the greatest influence on population growth (Sandercock et al. 2005a, p. 21; Wilson and Martin 2011, p. 466; Wann 2017, p. 128), followed by juvenile survival (Wann 2017, p. 128). Juvenile survival is one of the most difficult demographic rates to study, particularly for species like ptarmigan that generally emigrate from areas where they were born (Wann 2017, p. 72). Chick survival is lowest after hatch and increases with age, stabilizing at around 18 days old (Wann 2017, p. 47). Populations are maintained through immigration (Martin et al. 2000, p. 514; Sandercock et al. 2005b, p. 2183; Wann 2017, p. 91, p. 133), emphasizing the importance of demographic connectivity among suitable alpine habitats.

Both natal and breeding dispersal occur, particularly for females (Giesen and Braun 1993; Martin et al. 2000, p. 509). Few juvenile ptarmigan return to their natal areas (Sandercock et al. 2005b, p. 2180). Juvenile females disperse farther than males from their natal areas (Giesen and Braun 1993, p. 74), and most recruitment has been observed to occur from outside of study area boundaries (Giesen and Braun 1993, p. 75; Martin et al. 2000, p. 511). Juveniles of both sexes generally move farther than adults, and movement of juvenile females across populations is integral to maintaining stable populations of ptarmigan (Martin et al. 2000, p. 514; Wann 2017, p. 90).

The maximum dispersal distance recorded for ptarmigan is of an adult female moving 53 kilometers (Seglund et al. 2018, p. 76). Movements from summer areas to winter habitats based on telemetry locations averaged 6.36 kilometers (range 0.026 – 41.05 kilometers) for adult females and 1.27 kilometers (range 0.066 – 3.85 kilometers) for adult males (Seglund et al. 2018, p. 76). Movements during summer, defined as May 15 to October 31, averaged 0.52 kilometers and 0.40 kilometers for females and males, respectively. Winter movements averaged 6.58 kilometers and 1.29 kilometers for females and males, respectively (Seglund et al. 2018, p. 76). Introduced populations of white-tailed ptarmigan have been observed crossing 10-20 km (6.2-12.4 mi) gaps of unsuitable habitat (low-elevation forest) (Frederick and Gutierrez 1992, p. 899).

Breeding densities fluctuate between years and locations (Seglund et al. 2018, p. 70). Recent work by CPW calculated breeding estimates across several study locations in Colorado (Table 3). Historical estimates of breeding densities are also provided (Table 4).

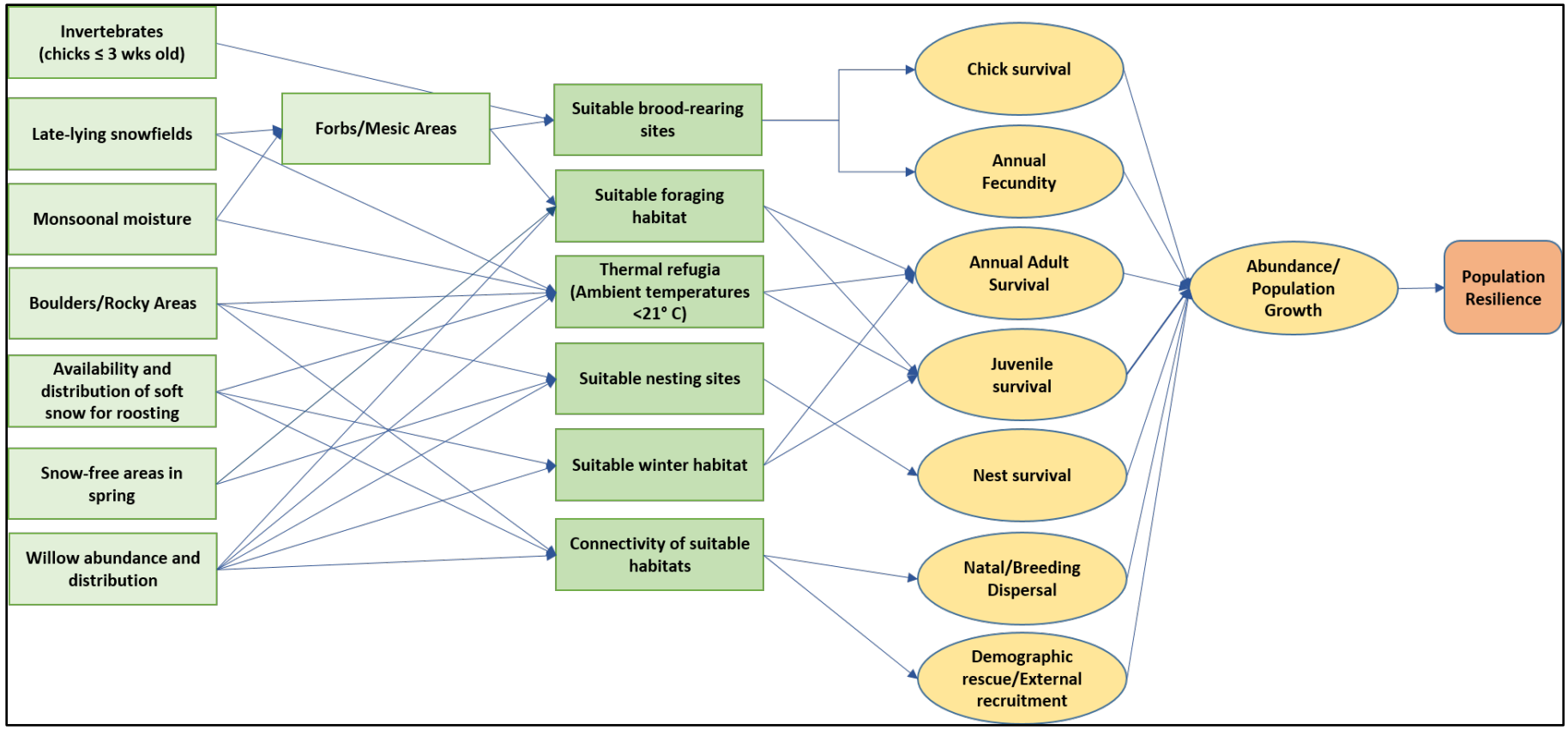


Figure 5. Conceptual model of habitat factors (green boxes) and demographic factors (tan ovals) needed by the southern white-tailed ptarmigan to maintain resiliency.

Table 3. Estimated breeding densities (birds/km$^2$) with associated 95% confidence intervals in parentheses for six study sites. Estimates are for adult and subadult birds. Byers Peak, Independence Pass, and Emerald Lake were not accessible in late spring to conduct breeding surveys in 2013 (Seglund et al. 2018, p. 70).

| | Mean breeding density (birds/km$^2$) | | |
|---|---|---|---|
| Study Area | 2013 | 2014 | 2015 |
| Byers Peak | n/a | 3.6 (2.8-6.5) | 2.1 (1.6-3.7) |
| Independence Pass | n/a | 5.3 (4.7-7.5) | 5.4 (5.1-7.4) |
| Mt. Yale | 1.5 (1.3-2.5) | 2.9 (2.4-5.3) | 3.7 (3.1-6.2) |
| Ophir | 2.7 (2.4-4.1) | 4.8 (4.0-8.0) | 3.5 (3.0-5.6) |
| Mesa Seco | 7.1 (6.3 -8.6) | 8.8 (8.2-11.9) | 5.9 (5.6-8.2) |
| Emerald Lake | n/a | 2.1 (1.7-3.8) | 2.5 (2.1-4.6) |

Table 4. Estimated breeding densities (birds/km$^2$) of white-tailed ptarmigan at study areas throughout Colorado (Hoffman 2006, p. 16). Numbers in parentheses represent the range of breeding densities over the study period.

| Study Area | Mean Density | Years | Citation |
|---|---|---|---|
| Rocky Mountain National Park | 8.6 (4.5-13.5) | 1966-91 | Giesen and Braun 1992 |
| Mt. Evans | 6.3 (2.2-10.3) | 1966-91 | Giesen and Braun 1992 |
| Niwot Ridge | 8.3 (6.4-9.5) | 1970-74 | May 1975 *in* Hoffman 2006 |
| Independence Pass | 7.4 (6.9-8.3) | 1966-69 | Braun and Rogers 1971 |
| Mesa Seco | 5.7 (5.3-6.2) | 1966-67, 69 | Braun and Rogers 1971 |
| Crown Point | 6.6 (5.6-8.2) | 1966-69 | Braun and Rogers 1971 |
| Square Tops | 3.5 (2.7-4.4) | 1993-96 | Martin et al. 2000 |
| Guanella Pass | 5.0 (2.1-6.4) | 1990-96 | Martin et al. 2000 |
| Loveland Pass | 4.7 (4.4-4.8) | 1990-92 | Martin et al. 2000 |
| Pikes Peak* | 6.0 (3.4-8.4) | 1976-80 | Hoffman and Giesen 1983 |

*Introduced population

Population viability analyses (PVAs) conducted for localized populations of white-tailed ptarmigan in Colorado indicate that growth rates are insufficient to maintain populations if such analyses do not include consideration of external sources (i.e., immigration) (Sandercock et al. 2005b, p. 2183; Wann 2017, p. 130). A modeling study conducted by Wann (2017, pp. 114-146), with quasi-extinction thresholds (i.e., the population size at which the extinction of ptarmigan becomes inevitable) set at 10 females and no incorporation of immigration rates, concluded that the probability of quasi-extinction at Rocky Mountain National Park/Trail Ridge would surpass 50% within 11 years, whereas the probability of quasi-extinction by year 50 was 2.1% at Mt. Evans (Wann et al. 2017, p. 129). These quasi-extinction probabilities reflect the internal demographics at these two areas in the absence of external recruitment (Wann 2017, p. 131) and emphasize the importance of external recruitment to population persistence (Martin et al. 2000, p. 514).

Separate modeling efforts by CPW (Seglund et al. 2018, pp. 37-96) used data collected at six study areas from 2013 to 2016 and incorporated a quasi-extinction threshold of two breeding females. In the absence of external recruitment, the statewide extinction probability was 1% by

year 50 (Seglund et al. 2018, p. 83); however, the risk of quasi-extinction was higher for the northern population, at 26% (Seglund et al. 2018, p. 84). They then modeled scenarios with increasing levels of fixed immigration rates into breeding sites, which resulted in virtually no risk of extinction over the next 50 years, even with low immigration rates (Seglund et al. 2018, p. 83).

Using the model developed by CPW (Seglund et al. 2018, pp. 64-68), we ran two additional scenarios for this SSA: one scenario did not incorporate immigration of individuals into populations and another scenario included randomized variation in the overall immigration rate (Appendix A). For both scenarios, we also incorporated a variable quasi-extinction threshold between two and 12 females to randomize extinction threshold across replicates and to account for our uncertainty regarding at what population size extinction is certain. That is, each replicate had a quasi-extinction threshold drawn at random between two and 12 to account for the differences in the two modeling studies described above. Results from our simulations under the no immigration scenario showed a quasi-extinction probability in the northern population of 35% and in the southern population of 7% over the next 50 years. Under the immigration scenario, the northern population was predicted to have a 12% chance of extinction, and the southern population had no chance of extinction in the next 50 years. This increase in extinction risk compared to the results from Seglund et al. 2018 was expected given the added uncertainty and variability incorporated into the immigration rates and quasi-extinction threshold. However, the results under the no immigration scenario were similar to Seglund et al. (2018).

We note that such long-term quasi-extinction probabilities should be interpreted with caution, as they are based on relatively few years of data. Short-term studies may be limited in their ability to capture demographic and environmental variation in vital rates and overall population trends (Fieberg and Ellner 2000, p. 2046). The accuracy of these probabilities can be degraded by uncertainties associated with unmodeled density dependence, sampling error, correlation among demographic rates, and genetics (Fieberg and Ellner 2000, pp. 2045-2046). Additionally, it is unknown to what degree data from the six study sites included in this analysis reflect conditions across the subspecies' range in Colorado, as not all sites were randomly selected.

### 2.6 Representative Units and Analytical Units for the Analysis

In this SSA report, we consider three representative units of the southern white-tailed ptarmigan; the northern representative unit, the southern representative unit, and the New Mexico representative unit (Figure 6). These units were delineated based on geographic, ecological, and genetic boundaries or differences between the three units (see **Species Taxonomy** section, above) (Langin et al. 2018; Zimmerman et al. 2020).

The northern representative unit is comprised of suitable alpine habitat primarily above approximately 3,300 meters (10,800 feet; Seglund et al. 2018, p. 38) in the Front Range of north central Colorado south through the Sangre de Cristo Mountains adjacent to Great Sand Dunes National Park. Suitable habitat also occurs in the more isolated alpine areas of Mt. Zirkel and the Flat Tops.

The southern representative unit includes suitable alpine habitat in the San Juan Mountains of southwest Colorado. The nearest suitable alpine habitat is in the Elk Mountain Range, over 50 kilometers to the north (Seglund et al. 2018, p. 17).

The New Mexico representative unit includes suitable alpine habitat in the Sangre de Cristo Mountains from the border with Colorado in the Culebra Range south into the peaks above Santa Fe (Figure 6). Currently, southern white-tailed ptarmigan inhabit three sites in New Mexico: the Wheeler Peak Wilderness, the Pecos Wilderness, and the Culebra Range on the New Mexico/Colorado border (Wolfe and Larsson 2018, pp. 4-5). Surveys in 2018 observed no birds in the Wheeler Peak Wilderness area, although two individuals were observed in 2017. In 2018, two birds were observed in the Pecos Wilderness (six in 2017), and four birds were observed in the Culebra Range (five in 2017). Breeding in New Mexico, as evidenced by observations of females with broods, has been noted as recently as 2016 (John Bulger 2018, pers. comm.). It is unknown to what degree these areas regularly maintain functional breeding populations (Don Wolfe 2020, pers. comm.). Several other areas have occasional sightings and likely just seasonal use (Latir Peak Wilderness, Little Costilla Peak, Santa Fe Baldy and Lake Peaks, and Gold Hill) (Wolfe and Larsson 2018, p. 5).

To evaluate the current condition of southern white-tailed ptarmigan, we divided the subspecies' range into 19 analytical units (AUs; Figure 6 and Table 5). AUs represent study areas or other known occupied sites within the historical range of the subspecies that have some historical or current habitat and demographic information for southern white-tailed ptarmigan. Dividing the range into AUs allowed us to assess the varying condition of southern white-tailed ptarmigan across its range, and we attempted to capture the breadth of resiliency, redundancy, and representation across the range of the subspecies. We do not consider populations in California, Utah, or Pikes Peak that were introduced outside of the historical range of southern white-tailed ptarmigan in our analysis.

Table 5. Three representative and 19 analytical units (AUs) used to evaluate resiliency, redundancy, and representation for the southern white-tailed ptarmigan. Shading identifies the representative unit: green = northern; tan = southern; blue = New Mexico.

| **Analytical Unit** | **Citations** |
|---|---|
| Crown Point | Braun and Rogers 1971 |
| Mt. Evans | Braun and Rogers 1971; Wann et al. 2016; Langin et al. 2018 |
| RMNP/Trail Ridge | Braun and Rogers 1971; Hoffman and Giesen 1983; Wann et al. 2016; Langin et al. 2018 |
| Niwot Ridge | May 1975 *in* Hoffman 2006; Giesen et al. 1980 |
| Independence Pass | Braun and Rogers 1971; Giesen et al. 1980; Langin et al. 2018; Seglund et al. 2018 |
| Square Top | Martin et al. 2000 |
| Guanella Pass | Martin et al. 2000 |
| Loveland Pass | Martin et al. 2000 |
| Byers Peak | Langin et al. 2018; Seglund et al. 2018 |
| Flat Tops | Langin et al. 2018; Seglund et al. 2018 |
| Mt. Yale | Langin et al. 2018; Seglund et al. 2018 |
| Mt. Zirkel | Seglund 2011; Braun and Wann 2017 |
| Sangre de Cristos | Seglund et al. 2011; Langin et al. 2018 |
| Snowy Range, Wyoming-Presumed Extirpated | Braun and Wann 2017 |
| Mesa Seco | Braun and Rogers 1971; Wann 2017; Langin et al. 2018; Seglund et al. 2018 |
| Emerald Lake | Langin et al. 2018; Seglund et al. 2018 |
| Ophir | Langin et al. 2018; Seglund et al. 2018 |
| Southern San Juans | Seglund et al. 2011; Langin et al. 2018 |
| Culebra, Wheeler Peak, Northern Pecos | Wolfe et al. 2011; Braun and Williams 2015; NMDGF 2016; Langin et al. 2018; Wolfe and Larsson 2018 |

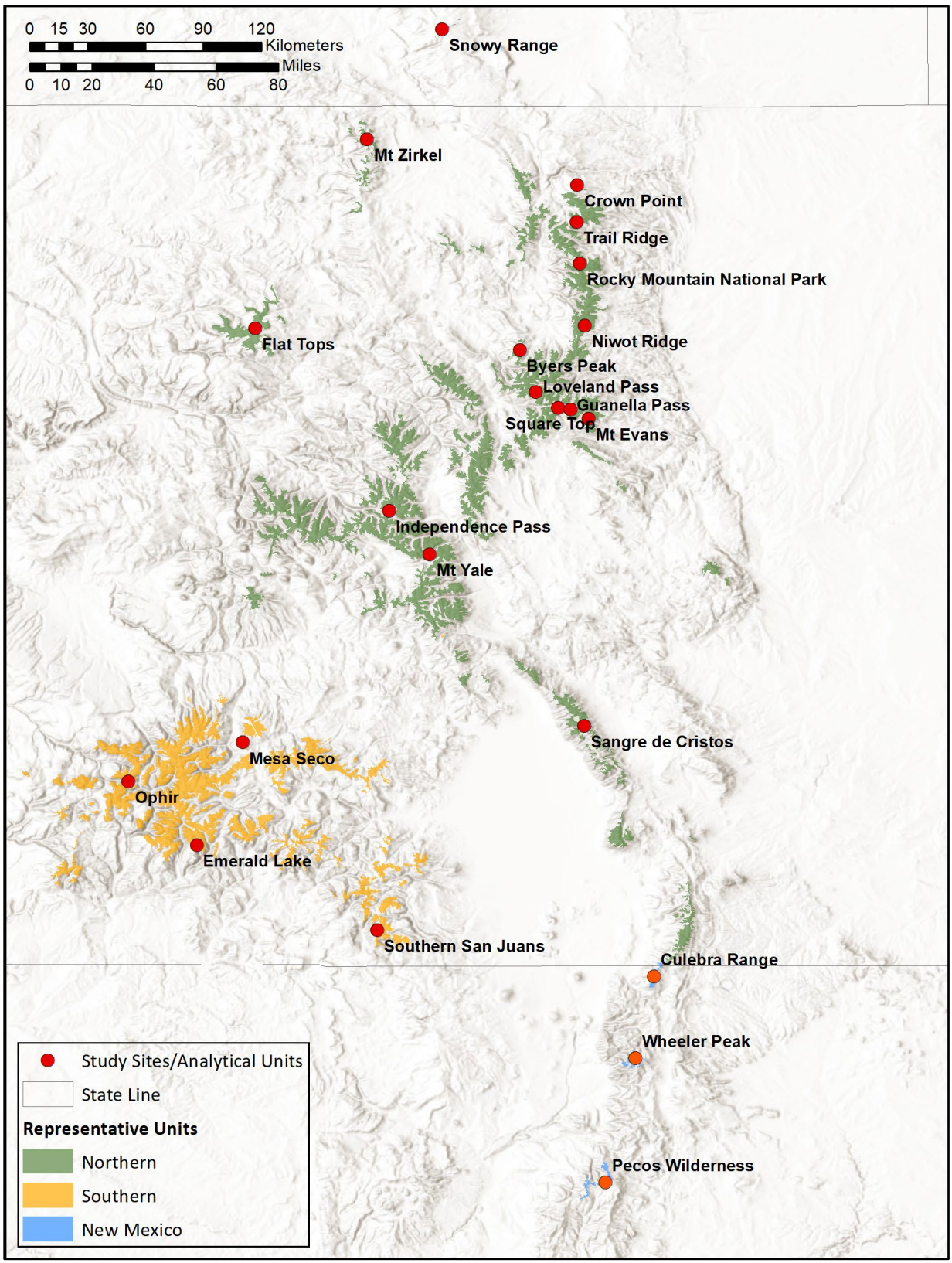


Figure 6. Southern white-tailed ptarmigan range, 19 analytical units (AUs), and three representative units considered in our analysis.

## 2.7 Subspecies-level Ecology

The ecological requirements of southern white-tailed ptarmigan at the subspecies level include having a sufficient number and distribution of healthy populations to ensure that the subspecies can withstand annual variation in its environment (resiliency), catastrophes (redundancy), and novel biological and physical changes in its environment (representation). Healthy populations of southern white-tailed ptarmigan widely distributed throughout suitable alpine habitat across its range allow for the subspecies to withstand stochastic disturbances and natural variation, and thus have greater resiliency. Additionally, demographic connectivity between populations is critical for resiliency, as it allows for genetic exchange, dispersal, and external recruitment. Multiple, healthy populations of southern white-tailed ptarmigan also guard against population losses due to catastrophic events and help maintain adaptive capacity across populations. The ability of the southern white-tailed ptarmigan to withstand novel changes in its environment is influenced by its adaptive capacity, which is a function of its ecological, morphological, behavioral, physiological, and genetic variation.

## 2.8 Summary of Subspecies Needs

In this chapter, we identified the habitat resources needed by individual southern white-tailed ptarmigan to breed, feed, and shelter, and transition from one life stage to the next. We also identified demographic factors that analytical units need to be resilient, or able to withstand stochastic events. At the subspecies level, we explored the number and distribution of the analytical units (redundancy) needed to help reduce risk from catastrophic events, and the diversity across the range of the subspecies (representation) needed to reduce risk from long-term environmental change.

Individual southern white-tailed ptarmigan need a variety of suitable and interconnected habitat types within their alpine environments for all life stages to breed, feed, and shelter (Table 2 and Figure 5, above). These habitat types and individual resource needs include:

- Suitable brood-rearing sites for females to raise chicks — These brood-rearing sites are mesic (wet) areas that provide invertebrates for chicks and desirable forbs for adult females and chicks. These brood-rearing sites are maintained by late-lying snowfields, recent snowmelt, and summer precipitation/monsoonal moisture.
- Suitable foraging habitats needed by all life stages to feed — Individuals of all life stages feed on a variety of plants depending on the season. Ptarmigan feed almost exclusively on willow during the winter. Mesic areas provide valuable invertebrates for young chicks and forage forbs in the summer and fall.
- Suitable nesting sites needed by females to breed — Snow-free areas in the breeding season are necessary for nesting. Boulders and willow provide valuable cover.
- Suitable winter habitat needed by juveniles, subadults, and adults to shelter and feed — Soft snow is needed for adults and juveniles for snow roosts to shelter from winter weather and willows are the primary food source throughout the winter.
- Thermal refugia, where ambient temperatures are less than 21°C (70°F) — All life stages need thermal refugia, provided by late-lying snowfields, summer

precipitation/monsoonal moisture, soft snow for roosting, boulders and other rocky areas, and willows to shelter from warm ambient temperatures.

Although we identified a variety of resources (habitat factors) needed by individual southern white-tailed ptarmigan to breed, feed, and shelter, not all of these resources can be qualitatively or quantitatively measured, so may not be as informative for our analysis of current and future condition. As a result, from our list of resource needs, we selected the habitat factors that are most important to resiliency of southern white-tailed ptarmigan and then selected those factors that we could measure, either qualitatively or quantitatively, relatively consistently across all 19 analytical units. From this selection, we identified the following five resource needs that are most important to the resiliency of the southern white-tailed ptarmigan and that we could use to evaluate current and future condition for each analytical unit:

- Winter snow conditions: captures the need of individual adults and juveniles to find well-distributed soft snow for snow roosts.
- Late-lying snowfields: which describes the need of all life stages for mesic areas and forbs to feed and shelter from ambient temperatures (thermal refugia).
- Summer precipitation/monsoonal moisture: provides regular cooling (thermal refugia) and late-season moisture for foraging.
- Brood-rearing habitat: describes the needs of chicks to feed on insects and chicks and adults to feed on desirable forage forbs.
- Willow availability: captures the importance of the availability and distribution of willows, used by all life stages to breed, feed, and shelter.

Analytical units need some level of nest, chick, juvenile, and adult survival, as well annual fecundity, natal and breeding dispersal, and external recruitment/demographic rescue to maintain or increase population abundance and growth, and subsequently maintain resiliency. The demographic factors that are most important to the resiliency of southern white-tailed ptarmigan analytical units are the external recruitment of individuals and breeding dispersal that maintain connectivity across analytical units, adult female survival, and population growth. We have some quantitative and qualitative information for these three demographic factors, and we carry these three demographic factors forward in our evaluation of current and future condition.

At the subspecies level, the southern white-tailed ptarmigan needs a sufficient number and distribution of analytical units in order to reduce risk associated with catastrophic events (redundancy). Additionally, the subspecies needs ecological and genetic diversity across the overall range in order to withstand novel biological and physical changes in its environment (representation).

## Chapter 3: Current Condition

In this chapter, we describe the current condition of the southern white-tailed ptarmigan using the same demographic and habitat factors that we identified as species needs in Chapter 2. We first provide a summary of potential stressors affecting the subspecies, as well as any positive influences on the subspecies, followed by our methodology for evaluating the current condition, and then a specific description for each factor that describes the current condition.

### 3.1 Causes and Effects: Factors Influencing Viability

In this section, we discuss the factors (stressors) that may influence the viability of the southern white-tailed ptarmigan, by either directly or indirectly affecting the habitat or demographic resources identified as needs in Chapter 2. These stressors include predation, mining and related poisoning due to toxic concentrations of trace metals, hunting, recreation, livestock and native ungulate grazing, and the effects of global climate change. These factors have been identified as potential stressors in the available scientific literature on southern white-tailed ptarmigan (Hoffman 2006, pp. 40-48; Seglund et al. 2018, pp. 25-36). We evaluated the effects of each potential stressor in detail (Appendix B), which we summarize in the following sections.

Based on this evaluation, we found no credible evidence that southern white-tailed ptarmigan is experiencing elevated levels of predation beyond the natural population dynamics of the subspecies. Ptarmigan are prey species, and predation is a major influence on the population dynamics of ptarmigan and all grouse species (Hoffman 2006, p. 33). Generalist predators such as coyotes and foxes are occasional predators on eggs, adults, and juveniles (Braun and Rogers 1971, p. 31; Giesen and Braun 1979, pp. 217-218). The abundance of generalist predators may increase in localized areas of concentrated recreation that may contain food subsidies and other attractants (Martin 2001, p. 17); however, we have no information that the level of predation on ptarmigan is currently elevated as a result. We have no indication that predation will increase beyond the natural population dynamics of the subspecies into the future. We therefore excluded consideration of predation from further analysis in this SSA report. We discuss the remaining stressors in the following sections and incorporated them into an influence diagram that models the cumulative impacts of stressors on the resiliency of the southern white-tailed ptarmigan (Figure 7).

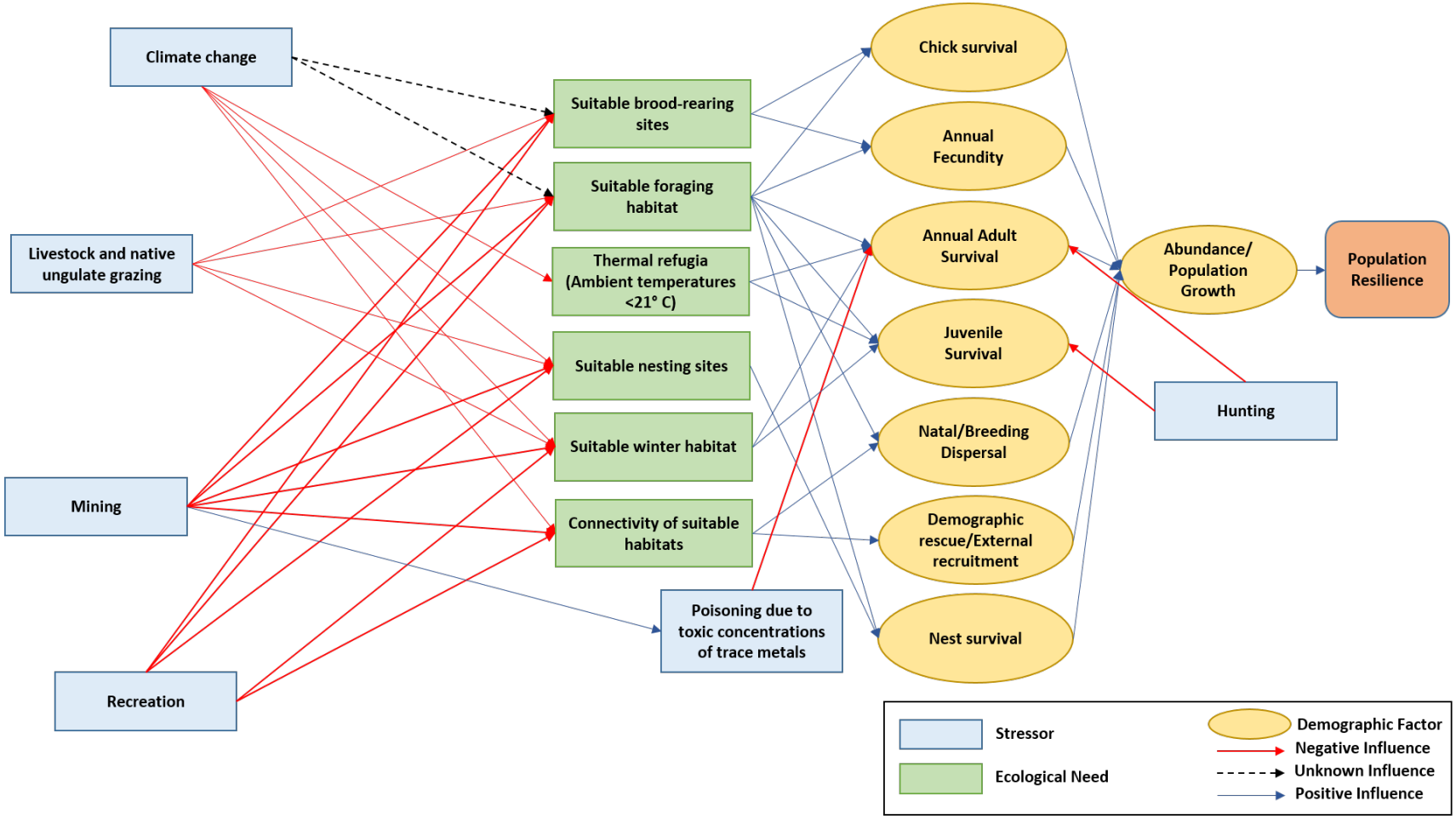


Figure 7. An influence diagram modeling how stressors can impact the resiliency of southern white-tailed ptarmigan. Stressors (blue boxes) may decrease the availability (represented by red arrows) of habitat factors (green boxes) needed by southern white-tailed ptarmigan. The habitat factors positively influence (represented by blue arrows) demographic factors, which then influence population resiliency.

### *3.1.1 Mining and Related Poisoning Due to Toxic Concentrations of Trace Metals*

The Colorado Mineral Belt is an approximately 500 km (311 mi) long and 25-50 km (15.5-31 mi) wide belt that trends northeast from the San Juan Mountains to the northeastern extent of the Front Range near Boulder, Colorado (Chapin 2012, p. 28). Colorado's Mineral Ore Belt overlaps much of the range of southern white-tailed ptarmigan in Colorado (Figure 8). The Mineral Belt contains localized areas of valuable ore deposits, and most of the metal mining districts in Colorado occur within the Colorado Mineral Belt. These ore deposits drew miners as early as the mid-1800s to areas along the Front Range and a few decades later in the San Juan Mountains (Encyclopedia Staff 2016). These mining operations along with their associated processing and support facilities had negative environmental consequences that persist today (Hoffman 2006, p. 44). Historical mining in New Mexico within the range of ptarmigan was much less widespread than in Colorado, and most mining occurred below treeline (Johnson 1972). Although present-day mining is much less widespread than in the past, modern mining operations occur at a much larger scale and have other associated impacts such as roads, power lines, and other ancillary facilities. The resulting disturbances include destruction of alpine vegetation and soils, disruption of surface and groundwater flows, and the release of toxic effluents into surface and subsurface waters (Hoffman 2006, p. 45). The establishment of various environmental laws to regulate the mining industry and the onset of reclamation processes have ameliorated some of the impacts of mining. However, reclamation in the alpine remains a challenge due to the severe climate and unproductive soils (Hoffman 2006, p. 45). Although destructive, mining is not currently a widespread stressor throughout the range of southern white-tailed ptarmigan (Hoffman 2006, p. 51). Thus, we conclude that mining does not have a substantial negative impact to southern white-tailed ptarmigan AU-level resiliency across the range of the southern subspecies currently and into the future.

An additional consequence of mining is the mobilization of naturally occurring trace heavy metals such as cadmium into the food web of ptarmigan. Specifically, cadmium is biomagnified by willow and as a result can reach toxic concentrations in the kidneys of ptarmigan (Larison et al. 2000, p. 181). Accumulation of cadmium is highest in older birds, particularly overwintering females, when willow is the primary forage species (Larison et al. 2000, p. 182). These toxic cadmium concentrations can lead to a loss of bone-calcium levels, resulting in brittle bones (Larison 2002, p. 2). The effect of cadmium on ptarmigan has been studied only in the Upper Animas River watershed in the San Juan Mountains, where adult females had reduced survival compared to populations outside of the Ore Belt (Larison et al. 2000, p. 182). The impacts of high cadmium levels on southern white-tailed ptarmigan is not known for other areas. Other intensively studied populations have not shown similar effects of cadmium poisoning (e.g., skeletal abnormalities, skewed sex ratios, or unusually high female mortality (Hoffman 2006, p. 47). Thus, we conclude that cadmium poisoning does not have a substantial negative impact to southern white-tailed ptarmigan AU-level resiliency across the range of the southern subspecies currently and into the future.

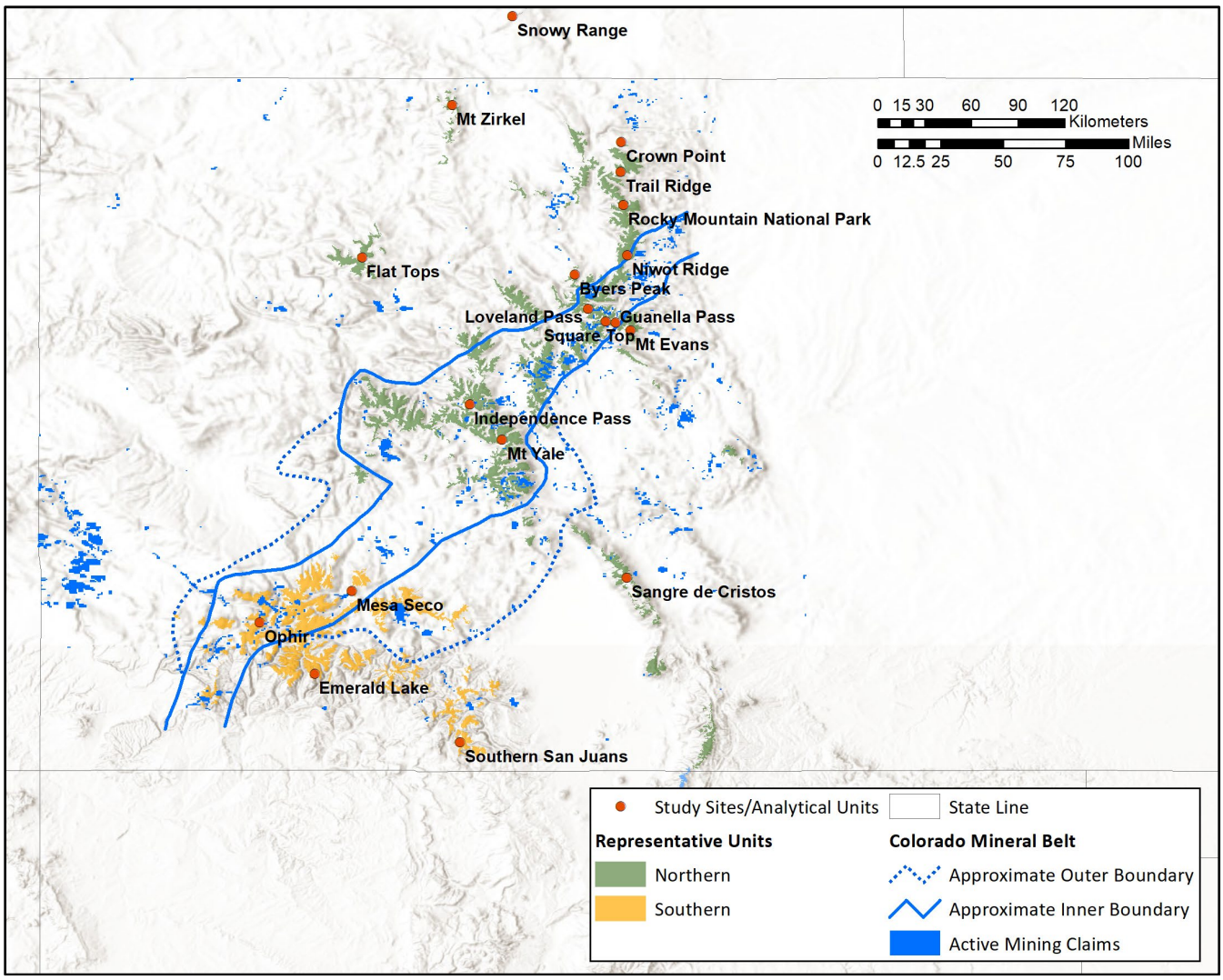


Figure 8. The Colorado Mineral Belt (Wilson and Sims 2003) and current active mining claims (BLM, Colorado State Office).

### *3.1.2 Hunting*

White-tailed ptarmigan are hunted throughout the range in Colorado, although most hunting pressure is confined to relatively accessible alpine areas along the Front Range near large population centers (Seglund et al. 2018, p. 31). Eight AUs experience some hunting pressure: Mt. Evans, Independence Pass, Guanella Pass, Loveland Pass, Square Tops, Byers Peak, Niwot Ridge, and Crown Point (Rick Hoffman 2020, pers. comm.; Amy Seglund 2020, pers. comm.). Hunting can have negative impacts to local ptarmigan populations in areas that are easily accessible by hunters. For example, Mt. Evans historically received considerable hunting pressure (Braun and Rogers 1971, p. 35), and the breeding population at this site gradually declined, resulting in lower breeding densities (Braun and Rogers 1971, p. 37). Additionally, most bird hunting takes place in the fall months when birds have formed flocks, allowing hunters to harvest their daily bag limit from a single flock (Braun and Rogers 1971, p. 35). A permanent hunting ban went into effect in 1994 at Mt. Evans for alpine habitats within 0.5 mile of the road, which considerably reduced hunter-related mortalities at this site (Wann 2017, p. 125). Although

hunting occurs throughout the Colorado range of the southern white-tailed ptarmigan, the number of individuals harvested is relatively low due to limited access to habitat and lack of hunter interest (Seglund et al. 2018, p. 32). Given the relatively limited exposure of ptarmigan to hunting, we conclude that hunting is unlikely to have a substantial negative impact to southern white-tailed ptarmigan AU-level resiliency across the range of the southern subspecies currently and into the future.

### *3.1.3 Recreation*

Recreation in alpine habitats includes activities associated with motorized recreation, such as the use off-highway vehicles (OHVs) in the summer and snowmobiles in the winter, and non-motorized recreation throughout the year, such as hiking, biking, snow-biking, and skiing. Motorized and non-motorized recreation in the alpine is largely confined to existing highways, roads, and trails, where activities are generally restricted to established routes. Recreation, whether motorized or non-motorized, becomes indiscriminate recreation when recreationists leave established roads or trails, either to temporarily access other areas or to establish unauthorized, "social trails." Alpine habitats are popular destinations for outdoor recreationists, so individual southern white-tailed ptarmigan may be exposed to recreation at any time of the year.

Recreation, as estimated by the number of visitors to alpine habitats, and based on anecdotal observations by researchers working in the alpine, is increasing and will likely continue to increase into the future as human populations grow and outdoor recreation in the alpine becomes even more popular. For example, the number of annual visits to Rocky Mountain National Park increased by approximately 1.6 million visits between 2013 and 2019 (National Park Service Visitor Use Statistics, accessed online April 17, 2020). Additionally, the popularity of hiking Colorado's famous "Fourteeners," peaks at least 14,000 feet (4,267 meters) in elevation, is increasing. Hiker use days (defined as one person hiking one peak on one day) were estimated at 353,000 in 2018 (Colorado Fourteeners Initiative 2018 Hiking Use Report, accessed online March 25, 2020). Much of the recreational use from hikers is concentrated along the Front Range of Colorado in the northern representative unit, but as trails and trailheads become increasingly more crowded, peaks further from population centers are experiencing increased activity (Ewing 2015, p. 122).

Direct or indirect disturbances to southern white-tailed ptarmigan may be either temporary or permanent, depending on the severity and duration of the disturbance, with the greatest disturbances associated with prolonged indiscriminate recreation. The potential effects of recreation on individual ptarmigan range from disturbance, to displacement, to mortality. Mortality from recreation may occur when OHVs or snowmobiles strike southern white-tailed ptarmigan. Researchers observed unleashed dogs chasing and disturbing breeding adults, and an unleashed dog killed a southern white-tailed ptarmigan chick at Independence Pass (Seglund et al. 2018, p. 91). Noise and activity associated with snowmobiles may disturb ptarmigan and cause them to flush, exposing them to predation (Hoffman 2006, p. 44).

Individuals may be displaced temporarily and return when the disturbance subsides. Prolonged or concentrated disturbance may permanently displace individuals. For instance, researchers noted an increased number of hikers at the Ophir AU travelling off-trail to more isolated areas,

possibly leading to the emigration of multiple radio-collared females out of the study area to an adjacent area of suitable habitat (Seglund et al. 2018, p. 90). These observed emigrations may have contributed to observed declines in abundance at this AU during the study period, although reduced productivity related to extreme weather may have also contributed to this observed decline (Seglund et al. 2018, pp. 90-91). Researchers at the Independence Pass AU also noted that spring skiers accompanied by unleashed dogs disturbed individual birds during the breeding season (Seglund et al. 2018, p. 91). Increased numbers of visitors along the Trail Ridge Road in Rocky Mountain National Park may have coincided with fewer observations of southern white-tailed ptarmigan in areas where they had been regularly observed (Greg Wann 2020, pers. comm.). Historically, heavy snowmobile use may have contributed to the presumed extirpation of the Snowy Range AU in Wyoming, although this has not been verified (Braun and Wann 2017, p. 209). For any of these anecdotal observations, additional research would be needed to establish a correlation between the recreational activity and any effects to the southern white-tailed ptarmigan.

Recreation may also indirectly affect individuals by reducing the quality or quantity of the habitat factors needed for feeding, breeding, and sheltering (Figure 7, above). In the winter, recreational skiing, snow bikes, and snowmobiles may compact soft snow and crush willows (Hoffman 2006, p. 44). Sensitive alpine soils may also erode or dry out following trampling and compaction from recreation, especially where it occurs away from roads and trails. When recreation occurs in alpine habitats, the effects of trampling, OHVs, skiing, and other forms of recreation on slow-growing alpine vegetation are well documented (Willard and Marr 1971, p. 257; Ebersole et al. 2004, p. 101). However, we have no evidence to suggest that the quality or quantity of habitat resources available to the southern white-tailed ptarmigan has been reduced such that it decreases AU resiliency either currently or into the future.

Currently, the timing, frequency, and intensity of recreation depends largely on the accessibility and proximity of the AUs to established highways, roads, and trails, particularly those near large population centers (Seglund et al. 2018, p. 36). The exposure of southern white-tailed ptarmigan to recreation may be limited to localized areas. Motorized and mechanized recreational access is limited within the range of the southern white-tailed ptarmigan. Approximately 55 percent of potentially suitable habitat for the southern white-tailed ptarmigan occurs within federally designated wilderness areas, where motorized and mechanical devices, such as OHVs, snowmobiles, and bikes are prohibited (Figure 9). An additional 22 percent of the suitable habitat in Colorado occurs within inventoried roadless areas (IRAs), which may also limit exposure of southern white-tailed ptarmigan to OHVs, snowmobiles, and bikes (Figure 9). Additionally, approximately 0.8 percent of the potentially suitable habitat for the southern white-tailed ptarmigan in Colorado overlaps with developed ski areas, suggesting the potential risk of exposure is relatively low (Figure 9).

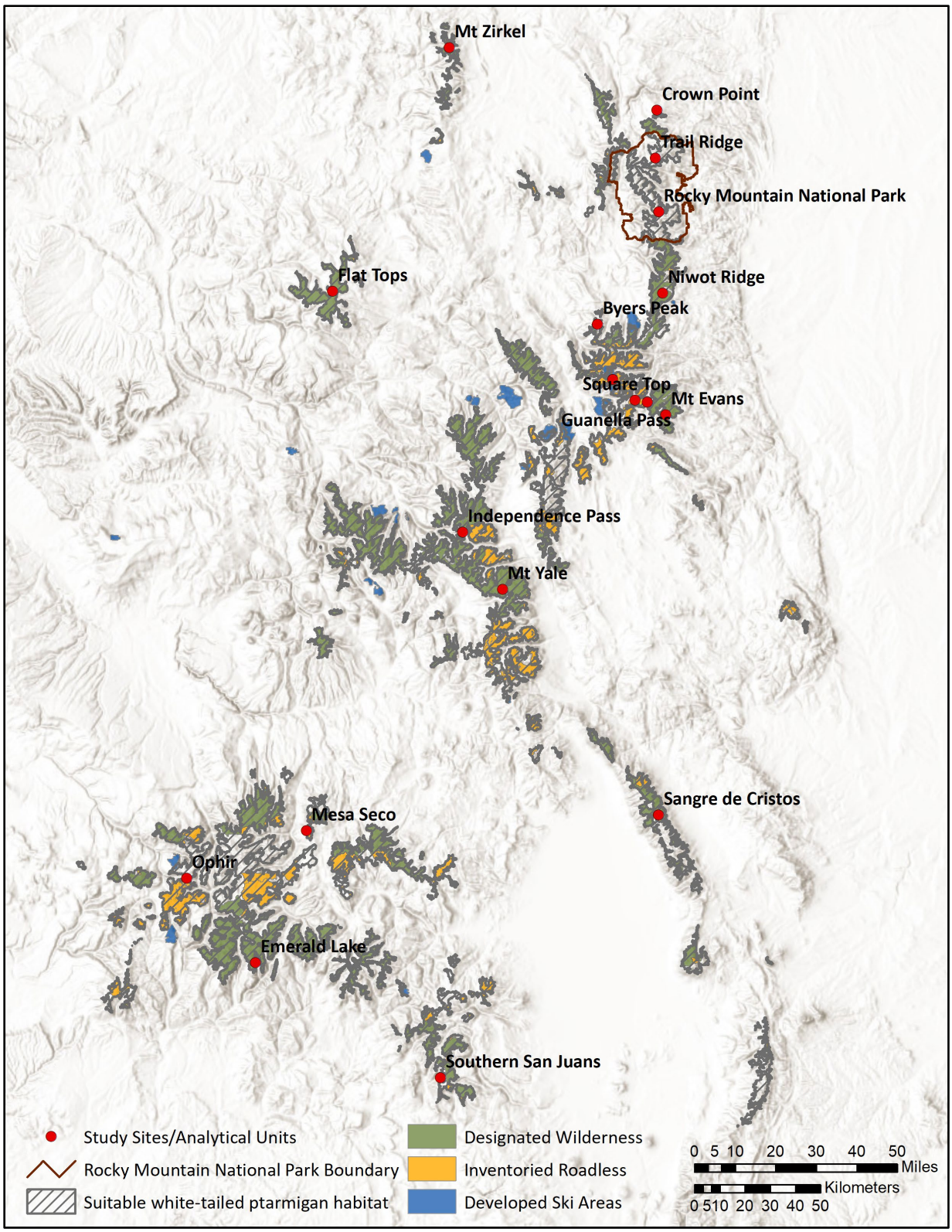


Figure 9. Designated wilderness areas, inventoried roadless areas, and developed ski areas within suitable southern white-tailed ptarmigan habitat in Colorado.

We evaluated the density of roads and trails within suitable southern white-tailed ptarmigan habitat using roads spatial data from the U.S. Geological Survey National Transportation Dataset and trails spatial data from the U.S. Forest Service and Rocky Mountain National Park. Approximately 464 miles (747 kilometers) of roads occurs within potential habitat for the southern white-tailed ptarmigan habitat in Colorado, with a road density of approximately 0.0002 miles of road per acre of potentially suitable habitat (0.10 kilometers of road per $km^2$). Although we have no evidence that vehicles along roads affect AU resiliency, the density of roads suggests that the risk of exposure of southern white-tailed ptarmigan to vehicles along roads is relatively low. Similarly, approximately 1,564 miles (2,518 kilometers) of designated trails occur within potentially suitable habitat for the southern white-tailed ptarmigan, with a trail density of approximately 0.0008 miles of trails per acre of potentially suitable habitat (0.33 kilometers of trails per $km^2$). Although anecdotal observations suggest that recreation along trails may disturb or displace individuals, the risk of exposure is relatively low based on this spatial analysis. We lack specific information on the scope, magnitude, and exposure of recreation in New Mexico, but recreation is considered to be light in all potential southern white-tailed ptarmigan habitats in New Mexico with the exception of the Wheeler Peak area (Don Wolfe 2020, pers. comm.), which experiences relatively high levels of hikers.

To summarize, although no published studies exist that directly link recreation to individual-level, AU-level, or subspecies-level effects to the southern white-tailed ptarmigan, potential effects ranging from disturbance, to displacement, to mortality, have been observed anecdotally. After considering potential direct and indirect effects to individual southern white-tailed ptarmigan, we then evaluated potential effects from recreation on the resiliency of the AUs. Historically, recreation may have reduced the redundancy of the subspecies by one AU due to the presumed extirpation of the Snowy Range AU in Wyoming. It is unknown whether the Snowy Range AU provided any diversity or adaptive capacity for the subspecies, but its northern extent and lower elevation may have provided some ecological diversity to support representation. Currently, disturbance associated with concentrated use by hikers may have contributed to observed declines in abundance at the Ophir AU, although we do not know if this is having long-term impacts to resiliency at this AU. If current trends continue into the future at the Ophir AU, more hikers could lead to more disturbance and displacement, and the abundance of southern white-tailed ptarmigan could decrease, reducing the resiliency of this AU.

The number of recreationists engaging in outdoor activities is expected to increase with increasing population growth in the coming decades (Bowker and Askew 2012, p. 120). Currently, recreation pressure across many AUs is believed to be high; however, we lack conclusive evidence that it is currently affecting any more than individual ptarmigan in localized areas and potentially affecting resiliency at one AU where hiking was concentrated. Historically, snowmobiling may have contributed to the presumed extirpation of another AU. Although we lack conclusive evidence to suggest that motorized recreation is currently affecting ptarmigan beyond disturbance to individuals, the risk of exposure is currently low and likely to remain low into the future given that a large percentage of potentially suitable habitat overlaps with designated wilderness and inventoried roadless areas. Future increases in non-motorized recreation along established roads and trails, although expected, are unlikely to impact ptarmigan beyond the level of individual birds. Indiscriminate recreation away from established roads and trails will likely also increase, as people seek out less crowded areas. However, we are unable to

conclude that any future increases in recreation would rise beyond individual-level impacts such that it affects subspecies redundancy or representation.

### *3.1.4 Grazing*

Livestock grazing, primarily sheep grazing, has been occurring in Colorado's alpine since the 1880s (Seglund et al. 2018, p. 30). Suitable habitat in the Snowy Range was intensively grazed by domestic sheep until 1997 (Hoffman 2006, p. 15). Prior to 1917, grazing was largely unregulated and caused sustained damage to alpine vegetation and soils. Sheep graze at a fraction of the numbers today, primarily occurring on U.S. Forest Service lands in the southern part of the ptarmigan range (Seglund et al. 2018, p. 30). Reduced sheep numbers and improved management has somewhat ameliorated the impacts of sheep grazing on ptarmigan habitats. However, sheep grazing and trailing through alpine habitats can result in trampling of alpine plants and erosion of alpine soils. Sheep consume the same alpine forb species used by ptarmigan, and sheep grazing can alter the species composition of alpine vegetation, resulting in the loss of valuable ptarmigan forage species (Seglund et al. 2018, p. 31). Additionally, the timing of sheep grazing in the alpine typically coincides with the brood-rearing period for ptarmigan, and Seglund et al. (2018, p. 31) anecdotally observed sheep disrupting hens from their broods.

In Colorado, current sheep grazing potentially impacts ptarmigan habitat in at least three analytical units: Mesa Seco, Southern San Juans, and Flat Tops. Historical sheep grazing in New Mexico (Braun and Williams 2015, p. 235) and the Snowy Range in Wyoming (Braun and Wann 2017, p. 209) may have impacted ptarmigan habitat. Although there is anecdotal evidence that sheep can disturb individual hens with broods (Seglund et al. 2018, p. 31), we have no other information regarding any population-level impacts of sheep grazing to the southern white-tailed ptarmigan. We recognize that the impacts of sheep grazing on alpine habitats may be exacerbated in a warmer drier future climate. However, no studies have examined the effects of livestock grazing on ptarmigan, and we have no information to suggest that sheep grazing has AU-level impacts to the southern white-tailed ptarmigan currently and into the future.

Native ungulate herbivory may also impact alpine vegetation, particularly in areas of concentrated use. Elk numbers in and around Rocky Mountain National Park peaked in the late 1990s and early 2000s (Mary Kay Watry 2020, pers. comm.). The Trail Ridge area of Rocky Mountain National Park was used heavily by elk during spring and fall migration during this period (Braun et al. 1991, p. 75). Braun et al. (1991) hypothesized that heavy browsing of willow by elk may have limited ptarmigan breeding densities by reducing the amount of available forage (i.e., willow) (p. 82). Alpine willow cover and height declined in subalpine and tundra communities of Rocky Mountain National Park during a survey period from 1971 to 1996 (Zeigenfuss 2006, p. 13), which coincided with very high elk population numbers. Long-term data for ptarmigan reproductive success displayed a declining trend over a similar time period (1968 to 2000) (Wann et al. 2016, p. 11).

In 2008, the park developed an Elk and Vegetation Management Plan to guide management actions in the park for a 20-year period with the goal of reducing the impacts of elk on vegetation and to restore, where possible, the natural range of variability in elk populations and affected plant communities (Zeigenfuss et al. 2011, p. 1). As part of its management plan, Rocky

Mountain National Park actively regulates its elk population, and elk population numbers are currently below the park's population objectives (Mary Kay Watry 2020, pers. comm.). Monitoring of vegetation as part of the management plan is ongoing. Willows are showing some signs of recovery, although recovery may be slow in some areas of the park (Zeigenfuss and Johnson 2015, p. 40).

Additionally, mountain goats, which were introduced to Colorado in the 1940s, have expanded their range and their habitat use overlaps that of ptarmigan where they co-occur (Gross et al. 2002). The diet of mountain goats overlaps somewhat with ptarmigan (Hibbs 1967, p. 245), although it is not known what impact this has on forage availability for ptarmigan.

Currently, ptarmigan habitat has been impacted by native ungulate (elk) herbivory at one analytical unit, Trail Ridge/Rocky Mountain National Park, but it is unlikely that herbivory is having AU-level impacts to southern white-tailed ptarmigan due to ongoing management of the elk population. Additionally, restoration efforts of willow habitats will continue in that AU. Further, we have no evidence that grazing by mountain goats is affecting resiliency at any AU. Thus, we conclude that herbivory by native ungulates does not have a substantial negative impact to white-tailed ptarmigan population resiliency across the range of the southern subspecies currently and into the future.

### *3.1.5 Climate Change*

Alpine areas are among the most vulnerable habitats to the impacts of climate change (Rangwala and Miller 2010, p. 89; Ernakovich et al. 2014, p. 3256). Although there is little information regarding how climate change is currently impacting southern white-tailed ptarmigan, it is expected to have substantial negative impacts (Siegel et al. 2014, p. 7; Jackson et al. 2015, p. 11). Several factors, including increases in minimum and maximum temperatures, changes in snow quantity, quality, extent, and duration, shifts in plant phenology, advancement of treeline and expansion of willow into alpine areas, and changes in the amount and timing of seasonal precipitation are expected to impact the habitat and demographic factors identified in Chapter 2 for the southern white-tailed ptarmigan into the foreseeable future. These impacts could affect the resiliency of analytical units and the redundancy and representation of the subspecies. Therefore, climate change will be carried forward in our analysis.

#### ***Potential Impacts to Habitat and Demographic Factors Due to Climate Change***

<u>Weather, Breeding Phenology, and Reproductive Success</u>

The timing of breeding advanced nine days at Mount Evans (1968 to 2012) and 12 days at Trail Ridge (1968 to 2000), with a significant warming trend over the same time period, indicating earlier breeding with warming springs (Wann et al. 2016, p. 11). Warm and dry conditions during the brood-rearing period were positively, but weakly, related to the number of chicks per hen (Wann et al. 2016, p. 9). Wang et al. (2002, p. 85) found that higher winter temperatures resulted in lower population growth rates from 1975 to 1999 at Trail Ridge, Rocky Mountain National Park, possibly as a result of reduced snow quality needed for roosting. In contrast, Wann et al. (2014, p. 564) did not find an effect of either winter temperature or precipitation on demographic rates. In general, breeding phenology appears strongly correlated with fluctuations

in spring temperatures, but earlier breeding does not necessarily influence reproductive success (Wann et al. 2016, p. 12).

Loss of Alpine Habitat due to Treeline Elevational Advancement

The position of treeline, the uppermost elevation at which trees occur, is thought to be limited primarily by temperature (Harsch and Bader 2011, p. 582), but it also depends on environmental site conditions such as soils, precipitation, wind, and topography (Harsch and Bader 2011, p. 592). Depending on the form treelines take, increasing temperatures may contribute to elevational advances in treeline, increases in tree density at or near treeline, or changes in growth form of low-growing, stunted krummholz trees to a more upright growth form (Harsch and Bader 2011, 589). Diffuse treelines, characterized by decreasing tree density with increasing altitude, are common in Colorado's alpine and may see increased growth rates and seedling survival with warmer growing season temperatures (Harsch et al. 2009, p. 1046; Harsch and Bader 2011, p. 589-590). Krummholz treelines, which are influenced by harsh environmental conditions that limit vertical growth, may only advance in elevation if winter temperatures increase enough to compensate for other environmental constraints on growth such as harsh, desiccating winds (Harsch et al. 2009, p. 1046). In a study of treeline advancement in the San Juan Mountains of southwestern Colorado, no elevational advancement of treeline was observed, but tree density had increased for the period 1951 to 2011 (Fink et al. 2014, p. 9). Additionally, krummholz trees were found to be shifting to a more upright growth form (Fink et al. 2014, p. 3). Front Range treeline showed both advances in treeline and increases in tree density related to increases in maximum temperature (Elliott and Kipfmueller 2011, p. 1198). Indeed, increasing tree density may suggest a shift to more favorable growing conditions that could facilitate treeline advancement (Elliott and Kipfmueller 2011, p. 1194). However, there is likely a lag between the onset of tree establishment and the development of forested vegetation, and changes in tree density may precede changes in treeline advancement by more than 200 years (Lloyd 2005, p. 1691). The rate of treeline advancement is highly variable. A study in the Canadian Rocky Mountains found that treeline advancement ranged from 0.23 to 2 meters/year (6.6 feet/year) (Davis et al. 2020, p. 15). Treeline advancement requires seed dispersal, germination, and successful establishment (Malanson et al. 2007, pp. 380-381). Tree establishment and recruitment depends upon local microclimatic conditions (Germino et al. 2002, p. 164) and the life history traits of the tree species (Dullinger et al. 2004, p. 250).

Loss of Snowpack and Changes in Snowmelt Timing

Losses of snowpack in recent decades have been noted across the western U.S. (Pederson et al. 2011). The loss of snowpack in Colorado's alpine has been ameliorated by colder temperatures and deeper snowpack at high elevations (Pederson et al. 2011, p. 334). The Colorado Rockies have seen only minor changes in snow accumulations (Clow 2010, p. 2294); however, the timing of snowmelt was observed to have shifted to earlier in the year for the period 1978 to 2007 (Clow 2010, p. 2305). Mountains in the Front Range of Colorado are cold enough to support strong snow accumulation from December through February, but lower precipitation and higher temperatures in November and March have shortened the snow accumulation season (Fassnacht et al. 2018, p. 13-14). Additionally, increased severity of dust deposition events as a result of anthropogenic disturbances and increased aridity on the Colorado Plateau can result in dust-on-snow that can result in faster and earlier melting of the snowpack (Painter et al. 2007, p. 1; Deems et al. 2013, p. 4401).

Changes in snowpack, particularly spring snowpack, are dependent upon elevation, slope, and aspect, with north-facing slopes at the highest elevations providing areas of potential habitat refugia (Lundquist and Flint 2006, p. 1214; Barsugli et al. 2020, p. 10). Future snowpack models developed for Rocky Mountain National Park project that the maintenance of spring snowpack is highly dependent upon elevation. These models project that at elevations used by southern white-tailed ptarmigan (>3,500 meters), snowpack is retained (< 15% reduction in snow covered area) into the middle of the 21st century under four of the five scenarios used in their analyses. The hottest and driest climate scenario projects an approximately 20% loss in snow covered area at 3,500 meters (11,482 feet) elevation and even less at higher elevations (Barsugli et al. 2020, p. 9). Future snowpack conditions in the San Juans are more uncertain as high resolution snow models have not been developed for the region.

Monsoonal Moisture and Late-season Precipitation

The North American Monsoon (NAM) contributes substantially to late summer precipitation in portions of the southwestern U.S. (Cook and Seager 2013, p. 1690). Within the range of the southern white-tailed ptarmigan, the influence of the NAM is most pronounced in southwest Colorado and northwestern New Mexico (Steenburgh et al. 2013, p. 60), contributing a higher proportion of the annual precipitation there than in the Front Range of northwestern Colorado (Cook and Seager 2013, p. 1691). The convective thunderstorms produced during the NAM can result in a peak in precipitation during July-September (Steenburgh et al. 2013, p. 61).

Willow Expansion into Alpine Tundra

Woody plants are expanding into tundra plant communities globally (Myers-Smith et al. 2011, p. 2). A study conducted at Niwot Ridge, noted that willow cover expanded by 441% in the study area over a 62-year period from 1946 to 2008 (Formica et al. 2014, p.621). Willow expansion increased at a higher rate in the latter years of the study (Formica et al. 2014, p. 621). Although elimination of historical sheep grazing may have contributed to this increase, other variables related to a changing climate such as increasing winter precipitation, nitrogen deposition, and summer temperatures have intensified the expansion of willow (Formica et al. 2014, p. 624). Willows are expanding into dry, moist, and wet alpine tundra community types (Formica et al. 2014, p. 624). Modeled simulations of alpine plant community changes conducted at Niwot Ridge also showed a predicted increase in shrub cover (Johnson et al. 2011, p. 702).

Changes in Alpine Plant Phenology

Changes in plant phenology can be a bioindicator of a changing climate (CaraDonna et al. 2014, p. 4916). Observed changes in the plant phenology of high-elevation regions include changes in first, peak, and last flowering, as well as changes in the duration of the flowering season (CaraDonna et al. 2014, p. 4917). Warmer temperatures can advance snowmelt, which can advance flowering in early-flowering plant species (Jabis 2018, p. 19) but flowering duration may not be extended in several plant species, resulting in a potentially shorter flowering season (Jabis 2018, p. 22). The extreme seasonality and short growing season in alpine environments may result in negative fitness consequences if breeding activities are mistimed with the availability of forage forbs. Wann et al. (2019) found evidence that a phenological mismatch

between the timing of breeding and food availability negatively impacts the chick survival of individual ptarmigan at Mount Evans and Trail Ridge. However, it is unknown what, if any, impact this has currently on population-level metrics such as abundance and productivity (Wann et al. 2019, p. 7210).

### 3.2 Assessing Population Resiliency

To evaluate resiliency for each of the 19 analytical units, we developed a condition category table (Table 6) to define a high, moderate, low, and very low condition category for the habitat and demographic factors that we previously identified as important to the resiliency of ptarmigan in Chapter 2. As summarized in Chapter 2, we selected a subset of needs, five habitat factors and three demographic factors, from those identified in Chapter 2 for our analysis of current condition that are likely most influential to population resiliency of the southern white-tailed ptarmigan. We then used the condition category table (Table 6) to systematically evaluate each habitat and demographic factor for each AU. AUs with little or no information available to assess condition for a habitat or demographic factor were labeled as unknown (Table 7).

We evaluated the stressors identified in **Section 3.1 Causes and Effects: Factors Influencing Viability** in terms of their individual and cumulative effects on the habitat and demographic factors important to the southern white-tailed ptarmigan (Figure 7, Appendix B). For all stressors except climate change, we only had evidence of localized impacts and no evidence that those stressors currently have widespread impacts now and into the future. This evaluation led us to carry forward climate change in our evaluation of current and future condition, as climate change could affect the habitat and demographic needs of the southern white-tailed ptarmigan, potentially impacting the resiliency of AUs and the redundancy and representation of the subspecies.

For our evaluation of current condition, we compiled information from peer-reviewed literature as well as agency surveys and reports from CPW. Information on the condition of habitat factors, including winter snow conditions, late-lying snowfields, late-summer precipitation/monsoonal moisture, brood-rearing habitat, and willow availability are largely qualitative. A few AUs have been extensively studied, some since the 1960s (e.g., Braun and Rogers 1971); however, detailed information for several AUs is sparse (Table 8). Although we have sufficient evidence that the habitat factors in Table 6 are needed by individual southern white-tailed ptarmigan, several AUs are lacking qualitative or quantitative information about these factors. Spear et al. (2020; Suppl. Material, Table S3) quantified several habitat characteristics important to ptarmigan during the nesting and brood-rearing periods for Trail Ridge/Rocky Mountain National Park and Mt. Evans; however, quantitative habitat data are lacking for most AUs. When available, we used quantitative data for adult female survival, recruitment and dispersal, and population growth. Long-term demographic data are available for Trail Ridge at Rocky Mountain National Park and Mt. Evans (Martin et al. 2000; Sandercock et al. 2005b; Wann et al. 2014; Wann 2017). Demographic data collected over multiple years is also available for Guanella Pass, Loveland Pass, and Square Tops (Martin et al. 2000; Sandercock et al. 2005b). These data were collected in the late 1980s through the late 1990s, and it is unknown to what degree these data represent current conditions for ptarmigan. Additionally, recent demographic data have been collected at Independence Pass, Byers Peak, Mt. Yale, Mesa Seco, Ophir, and Emerald Lake (Seglund et al. 2018).

To evaluate current condition, we assigned each condition category a number where High = 4, Medium = 3, Low = 2, and Very Low = 1. Factors that are in a high condition category are at less risk from stochastic events compared to those in lower condition categories, which are at greater risk from stochastic events. Factors categorized as Unknown were not considered in the scoring. Each habitat factor was given equal weight, and habitat factor scores were averaged to come up with an overall Habitat Current Condition Score. Demographic factors were given twice the weight of the habitat factors, as these are the primary drivers of resiliency for ptarmigan. The scores for the demographic factors Adult Female Survival and Population Growth were averaged, whereas the External Recruitment/Breeding Dispersal demographic factor was considered on its own in the calculation of current condition, as it is likely the most influential demographic factor maintaining resiliency. The overall current condition score for each AU was calculated as the average of Habitat Current Condition Score, averaged Adult Female Survival/Population Growth Current Condition Score, and the weighted External Recruitment/Breeding Dispersal Score. The overall condition score thresholds were based on the difference between the highest and lowest possible condition scores (6.667 and 1.667, respectively). This number was divided into four equal intervals (6.667-1.667/4 = 1.25) to develop the four condition categories. A score of 5.4 or greater = High Condition; 4.2 – 5.3 = Medium Condition; 2.9 – 4.1 = Low Condition; and <2.9 = Very Low Condition. If one or more of the demographic factors are given an "X", then the entire AU is categorized as Extirpated, regardless of the condition category assigned to the habitat factors (e.g., Snowy Range AU in Wyoming).

Table 6. Condition category table for southern white-tailed ptarmigan habitat factors (green columns) and demographic factors (red columns). Factors that are in a high condition category are at less risk from stochastic events compared to those in lower condition categories, which are at greater risk from stochastic events.

| Condition Category | Winter snow conditions | Late-lying snowfields | Summer precipitation/ monsoonal moisture | Brood-rearing habitat (insects/forbs) | Willow availability | External recruitment of immigrants/ breeding dispersal | Adult female survival | Population growth |
|---|---|---|---|---|---|---|---|---|
| **High** | Winter snow conditions are not limiting for snow roosting. | Late-lying snowfields remain into the summer in most years regardless of snowfall amounts. | Summer precipitation provides regular cooling and late-season moisture. | Brood-rearing habitat that supports insects and forbs is not limiting. | Willow abundance and distribution is not limiting and provides suitable habitat in all seasons. | There is regular exchange of individuals across AUs. Immigration and breeding dispersal are not limiting. Connectivity is unimpeded. | Adult female survival ≥ 0.5. Extremes in demographic lows are infrequent (approximately 1 in 12 years). | Lambda ≥ 1.0 or population shows a stable or increasing trend. |
| **Medium** | Winter snow conditions are somewhat limiting for snow roosting. | Late-lying snowfields remain into the summer in most years except in years of low snowfall. | Summer precipitation provides somewhat regular cooling and late-season moisture. | Brood-rearing habitat that supports insects and forbs is somewhat limiting. | Willow abundance and distribution is somewhat limiting, but provides adequate habitat in all seasons. | Immigration and breeding dispersal of individuals are somewhat limiting in some years. Connectivity is somewhat impeded but suitable habitat is still accessible. | Adult female survival < 0.5. Extremes in demographic lows are somewhat frequent (approximately 1 in 7 years). | Lambda < 1.0 but regular exchange across AUs occurs and maintains population. |
| **Low** | Winter snow conditions are very limiting; few areas available that are suitable for snow roosting. | Late-lying snowfields are rare except in years of exceptionally high snowfall. | Summer precipitation events occur but are less frequent and occasionally occur as intense storms. | Brood-rearing habitat that supports insects and forbs is very limiting. | Willow abundance and distribution is limiting and provides only seasonal habitat. | Exchange of individuals across AUs is infrequent. External recruitment of immigrants and breeding dispersal of individuals is severely limited. | Adult female survival <0.5 and shows consistent decline. Extremes in demographic lows occur frequently (approximately 1 in 3 years). | Lambda < 1.0 and/or shows consistent declining population trend. |
| **Very Low** | Poor winter snow conditions result in no suitable areas for snow roosting. | Late-lying snowfields are typically absent in most years. | Summer precipitation events occur infrequently and typically as intense storms. | Brood-rearing habitat that supports insects and forbs is only available in years with adequate moisture. | Willow abundance and distribution is very limiting. Only seasonal habitat is available in years with adequate moisture. | External recruitment of immigrants and breeding dispersal of individuals is not occurring because the distance to nearest suitable habitat exceeds 50 km. | Adult females are not present in all years. | A breeding population is not sustained in all years. |
| **Presumed Extirpated** | N/A | N/A | N/A | N/A | N/A | No external recruitment or breeding dispersal is occurring because suitable habitat is no longer occupied. | No adult female survival. | Functionally extirpated. |

Table 7. Evaluation of current condition for southern white-tailed ptarmigan analytical units using the condition categories from Table 6. A score of 5.4 or greater = High Condition; 4.2 – 5.3 = Medium Condition; 2.9 – 4.1 = Low Condition; and <2.9 = Very Low Condition. For the Snowy Range AU in Wyoming, we evaluated condition for the habitat factors but assigned an "X" to the demographic factors, as this AU is presumed extirpated. See text for explanation on methodology for calculating an overall condition score.

| **Analytical Unit (Shading identifies the representative unit: green = northern; tan = southern; blue = New Mexico)** | **Winter snow conditions** | **Late-lying snowfields** | **Summer precipitation/ monsoonal moisture** | **Brood-rearing habitat (insects/forbs)** | **Willow availability** | **External recruitment of immigrants/ Breeding dispersal** | **Adult female survival** | **Population growth** |
|---|---|---|---|---|---|---|---|---|
| Crown Point | High | Unknown | Medium | Medium | High | High | Unknown | Unknown |
| Mt. Evans | High | Medium | Medium | High | High | High | High | High |
| RMNP/Trail Ridge | High | Medium | Medium | High | Low | High | High | Low |
| Niwot Ridge | High | High | Medium | Medium | High | High | Unknown | Unknown |
| Independence Pass | High | High | High | High | High | High | High | High |
| Square Top | High | Unknown | Medium | Unknown | High | High | Medium | Medium |
| Guanella Pass | High | Unknown | Medium | Unknown | High | High | Medium | Medium |
| Loveland Pass | High | Unknown | Medium | Unknown | Medium | High | Medium | Medium |
| Byers Peak | High | High | High | High | High | High | High | High |
| Flat Tops | High | High | Unknown | High | High | Medium | Unknown | Unknown |
| Mt. Yale | High | High | High | High | High | High | High | High |
| Mt. Zirkel | High | Medium | High | Medium | Medium | Medium | Unknown | Unknown |
| Sangre de Cristos | Medium | Low | Medium | Medium | Medium | Medium | Unknown | Unknown |
| Snowy Range, Wyoming-Extirpated | Medium | Unknown | Unknown | Medium | Medium | X | X | X |
| Mesa Seco | High | Low | High | High | High | High | High | High |
| Emerald Lake | High | High | High | High | High | High | High | High |
| Ophir | High | High | High | High | High | High | High | Low |
| Southern San Juans | High | Medium | High | High | High | High | Unknown | High |
| New Mexico (Culebra, Wheeler Peak, Northern Pecos) | Unknown | Very Low | Medium | Medium | Low | Very Low | Very Low | Very Low |

Table 8. Analytical units where habitat and demographic data for southern white-tailed ptarmigan have been collected, the years of the study, and the relevant citations. Green shading represents analytical units in the northern representative unit and tan shading represent analytical units in the southern representative unit.

| Analytical Unit | Years of Study | Citations |
|---|---|---|
| Trail Ridge/Rocky Mountain National Park | 1966-2000; 2010-2016 | Braun and Rogers 1971; Wann et al. 2014; Wann et al. 2016; Wann 2017; Wann et al. 2019 |
| Mt. Evans | 1966-2016 | Braun and Rogers 1971; Martin et al. 2000; Sandercock et al. 2005a, b; Wann et al. 2014; Wann et al. 2016; Wann 2017; Wann et al. 2019 |
| Niwot Ridge | 1966-1977; 1970-1974 | May and Braun 1972; May and Braun 1973; May 1975 *in* Hoffman 2006; Giesen et al. 1980 |
| Independence Pass | 1966-1977; 2013-2017 | Weeden 1967; Braun and Rogers 1971; Giesen et al. 1980; Seglund et al. 2018 |
| Crown Point | 1966-1977 | Braun and Rogers 1971; May and Braun 1972; Giesen et al. 1980 |
| Square Tops | 1992-1996 | Martin et al. 2000; Sandercock et al. 2005a, b |
| Guanella Pass | 1966-1970; 1972-1974; 1982-1983; 1987-1996 | Braun and Schmidt 1971; Hoffman and Braun 1975; Hoffman and Braun 1977; Giesen and Braun 1992; Martin et al. 2000; Sandercock et al. 2005a, b |
| Loveland Pass | 1966-1977; 1987, 1989-1992, 1994 | Giesen et al. 1980; Martin et al. 2000; Sandercock et al. 2005a, b |
| Byers Peak | 2013-2017 | Seglund et al. 2018 |
| Mt. Yale | 2013-2017 | Seglund et al. 2018 |
| Mesa Seco | 1966-1969; 2013-2017 | Braun and Rogers 1971; Wann 2017; Seglund et al. 2018 |
| Emerald Lake | 2013-2017 | Seglund et al. 2018 |
| Ophir | 2013-2017 | Seglund et al. 2018 |

### 3.3 Current Condition Uncertainty

We had varying degrees of certainty regarding the current conditions of the habitat and demographic factors used to evaluate current condition. Given that the breeding distribution of ptarmigan has remained relatively stable across most of the AUs in Colorado, we assumed that winter snow conditions for the most part are in high condition across Colorado. Seglund et al. (2018) and Wann (2017) provided information regarding the presence of late-lying snowfields, brood-rearing habitat, and willow availability at some AUs. Additionally, we had little specific information regarding external recruitment/breeding dispersal; however, we made assumptions regarding the movements of birds across AUs based largely on the distance to nearest suitable breeding habitat (Seglund et al. 2018). Current condition information for adult female survival and population growth were based on data presented in Sandercock et al. 2005a and 2005b,

Wilson and Martin 2011, Wann 2017, and Seglund et al. 2018. However, data on these demographic factors are unknown for several AUs.

### 3.4 Assessing Population Redundancy

Redundancy describes the number and distribution of populations and illustrates the ability of the species to withstand catastrophic events. The southern white-tailed ptarmigan currently occurs throughout alpine habitats of Colorado, occupying the vast majority of its historical range (see Figure 2). It is presumed extirpated from the northern extent of its range in the Snowy Range of Wyoming (Braun and Wann 2017, p. 209). The southern white-tailed ptarmigan still occurs in the southern extent of its range in northern New Mexico, although it may have been extirpated in the extreme southern portion of its range (e.g., Pecos Wilderness and south; Braun and Williams 2015, p. 235). Historically, there were 19 AUs and currently there are 18 AUs distributed in Colorado and northern New Mexico. The distribution of these remaining AUs has largely remained unchanged. This suggests that the redundancy of southern white-tailed ptarmigan has not decreased from its historical levels.

### 3.5 Assessing Population Representation

Representation describes the subspecies' ability to adapt to changing environmental conditions. As described in **Section 2.6**, the southern white-tailed ptarmigan occurs in three representative units representing different environmental conditions, particularly along temperature and precipitation gradients (Zimmerman et al. 2020). Although some local extirpations (e.g., Snowy Range in Wyoming) and local declines (e.g., New Mexico) have occurred, the southern white-tailed ptarmigan still occupies nearly all of its historical range. Genomic analysis of white-tailed ptarmigan across the range of the entire species found that measures of genetic diversity of ptarmigan in New Mexico were lowest of all areas sampled (Langin et al. 2018, p. 1482, Suppl. Materials, Table S5), likely due to isolation and/or small population size. This suggests that the southern subspecies may be at risk of reductions in genetic and/or ecological diversity provided by ptarmigan in the New Mexico representative unit.

### 3.6 Summary of Current Conditions

Of the 19 analytical units we evaluated, 14 have high resiliency, 3 have medium resiliency, 1 AU has very low resiliency, and 1 AU is presumed extirpated (Table 9, Figure 10). Redundancy has remained largely unchanged from historical conditions, with the exception of the historical loss of one AU, the Snowy Range in Wyoming, at the northernmost extent of the subspecies' overall range. Currently, 18 of 19 AUs are distributed across Colorado and northern New Mexico, and the subspecies still occurs within three representative units.

Table 9. Summary of current conditions for southern white-tailed ptarmigan analytical units. A score of 5.4 or greater = High Condition; 4.2 – 5.3 = Medium Condition; 2.9 – 4.1 = Low Condition; and <2.9 = Very Low Condition. For the Snowy Range AU in Wyoming, we evaluated condition for the habitat factors but assigned an "X" to the demographic factors, as this AU is presumed extirpated. See text for explanation on methodology for calculating an overall condition score.

| **Analytical Unit (Shading identifies the representative unit: green = northern; tan = southern; blue = New Mexico)** | **Winter snow conditions** | **Late-lying snowfields** | **Summer precipitation/ monsoonal moisture** | **Brood-rearing habitat (insects/forbs)** | **Willow availability** | **External recruitment of immigrants/ Breeding dispersal** | **Adult female survival** | **Population growth** | **Overall Current Condition Score** | **Overall Current Condition** |
|---|---|---|---|---|---|---|---|---|---|---|
| Crown Point | High | Unknown | Medium | Medium | High | High | Unknown | Unknown | 5.8 | High |
| Mt. Evans | High | Medium | Medium | High | High | High | High | High | 6.5 | High |
| RMNP/Trail Ridge | High | Medium | Medium | High | Low | High | High | Low | 5.7 | High |
| Niwot Ridge | High | High | Medium | Medium | High | High | Unknown | Unknown | 5.8 | High |
| Independence Pass | High | High | High | High | High | High | High | High | 6.7 | High |
| Square Top | High | Unknown | Medium | Unknown | High | High | Medium | Medium | 5.9 | High |
| Guanella Pass | High | Unknown | Medium | Unknown | High | High | Medium | Medium | 5.9 | High |
| Loveland Pass | High | Unknown | Medium | Unknown | Medium | High | Medium | Medium | 5.8 | High |
| Byers Peak | High | High | High | High | High | High | High | High | 6.7 | High |
| Flat Tops | High | High | Unknown | High | High | Medium | Unknown | Unknown | 5.0 | Medium |
| Mt. Yale | High | High | High | High | High | High | High | High | 6.7 | High |
| Mt. Zirkel | High | Medium | High | Medium | Medium | Medium | Unknown | Unknown | 4.7 | Medium |
| Sangre de Cristos | Medium | Low | Medium | Medium | Medium | Medium | Unknown | Unknown | 4.4 | Medium |
| Snowy Range, Wyoming-Extirpated | Medium | Unknown | Unknown | Medium | Medium | X | X | X | X | X |
| Mesa Seco | High | Low | High | High | High | High | High | High | 6.5 | High |
| Emerald Lake | High | High | High | High | High | High | High | High | 6.7 | High |
| Ophir | High | High | High | High | High | High | High | Low | 6.0 | High |
| Southern San Juans | High | Medium | High | High | High | High | Unknown | High | 6.6 | High |
| New Mexico (Culebra, Wheeler Peak, Northern Pecos) | Unknown | Very Low | Medium | Medium | Low | Very Low | Very Low | Very Low | 2.1 | Very Low |

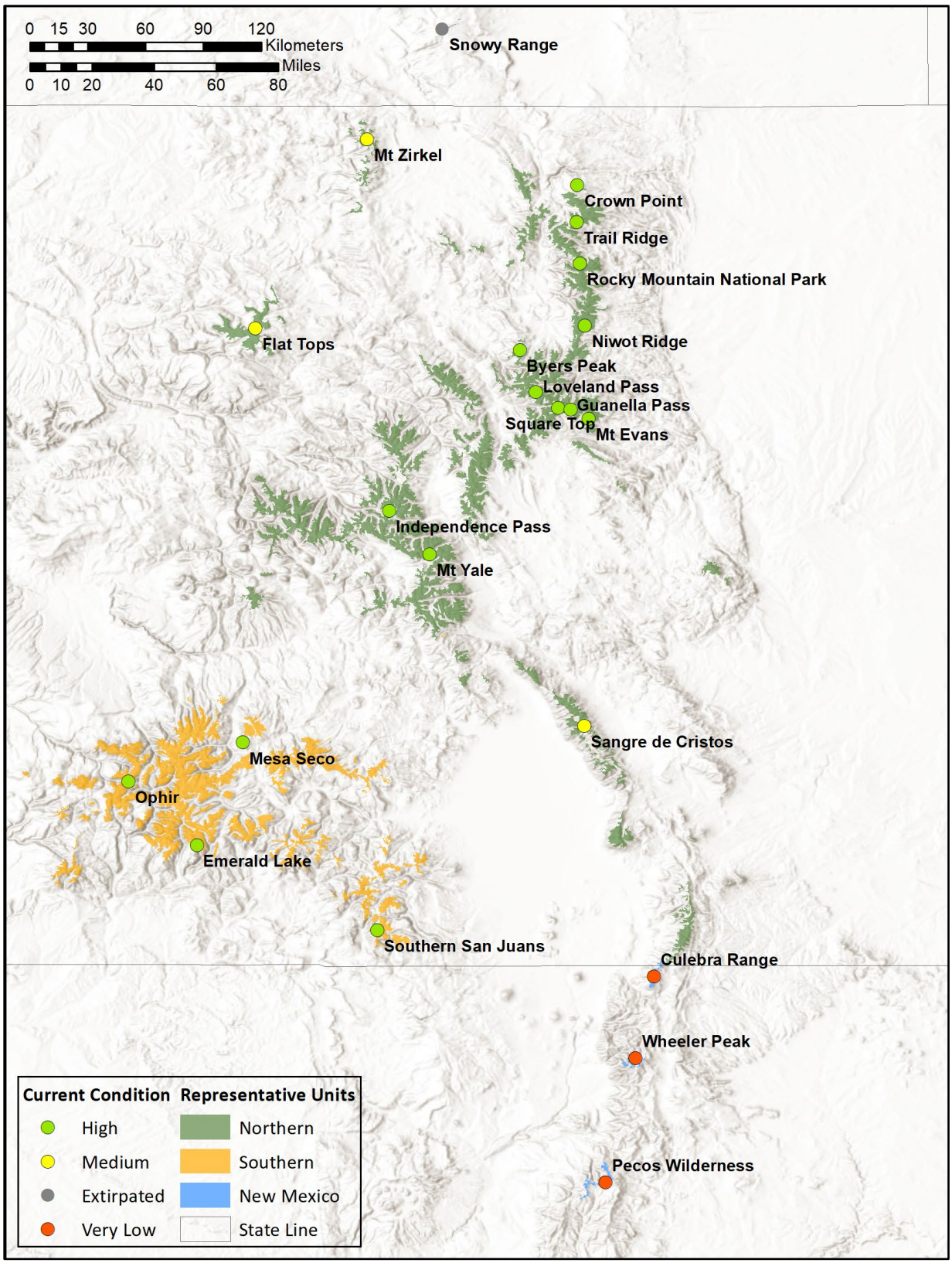


Figure 10. Summary of current condition of the 19 analytical units considered for this report.

# Chapter 4: Future Conditions

In this chapter, we evaluate the range of expected future conditions for southern white-tailed ptarmigan by 2050 using projections and plausible future scenarios. We selected 2050 because we had localized climate models available for this timeframe. This timeframe also represents approximately 10 generations of southern white-tailed ptarmigan. Accounting for the current conditions for southern white-tailed ptarmigan and its habitat described in Chapter 3, we evaluate future conditions for ptarmigan. The viability of southern white-tailed ptarmigan is dependent upon maintaining demographic connectivity across suitable alpine habitat. Future change in climate is the primary factor expected to influence future conditions for southern white-tailed ptarmigan, specifically changes in temperature and precipitation.

We considered the use of dynamic global vegetation models (DGVMs) as a tool to inform our evaluation of future condition. DGVMs simulate shifts, or future changes, in broad categories of vegetation classes in response to climate change. We believe that the DGVM evaluated for this analysis does not accurately project future habitat conditions for the southern white-tailed ptarmigan due to its coarse spatial resolution, its use of simplified descriptions of complex biotic and abiotic mechanisms that influence the distribution and dynamics of vegetation, and the limited availability of climate data observations at high elevations. Therefore, we did not use these models in our analysis of future viability for this subspecies. Instead, we relied on demographic and ecological data for the southern white-tailed ptarmigan collected over several decades as well as expert input to help evaluate the future condition for the southern white-tailed ptarmigan under three climate-based future scenarios. See Appendix C for a detailed evaluation of DGVMs.

## 4.1 Description of Climate Scenarios

The Cooperative Institute for Research and Environmental Sciences and the North Central Climate Adaptation Science Center (NCCASC), University of Colorado, Boulder conducted a climate analysis using three downscaled global climate models (GCMs) for two future Representative Concentration Pathways (RCPs): RCP 4.5 and RCP 8.5. These divergent GCMs represent a range of plausible futures. RCPs represent a range of trajectories of emissions and other human impacts on climate, and these trajectories are similar until 2050, when they diverge through the end of the century. The RCP numbers refer to the amount of extra energy trapped in the climate system by the addition of greenhouse gases and other human-caused changes by the year 2100, as compared to pre-industrial levels (~1750) (Lukas et al. 2014, p. 42). RCP 4.5 and RCP 8.5 together cover most of the range of RCP trajectories at 2050 (Lukas et al. 2014, p. 43) and are used in this report. RCP 4.5 assumes large reductions in greenhouse gas emissions, whereas RCP 8.5 assumes no reduction in emissions and is often considered a "business as usual" scenario (Lukas et al. 2014, p. 42). From these models, NCCASC developed three climate scenarios for the northern and southern portion of the ptarmigan range in Colorado: **Very Hot and Dry** (IPSL-CM5A-MR.rcp85), **Hot** (CCSM4.rcp45), and **Hot and Very Wet** (MIROC5.rcp45) (Rangwala 2020). These scenarios represent projected changes in climate by the year 2050 based on the projected conditions averaged over the 30-year period 2040 to 2069 relative to the historical conditions for the period 1971 to 2000. The scenarios were developed

separately for the northern portion of the ptarmigan range, representing 39.7708ºN; 105.9069ºW and the southern portion of the ptarmigan range, representing 37.8125ºN; 107.7819ºW.

The three climate scenarios include projections for the North American Monsoon (NAM). Modeling the influence of global climate change on the NAM is challenging because it is influenced by several factors occurring at multiple spatial and temporal scales (Cayan et al. 2013, p. 116; Pascale et al. 2017, p. 806). Climate models predict various effects of the NAM on monsoonal precipitation from little change in precipitation (Cook and Seager 2013, p. 1697) to substantial reductions in precipitation, particularly in the northern periphery of the NAM region (Pascale et al. 2017, p. 811) to substantial increases in precipitation in the northern periphery, particularly over mountainous areas (Chang et al. 2015, p. 8250). Some models predict that the onset of the NAM will be delayed (Cook and Seager 2013, p. 1697), which may have implications for ptarmigan habitat including plant phenology, food availability, and thermoregulation.

Although there is considerable model uncertainty regarding future changes to the NAM, several models suggest a drying effect at the periphery of the monsoon with stronger monsoonal precipitation in and near the core of the NAM (Melissa Bukovsky 2019, pers. comm.). However, during periods of strong convective activity, monsoonal precipitation will spread northward, often bringing intense storm events. The models support a pattern of fewer but more intense thunderstorms, suggesting that the alpine may experience longer dry periods between storms.

Climate Scenario 1: Very Hot and Dry

Under the Very Hot and Dry scenario, the northern portion of the ptarmigan range is projected to experience very large increases in summer and fall temperatures (+8°F) and substantial reductions in spring and summer precipitation (-15%). The hottest summer daytime temperatures could increase by 8°F with severe drought (similar to 2002) every other year and extreme drought conditions lasting up to five years. The area is projected to experience a 25% reduction in spring snowpack and warmer winter temperatures (+6°F) resulting in earlier snowmelt. The growing season could increase by more than two months. Notably, this scenario predicts that overall summer precipitation could decrease substantially with 20% more intense rainfall events.

The southern portion of the range is projected to experience very large increases in annual and summer temperatures (+8°F) with substantial reductions in annual (-20%) and summer (-30%) precipitation. The hottest summer daytime temperatures could increase by 8°F with severe drought (similar to 2002) occurring almost every year and extreme drought conditions lasting up to six years. The area is projected to experience a 40% reduction in spring snowpack and warmer winter temperatures (+7°F) resulting in earlier snowmelt. The growing season could increase by approximately 50 days. Notably, monsoonal precipitation is projected to decrease substantially with 20% more intense rainfall events.

Climate Scenario 2: Hot

Under the Hot scenario, the northern portion of the ptarmigan range is projected to experience a moderate increase in annual temperature (4°F) with no change in summer precipitation. The hottest summer daytime temperatures could increase by 4°F with severe drought (similar to

2002) every two to three years and extreme drought conditions lasting up to four years. The area could experience no change to a slight increase in spring snowpack due to increases in winter and spring precipitation. The growing season is projected to increase by approximately 50 days. The area could experience a 10% increase in intense rainfall events.

The southern portion of the range is projected to experience a moderate increase in annual temperature (4°F) but no change in the amount of precipitation. Hottest summer daytime temperatures could increase by 5°F with severe drought (similar to 2002) occurring every six years and extreme drought conditions lasting up to two years. The area could experience a moderate reduction (15%) in spring snowpack resulting in earlier snowmelt. Growing season is projected to increase by over three weeks. Monsoonal precipitation could decrease very slightly with 10% more intense rainfall events.

Climate Scenario 3: Hot and Very Wet

Under the Hot and Very Wet scenario, the northern portion of the ptarmigan range is projected to experience an increase in summer daytime high temperatures of 3°F and very warm springs (+8°F). The area could experience a 40% increase in spring precipitation with a high proportion of that falling as rain. Spring snowpack could be reduced by 29%. Severe drought (similar to 2002) could occur every three years with extreme drought conditions lasting up to two years. Warmer and drier falls could lead to reduced snowpack in the early winter. The growing season is projected to increase by approximately 40 days. Summer precipitation could increase substantially (+15%) with 10% more intense rainfall events.

The southern portion of the range is projected to experience an increase in summer daytime high temperatures of 3°F and extremely warm springs (+10°F). The area could experience a 40% increase in spring precipitation with a high proportion of that falling as rain. The area is projected to experience a 40% reduction in spring snowpack. Severe drought (similar to 2002) could occur every three to four years with extreme drought conditions lasting up to two years. Warmer and drier falls could lead to reduced snowpack in the early winter. The growing season is projected to increase by four weeks. Monsoonal precipitation could increase substantially (+30%) with 10% greater intensity.

Table 10 summarizes and compares these three climate scenarios. Values and projected changes in climate relative to historical conditions under these three scenarios are detailed in Table 11.

Predicted impacts of each climate scenario on habitat and demographic factors influencing southern white-tailed ptarmigan resiliency are provided in Table 12. These predicted impacts are necessarily generalized and qualitative. Complex topography and microhabitats in already highly variable alpine environments contribute to the uncertainties of forecasting future impacts to ptarmigan.

Table 10. Summary of three future climate scenarios representing projected changes in climate by the year 2050 based on projected conditions averaged over the period 2040 to 2069 relative to the historical conditions for the period 1971 to 2000. Scenarios were developed separately for the northern and the southern portion of the southern white-tailed ptarmigan range.

| Very Hot and Dry | Hot | Hot and Very Wet |
|---|---|---|
| • Substantial decreases in spring and summer precipitation in the North (-15%) and in the South (-30%)<br>• Substantial increases in summer and fall temperatures (+8°F)<br>• Large reductions spring snowpack in the North (-25%) and in the South (-40%)<br>• Warmer winter temperatures in the North (+6°F) and in the South (7°F)<br>• Severe drought occurs every year in the North and every other year in the South<br>• Duration of extreme drought conditions lasts for 5 years in the North and 6 years in the South<br>• Growing season increases by 60 days in the North and by 50 days in the South<br>• Increased frequency of intense rainfall events (20%) | • No change in precipitation in the North and a very slight decrease (-2%) in summer precipitation in the South<br>• Moderate increase in summer (+4°F) and fall temperatures (+5°F)<br>• Slight increases in winter and spring precipitation in the North<br>• Moderate reductions in early winter and spring snowpack (-15%) in the South<br>• Severe drought occurs every 2-3 years and lasts up to 4 years in the North<br>• Severe drought occurs every 6 years and lasts up to 2 years in the South<br>• Growing season increases by 50 days in the North and 3 weeks in the South<br>• Increased frequency of intense rainfall events (+10%) | • Substantial increase in spring precipitation (+40%)<br>• Substantial increase in spring temperatures in the North (+8°F) and in the South (10°F)<br>• Slight increase in summer temperature (+3°F)<br>• Substantial reductions in early season and spring snowpack in the North (-29%) and in the South (-40%)<br>• Severe drought occurs every 3-4 years and last up to 2 years.<br>• Growing season increases 30 in the South and 40 days in the North<br>• Substantial increases in summer precipitation (+15%) in the North and monsoonal precipitation (+30%) in the South<br>• Increased frequency of intense rainfall events (10%) |

Table 11. Changes in future climate by 2050 (2040-2069) relative to the 1971-2000 period under three climate scenarios. Values and projected changes are for the a) northern portion of the southern white-tailed ptarmigan range (39.7708°N; 105.9069°W) and a mean elevation of 11,521 feet and the b) southern portion of the southern white-tailed ptarmigan range (37.8125°N; 107.7819°W) and a mean elevation of 11,475 feet. Interpretation of these results are expected to apply at a relatively higher elevation regime, as changes in these metrics are robust at large scales. Winter is December, January, February; spring is March, April, May; summer is June, July, August; fall is September, October, November (Rangwala 2020).

### a. Northern portion of the range

| **Climate Metric** | Time Period | Very Hot and Dry | Hot | Hot and Very Wet | *Historical Value* |
|---|---|---|---|---|---|
| Mean Temperature (°F) | Annual | 8 | 4 | 6 | *30 °F* |
| | Winter | 6 | 3 | 4 | *14 °F* |
| | Spring | 6 | 3 | 8 | *28 °F* |
| | Summer | 8 | 4 | 3 | *49 °F* |
| | Fall | 8 | 5 | 5 | *31 °F* |
| Precipitation (%) | Annual | -8 | 6 | 6 | *31 inches* |
| | Winter | 6 | 16 | 4 | *8 inches* |
| | Spring | -16 | 11 | 12 | *10 inches* |
| | Summer | -16 | 3 | 16 | *7 inches* |
| | Fall | 2 | 3 | 0 | *6 inches* |
| Daytime Maximum Temperature (°F) | Annual | 7 | 4 | 5 | *42 °F* |
| | Winter | 6 | 3 | 4 | *25 °F* |
| | Spring | 7 | 4 | 8 | *40 °F* |
| | Summer | 8 | 5 | 3 | *60 °F* |
| | Fall | 8 | 5 | 5 | *42 °F* |
| Daytime Minimum Temperature (°F) | Annual | 7 | 4 | 5 | *19 °F* |
| | Winter | 7 | 4 | 5 | *3 °F* |
| | Spring | 6 | 3 | 7 | *16 °F* |
| | Summer | 8 | 4 | 4 | *37 °F* |
| | Fall | 7 | 4 | 4 | *21 °F* |
| Snow Water Equivalent (%) | January 1 | -19 | 6 | -19 | *5 inches* |
| | April 1 | -9 | 3 | -2 | *12 inches* |
| | May 1 | -27 | 1 | -29 | *15 inches* |
| Soil Moisture (%) | Spring | 0 | -2 | 15 | *10 inches* |
| | Summer | -25 | -3 | -16 | *16 inches* |
| | Fall | -27 | -14 | -14 | *11 inches* |
| Potential Evapotranspiration (%) | Summer | 22 | 11 | 10 | *15 inches* |
| | Fall | 61 | 34 | 39 | *4 inches* |

**b. Southern portion of the range**

| **Climate Metric** | Time Period | Very Hot and Dry | Hot | Hot and Very Wet | *Historical Value* |
|---|---|---|---|---|---|
| Mean Temperature (ºF) | Annual | 8 | 4 | 6 | *33 ºF* |
| | Winter | 7 | 4 | 6 | *19 ºF* |
| | Spring | 7 | 4 | 10 | *31 ºF* |
| | Summer | 8 | 4 | 4 | *49 ºF* |
| | Fall | 8 | 5 | 5 | *34 ºF* |
| Precipitation (%) | Annual | -18 | 0 | 6 | *38 inches* |
| | Winter | -10 | 5 | -6 | *11 inches* |
| | Spring | -22 | -1 | 41 | *10 inches* |
| | Summer | -27 | -2 | 28 | *7 inches* |
| | Fall | -16 | -3 | -9 | *10 inches* |
| Daytime Maximum Temperature (ºF) | Annual | 8 | 4 | 6 | *47 ºF* |
| | Winter | 7 | 3 | 6 | *32 ºF* |
| | Spring | 8 | 4 | 10 | *45 ºF* |
| | Summer | 8 | 5 | 3 | *63 ºF* |
| | Fall | 9 | 5 | 5 | *47 ºF* |
| Daytime Minimum Temperature (ºF) | Annual | 7 | 3 | 6 | *20 ºF* |
| | Winter | 7 | 4 | 7 | *5 ºF* |
| | Spring | 6 | 3 | 9 | *17 ºF* |
| | Summer | 8 | 3 | 4 | *36 ºF* |
| | Fall | 8 | 3 | 4 | *22 ºF* |
| Snow Water Equivalent (%) | January 1 | -27 | -13 | -28 | *9 inches* |
| | April 1 | -17 | -7 | -17 | *21 inches* |
| | May 1 | -37 | -14 | -37 | *24 inches* |
| Soil Moisture (%) | Spring | -9 | -1 | 4 | *22 inches* |
| | Summer | -19 | -8 | -10 | *24 inches* |
| | Fall | -25 | -8 | -6 | *21 inches* |
| Potential Evapotranspiration (%) | Summer | 20 | 11 | 7 | *16 inches* |
| | Fall | 54 | 28 | 28 | *6 inches* |

Table 12. Predicted impacts to habitat and demographic factors influencing resiliency of the southern white-tailed ptarmigan under three future (year 2050) climate scenarios: Very Hot and Dry, Hot, and Hot and Very Wet.

| Climate Scenario | Habitat Factors | | | | | Demographic Factors | | |
|---|---|---|---|---|---|---|---|---|
| | **Winter Snow Conditions** | **Late-lying Snowfields** | **Summer precipitation /monsoonal moisture** | **Brood-rearing habitat (insects/forbs)** | **Willow Availability** | **External recruitment of immigrants/ Breeding dispersal** | **Adult Female Survival** | **Population growth** |
| **Very Hot and Dry** | • Higher maximum daytime winter temperatures will reduce the suitability of snow for snow roosting because more frequent freeze/thaw events are likely to create snow crust on the surface (**North and South**).<br>• Increased frequency and duration of droughts will increase soil aridity, resulting in more frequent and extreme dust-on-snow events that lower albedo and hasten melting of the snowpack (**North and South**). | • Reductions in winter precipitation **(South),** and reductions in spring snowpack and spring precipitation along with substantial increases in summer daytime temperatures **(North and South)** will reduce the availability of late-lying snowfields.<br>• Increased frequency and duration of droughts will increase soil aridity, resulting in more frequent and extreme dust-on-snow events that lower albedo and hasten melting of the snowpack (**North and South**). | • Substantial reductions in summer precipitation along with substantial increases in summer temperature will reduce the cooler temperatures and moisture associated with summer thunderstorms/monsoonal moisture (**North and South**). | • Substantial reductions in spring and summer precipitation as well as reductions in spring snowpack will reduce soil moisture, resulting in reduced plant productivity and earlier plant senescence **(North and South)**.<br>• Frequent and prolonged drought as well as substantial increases in summer temperature will increase potential evapotranspiration and reduce soil moisture, resulting in reduced plant productivity and earlier plant senescence **(North and South)**.<br>• Growing season will increase by more than two months **(North)** and seven weeks **(South),** altering plant and insect phenology.<br>• Earlier snowmelt may lead to earlier flowering, particularly for early-season forage species. Warmer summer temperatures may advance flowering for late-flowering species, resulting in a shorter flowering season **(North and South)**. | • Substantial reductions in spring and summer precipitation as well as reductions in spring snowpack will result in reduced soil moisture, possibly limiting willow growth and establishment **(North and South)**.<br>• Frequent and prolonged drought as well as substantial increases in summer temperature will increase potential evapotranspiration and reduce soil moisture, resulting in reduced plant productivity and earlier plant senescence **(North and South)**.<br>• Warmer temperatures may increase the abundance and cover of willows **(North and South)**.<br>• Growing season will increase by more than two months **(North)** and seven weeks **(South),** altering plant and insect phenology.<br>• Increase in growing degree days may increase density of woody plants (**North and South)**. | • Substantial increases in summer temperatures and reduced summer precipitation may reduce the suitability of nesting and brood-rearing, impacting connectivity (**North and South**).<br>• Increased drought conditions along with increased summer temperatures, increased potential evapotranspiration, and reduced summer and fall soil moisture may reduce the extent of some seasonal habitats (e.g., late summer/fall) (**North and South**). | • Changing snow quality and quantity may reduce the availability of suitable snow roosting sites, reducing winter survival (**North and South**).<br>• Reductions in the availability of late-lying snowfields and cooling brought by summer precipitation may reduce the capacity of ptarmigan to find thermal refugia (**North and South**).<br>• Reduced forage availability may reduce survival in all seasons but particularly during the nesting and brood-rearing periods (**North and South**). | • Earlier snowmelt and warmer springs may allow for a longer breeding season, providing more opportunity for renesting (**North and South**).<br>•Changes in plant and insect phenology could lead to a mismatch between breeding and food availability, reducing chick survival (**North and South**).<br>• Impacts to brood-rearing habitat may reduce chick survival (**North and South**).<br>• Impacts to wintering habitat may reduce juvenile and adult survival (**North and South**).<br>• Reduced connectivity could reduce immigration and dispersal opportunities (**North and South**).<br>• More prolonged, intense rainfall events may reduce chick survival (**North and South**). |

| Climate Scenario | Habitat Factors | | | | | Demographic Factors | | |
|---|---|---|---|---|---|---|---|---|
| | **Winter Snow Conditions** | **Late-lying Snowfields** | **Summer precipitation/ monsoonal moisture** | **Brood-rearing habitat (insects/forbs)** | **Willow Availability** | **External recruitment of immigrants/ Breeding dispersal** | **Adult Female Survival** | **Population growth** |
| **Hot** | • Increased winter precipitation may maintain snow quality for snow roosting **(North).**<br>• Moderate reductions in early season snowpack may reduce snow conditions (**South**).<br>• Increased frequency and duration of droughts will increase soil aridity, resulting in more frequent and extreme dust-on-snow events that lower albedo and hasten melting of the snowpack (**North and South**). | • Increased winter and spring precipitation may maintain the availability of late-lying snowfields **(North).**<br>• Moderate increases in daytime summer temperatures may reduce the availability of late-lying snowfields in years with lower snowfall **(North).**<br>• Moderate reductions in spring snowpack and increased summer temperatures may reduce the availability of late-lying snowfields **(South).**<br>• Increased frequency and duration of droughts will increase soil aridity, resulting in more frequent and extreme dust-on-snow events that lower albedo and hasten melting of the snowpack (**North and South**). | •Summer thunderstorms will continue to bring cooler afternoon temperatures and late-season moisture **(North).**<br>• Slight decreases in monsoonal precipitation will reduce the cooler afternoon temperatures and moisture associated with summer thunderstorms **(South).** | • Frequent and prolonged drought as well as moderate increases in summer temperature will increase potential evapotranspiration and reduce soil moisture, resulting in reduced plant productivity and early plant senescence **(North and South)**.<br>• Growing season will increase by about seven weeks **(North)** and three weeks **(South),** altering plant and insect phenology.<br>• Earlier snowmelt may lead to earlier flowering, particularly for early-season forage species. Warmer summer temperatures may advance flowering for late-flowering species, resulting in a shorter flowering season **(North and South)**. | • Frequent and prolonged drought as well as moderate increases in summer temperature will increase potential evapotranspiration and reduce soil moisture, possibly limiting willow growth and establishment **(North and South)**.<br>• Warmer temperatures may increase the abundance and cover of willows **(North and South)**.<br>• Growing season will increase by about seven weeks **(North)** and three weeks **(South),** altering plant and insect phenology.<br>• Increase in growing degree days may increase density of woody plants **(North and South)**. | • Increased drought conditions along with increased summer temperatures, increased potential evapotranspiration, and reduced summer and fall soil moisture may reduce the extent of some seasonal habitats (e.g., late summer/fall) **(North and South)**. | • In drought years, reduced forage availability may reduce survival in all seasons but particularly during the nesting and brood-rearing periods **(North and South)**. | • Earlier snowmelt and warmer springs may allow for a longer breeding season, providing more opportunity for renesting (**North and South**).<br>•Changes in plant and insect phenology could lead to a mismatch between breeding and food availability, reducing chick survival **(North and South)**.<br>• Impacts to brood-rearing habitat may reduce chick survival **(North and South)**.<br>• More prolonged, intense rainfall events may reduce chick survival **(North and South)**. |

| Climate Scenarios | Habitat Factors | | | | | Demographic Factors | | |
|---|---|---|---|---|---|---|---|---|
| | **Winter Snow Conditions** | **Late-lying Snowfields** | **Summer precipitation/ monsoonal moisture** | **Brood-rearing habitat (insects/forbs)** | **Willow Availability** | **External recruitment of immigrants/ Breeding dispersal** | **Adult Female Survival** | **Population growth** |
| **Hot and Very Wet** | • Substantial reductions in early season snowpack will reduce snow conditions (**North and South**).<br>• Increased frequency and duration of droughts will increase soil aridity, resulting in more frequent and extreme dust-on-snow events that lower albedo and hasten melting of the snowpack (**North and South**). | • Substantial increases in spring temperatures, reductions in spring snowpack, and substantial increases in spring precipitation falling as rain may reduce the extent of late-lying snowfields **(North and South)**.<br>• Increased frequency and duration of droughts will increase soil aridity, resulting in more frequent and extreme dust-on-snow events that lower albedo and hasten melting of the snowpack (**North and South**). | •Summer thunderstorms will continue to bring cooler afternoon temperatures and late-season moisture **(North).**<br>• Substantial increases in monsoonal moisture will bring cooler afternoon temperatures and late-season moisture but storms may be of greater severity and intensity **(South).** | • Frequent and prolonged drought will increase potential evapotranspiration and reduce summer soil moisture, resulting in reduced plant productivity and early plant senescence **(North and South)**.<br>• Growing season will increase by about six weeks **(North)** and four weeks **(South),** altering plant and insect phenology.<br>• Earlier snowmelt may lead to earlier flowering, particularly for early-season forage species. Warmer summer temperatures may advance flowering for late-flowering species, resulting in a shorter flowering season **(North and South)**. | • Frequent and prolonged drought will increase potential evapotranspiration and reduce summer soil moisture, possibly limiting willow growth and establishment **(North and South)**.<br>• Warmer temperatures and increased precipitation may increase the abundance and cover of willows **(North and South)**.<br>• Growing season will increase by about six weeks **(North)** and four weeks **(South)**, potentially altering plant and insect phenology.<br>• Increase in growing degree days may increase density of woody plants (**North and South**). | • Increased drought conditions along with increased potential evapotranspiration, and reduced summer and fall soil moisture may reduce the extent of some seasonal habitats (e.g., late summer/fall) (**North and South**). | • Changing snow quality and quantity may reduce the availability of suitable snow roosting sites, reducing winter survival (**North and South**).<br>• Reductions in the availability of late-lying snowfields and cooling brought by summer precipitation may reduce the capacity of ptarmigan to find thermal refugia (**North and South**).<br>• In drought years, reduced forage availability may reduce survival in all seasons but particularly during the nesting and brood-rearing periods (**North and South**). | • Earlier snowmelt and warmer springs may allow for a longer breeding season, providing more opportunity for renesting.<br>• Changes in plant and insect phenology could lead to a mismatch between breeding and food availability, reducing chick survival (**North and South**).<br>• Impacts to brood-rearing habitat may reduce chick survival (**North and South**).<br>• More prolonged, intense rainfall events may reduce chick survival (**North and South**). |

## 4.2 Evaluation of Future Conditions

To evaluate future conditions, we considered three plausible future scenarios based on changes in climate. These future scenarios are all plausible, yet their likelihoods may vary. Actual future conditions could include a combination of factors from any of these three scenarios or fall somewhere in between these scenarios. However, we expect that these scenarios represent the full range of plausible future conditions that could occur. We evaluated each of these scenarios in terms of how it would influence resiliency, redundancy, and representation of southern white-tailed ptarmigan by the year 2050.

<u>Future Scenario 1: Very Hot and Dry Scenario</u>

Northern, Southern, and New Mexico Representative Units:

**Resiliency**: Under this scenario, we anticipate that all AUs will have reduced resiliency from the current condition as a result of a (1) substantial decrease in spring and summer precipitation; (2) substantial increase in summer temperature; (3) large reductions in early winter and spring snowpack; (4) increased frequency and duration of extreme drought conditions; and (5) significant reduction in monsoonal precipitation in the south. Eleven AUs currently ranked as High condition will decline to Medium condition and three AUs currently ranked as High condition will decline to Low condition. Three AUs currently ranked as Medium condition will decline to Low condition. We expect that southern white-tailed ptarmigan in New Mexico, currently in Very Low condition, may be extirpated under this scenario, as the habitat and demographic factors there are already very limiting. Substantial reductions in snowpack, substantial decreases in spring and summer precipitation including significant reductions in monsoonal precipitation, along with substantial increases in summer temperature and increased severity and frequency of extreme drought conditions may substantially reduce or eliminate suitable habitat such that ptarmigan no longer occupy alpine areas at the southern extent of the range in New Mexico.

**Redundancy**: Currently there are 18 extant AUs, and under this scenario there would be 17 AUs in the future with the expected loss of ptarmigan in New Mexico. The overall distribution of the 17 remaining AUs remains unchanged under this scenario (Figure 11).

**Representation:** Under this scenario we anticipate that the ecological diversity of the subspecies could decline due to the loss of ptarmigan in New Mexico in the southern extent of the range (Figure 10). Loss of the New Mexico population may represent a loss of local adaptation to warmer temperatures present in ptarmigan in this part of the range (Zimmerman et al. 2020).

**Summary of Future Scenario 1**: Under this scenario, there are 11 AUs in Medium condition, 6 AUs in Low condition, and 2 AUs that are extirpated. All AUs have reduced resiliency from current conditions, which represents an increase in risk from stochastic events. Redundancy would be reduced from 18 AUs currently occupied to 17 AUs due to the potential loss of New Mexico, which is currently the only AU in Very Low condition (Table 13; Figure 11). Representation would be reduced with the loss of local adaptation to temperature and precipitation potentially present in New Mexico ptarmigan (Zimmerman et al. 2020). These

reductions in redundancy and representation could represent an increase in risk from catastrophic events and environmental change from current conditions.

Future Scenario 2: Hot Scenario

**Resiliency**: Under this scenario, we expect that resiliency for all AUs will be maintained at current condition levels with the exception of the Ophir AU in the southern representative unit. Thirteen AUs will remain in High condition while the Ophir AU declines from High to Medium condition, 3 AUs will remain in Medium condition, and 1 AU, New Mexico, will remain in Very Low condition.

Specifically, in the Northern representative unit:

- Winter snow conditions are expected to remain in High condition due to increases in winter and spring precipitation in all AUs but the Snowy Range. Snow conditions in the Snowy Range continue to be in Medium condition due to expected continuation of snowmobiling and impacts to snow quality.
- Late-lying snowfields are expected to remain in High condition given maintenance of the spring snowpack and increases in winter and spring precipitation, except for Mt. Zirkel and the Sangre de Cristos, which remain in Medium and Low condition, respectively.
- Summer precipitation is not expected to change, so the conditions for summer precipitation in the northern AUs would not change from current condition.
- Similarly, brood-rearing habitat and willow availability are not expected to change from current condition given the maintenance of annual precipitation and late-season moisture with only slight increases in summer temperature.
- We do not anticipate any changes in demographic connectivity that would impact dispersal or recruitment, or any changes to adult female survival and population growth.

In the Southern representative unit:

- Winter snow conditions are expected to fall to Medium condition across AUs due to reductions in early winter (January) and spring snowpack.
- Reduced snowpack will lower the condition of late-lying snowfields in all southern AUs. Emerald Lake and Ophir are expected to have late-lying snowfields in some years due to relatively high snowfall amounts and northerly aspects found at these AUs, so these are expected to be in Medium condition.
- The Mesa Seco AU currently has late-lying snowfields only in high snow years. This AU is expected to fall to Very Low condition for late-lying snowfields. The Southern San Juans AU is expected to fall to Low condition.
- Summer monsoons are expected to decrease very slightly but are still expected to provide adequate late-season moisture and cooling.
- We do not anticipate any changes in demographic connectivity that would impact dispersal or recruitment or adult female survival.
- We anticipate possible reductions in reproductive success and chick survival at Mesa Seco and the Southern San Juans due to loss of late-lying snowfields and reductions in brood-rearing habitat, which may impact population growth.

New Mexico representative unit:

- We expect brood-rearing habitat to drop from Medium to Low condition as a result of reduced snowpack. Other habitat and demographic factors are expected to remain the same as current conditions in New Mexico given similar temperature and spring and summer precipitation under this scenario.

**Redundancy**: Currently there are 18 extant AUs, and under this scenario there would continue to be 18 extant AUs in the future in the same configuration as current conditions (Figure 12).

**Representation:** Under this scenario, we anticipate that the ecological diversity of the subspecies will be maintained as it is under current conditions (Figure 12).

**Summary of Future Scenario 2**: Under this scenario, there are 13 AUs in High condition, 4 AUs in Medium condition and 1 AU in Very Low condition. Redundancy and representation would remain unchanged from current conditions (Table 14, Figure 12).

Future Scenario 3: Hot and Very Wet Scenario

Under this scenario, we anticipate that several AUs will have reductions in resiliency as a result of (1) reduced early and late season snowpack affecting winter snow conditions; (2) reductions in late-lying snowfields affecting availability of thermal refugia; (3) reductions in brood-rearing habitat due to losses of mesic habitats; and (4) declines in both adult female survival and population growth. Nine AUs will remain in High condition while five AUs decline from High to Medium condition, three AUs will remain in Medium condition, and one AU will remain in Very Low condition.

Specifically, in the Northern representative unit:

- Winter snow conditions are expected to fall to Medium condition in all AUs but the Snowy Range due to substantial reductions in both early season (January) and spring snowpack. Snow conditions in the Snowy Range continue to be in Medium condition due to expected continuation of snowmobiling and impacts to snow quality.
- Late-lying snowfields are expected to decline from current conditions due to substantial increases in spring temperatures and spring precipitation that result in rain on snow events and substantial decreases in early winter and spring snowpack.
- Substantial increases in summer precipitation will increase late-season moisture and cooling, and we expect all AUs to have regular summer precipitation that provides late-season moisture and cooler temperatures.
- Although all AUs will see substantial increases in spring and summer precipitation, we expect brood-rearing habitat to be reduced in all AUs as a result of reductions in the availability of late-lying snowfields. We do not anticipate that willow availability will decrease given increased moisture and temperature.
- We do not expect changes to demographic connectivity, but we do anticipate reductions in adult female survival as a result of poorer winter and spring conditions. We also expect declines in population growth as a result of reduced chick survival due to reductions in brood-rearing habitat.

In the Southern representative unit:

- Winter snow conditions are expected to decline to Medium condition across AUs due to decreases in winter precipitation, increases in winter temperatures, and reductions in early winter (January) and spring snowpack.
- Late-lying snowfields are expected to decline from current conditions due to substantial reductions in early winter snowpack and increases in spring temperatures and spring precipitation that will result in rain on snow events.
- Substantial increases in monsoonal precipitation are expected to maintain High conditions for monsoonal moisture.
- Extremely wet springs and substantial increases in monsoonal precipitation are expected to maintain brood-rearing habitat and willow availability; however, we expect brood-rearing habitat to be reduced due to the loss of late-lying snowfields and possibly other mesic areas.
- We do not anticipate any changes in demographic connectivity that would impact dispersal or recruitment. However, we expect that both adult female survival and population growth will decline due to reductions in the quality of winter habitat as well as brood-rearing habitat.

New Mexico representative unit:

- We expect increases in summer precipitation related to monsoonal moisture and reductions in brood-rearing habitat due to potential reductions in snowpack. We expect demographic factors to remain in Very Low condition.

**Redundancy**: Currently there are 18 extant AUs, and under this scenario there would continue to be 18 extant AUs in the future in the same configuration as current conditions (Figure 13).

**Representation:** Under this scenario we anticipate that the ecological diversity of the subspecies will be maintained as it is under current conditions (Figure 13).

**Summary of Future Scenario 3**: Under this scenario, there are 9 AUs in High condition, 8 AUs in Medium condition and 1 AU in Very Low condition. Redundancy and representation would remain unchanged from current conditions (Table 15, Figure 13).

### 4.3 Additional Uncertainties

As described in Chapter 2, southern white-ptarmigan are highly adapted to extreme biotic and abiotic conditions inherent to alpine environments. The maintenance of populations depends on extensive movement of birds across connected alpine habitats (Martin 2001, p. 9). Additionally, populations are rather robust to fluctuations in seasonal weather (Wann et al. 2016, p. 12). However, increased frequency and duration of extreme weather events such as drought and periods of prolonged, intense rainfall anticipated under future scenarios 2 and 3 could have negative impacts to habitat and demographic factors for ptarmigan, but it is unknown to what degree these events would have population-level impacts. The three scenarios show an increase in maximum daytime summer temperature, with the Very Hot and Dry scenario showing the largest increase (+8°F) for both the north and south. However, the average temperature for this metric is still below 70°F under all scenarios except for the Very Hot and Dry scenario in the

south (Table 11), suggesting high temperatures may not be limiting for ptarmigan by 2050. Additionally, changing phenologies related to earlier snowmelt and warmer temperatures could result in a mismatch between resource availability and breeding. Mismatches have been observed at the individual level when breeding is asynchronous with resource availability (Wann et al. 2019, p. 7210). However, we do not know at what frequencies this may occur in the future and at what level it will exhibit a population-level response.

Table 13. Future conditions for southern white-tailed ptarmigan under the Very Hot and Dry Scenario by year 2050. A score of 5.4 or greater = High Condition; 4.2 – 5.3 = Medium Condition; 2.9 – 4.1 = Low Condition; and <2.9 = Very Low Condition. For the Snowy Range AU and New Mexico, we evaluated condition for the habitat factors but assigned an "X" to the demographic factors, as these AUs are presumed extirpated under this scenario. See text for explanation on methodology for calculating an overall condition score.

| **Analytical Unit (Shading identifies the representative unit: green = northern; tan = southern; blue = New Mexico)** | **Winter snow conditions** | **Late-lying snowfields** | **Summer precipitation/ monsoonal moisture** | **Brood-rearing habitat (insects/forbs)** | **Willow availability** | **External recruitment of immigrants/ Breeding dispersal** | **Adult female survival** | **Population growth** | **Overall Future Condition Score** | **Overall Future Condition** |
|---|---|---|---|---|---|---|---|---|---|---|
| Crown Point | Medium | Unknown | Low | Low | Medium | Medium | Unknown | Unknown | 4.3 | Medium |
| Mt. Evans | Medium | Low | Low | Low | Medium | Medium | Medium | Medium | 4.5 | Medium |
| RMNP/Trail Ridge | Medium | Low | Low | Low | Low | Medium | Medium | Low | 4.4 | Medium |
| Niwot Ridge | Medium | Low | Low | Low | Medium | Medium | Unknown | Unknown | 4.2 | Medium |
| Independence Pass | Medium | Low | Low | Low | Medium | Medium | Medium | Medium | 4.5 | Medium |
| Square Top | Medium | Unknown | Low | Unknown | Medium | Medium | Low | Low | 4.2 | Medium |
| Guanella Pass | Medium | Unknown | Low | Unknown | Medium | Medium | Low | Low | 4.2 | Medium |
| Loveland Pass | Medium | Unknown | Low | Unknown | Low | Medium | Low | Low | 4.1 | Low |
| Byers Peak | Medium | Low | Low | Low | Medium | Medium | Medium | Medium | 4.5 | Medium |
| Flat Tops | Medium | Low | Unknown | Low | Medium | Low | Unknown | Unknown | 3.3 | Low |
| Mt. Yale | Medium | Low | Low | Low | Medium | Medium | Medium | Medium | 4.5 | Medium |
| Mt. Zirkel | Medium | Low | Low | Low | Low | Low | Unknown | Unknown | 3.1 | Low |
| Sangre de Cristos | Medium | Very Low | Low | Low | Low | Low | Unknown | Unknown | 3.0 | Low |
| Snowy Range, Wyoming-Extirpated | Medium | Unknown | Unknown | Low | Low | X | X | X | X | X |
| Mesa Seco | Medium | Very Low | Low | Low | Medium | Medium | Medium | Medium | 4.4 | Medium |
| Emerald Lake | Medium | Low | Low | Low | Medium | Medium | Medium | Medium | 4.5 | Medium |
| Ophir | Medium | Low | Low | Low | Medium | Low | Medium | Low | 3.8 | Low |
| Southern San Juans | Medium | Low | Low | Low | Medium | Medium | Unknown | Low | 4.1 | Low |
| New Mexico (Culebra, Wheeler Peak, Northern Pecos) | Unknown | Very Low | Low | Low | Very Low | X | X | X | X | X |

Table 14. Future conditions for southern white-tailed ptarmigan under the Hot Scenario by year 2050. A score of 5.4 or greater = High Condition; 4.2 – 5.3 = Medium Condition; 2.9 – 4.1 = Low Condition; and <2.9 = Very Low Condition. For the Snowy Range AU in Wyoming, we evaluated condition for the habitat factors but assigned an "X" to the demographic factors, as this AU is presumed extirpated. See text for explanation on methodology for calculating an overall condition score.

| **Analytical Unit (Shading identifies the representative unit: green = northern; tan = southern; blue = New Mexico)** | **Winter snow conditions** | **Late-lying snowfields** | **Summer precipitation/ monsoonal moisture** | **Brood-rearing habitat (insects/forbs)** | **Willow availability** | **External recruitment of immigrants/ Breeding dispersal** | **Adult female survival** | **Population growth** | **Overall Future Condition Score** | **Overall Future Condition** |
|---|---|---|---|---|---|---|---|---|---|---|
| Crown Point | High | Unknown | Medium | Medium | High | High | Unknown | Unknown | 5.8 | High |
| Mt. Evans | High | Medium | Medium | High | High | High | High | High | 6.5 | High |
| RMNP/Trail Ridge | High | Medium | Medium | High | Medium | High | High | Low | 5.7 | High |
| Niwot Ridge | High | High | Medium | Medium | High | High | Unknown | Unknown | 5.8 | High |
| Independence Pass | High | High | High | High | High | High | High | High | 6.7 | High |
| Square Top | High | Unknown | Medium | Unknown | High | High | Medium | Medium | 5.9 | High |
| Guanella Pass | High | Unknown | Medium | Unknown | High | High | Medium | Medium | 5.9 | High |
| Loveland Pass | High | Unknown | Medium | Unknown | Medium | High | Medium | Medium | 5.8 | High |
| Byers Peak | High | High | High | High | High | High | High | High | 6.7 | High |
| Flat Tops | High | High | Unknown | High | High | Medium | Unknown | Unknown | 5.0 | Medium |
| Mt. Yale | High | High | High | High | High | High | High | High | 6.7 | High |
| Mt. Zirkel | High | Medium | High | Medium | Medium | Medium | Unknown | Unknown | 4.7 | Medium |
| Sangre de Cristos | Medium | Low | Medium | Medium | Medium | Medium | Unknown | Unknown | 4.4 | Medium |
| Snowy Range, Wyoming-Extirpated | Medium | Unknown | Unknown | Medium | Medium | X | X | X | X | X |
| Mesa Seco | Medium | Very Low | High | Medium | High | High | High | Medium | 6.0 | High |
| Emerald Lake | Medium | Medium | High | Medium | High | High | High | High | 6.5 | High |
| Ophir | Medium | Medium | High | Medium | High | High | High | Low | 5.1 | Medium |
| Southern San Juans | Medium | Low | High | Medium | High | High | Unknown | Medium | 5.7 | High |
| New Mexico (Culebra, Wheeler Peak, Northern Pecos) | Unknown | Very Low | Medium | Low | Low | Very Low | Very Low | Very Low | 2.0 | Very Low |

Table 15. Future conditions for southern white-tailed ptarmigan under the Hot and Very Wet Scenario by year 2050. A score of 5.4 or greater = High Condition; 4.2 – 5.3 = Medium Condition; 2.9 – 4.1 = Low Condition; and <2.9 = Very Low Condition. For the Snowy Range AU in Wyoming, we evaluated condition for the habitat factors but assigned an "X" to the demographic factors, as this AU is presumed extirpated. See text for explanation on methodology for calculating an overall condition score.

| **Analytical Unit (Shading identifies the representative unit: green = northern; tan = southern; blue = New Mexico)** | **Winter snow conditions** | **Late-lying snowfields** | **Summer precipitation/ monsoonal moisture** | **Brood-rearing habitat (insects/forbs)** | **Willow availability** | **External recruitment of immigrants/ Breeding dispersal** | **Adult female survival** | **Population growth** | **Overall Future Condition Score** | **Overall Future Condition** |
|---|---|---|---|---|---|---|---|---|---|---|
| Crown Point | Medium | Unknown | High | Low | High | High | Unknown | Unknown | 5.6 | High |
| Mt. Evans | Medium | Low | High | Medium | High | High | Medium | Medium | 5.7 | High |
| RMNP/Trail Ridge | Medium | Low | High | Medium | Medium | High | Medium | Low | 5.3 | Medium |
| Niwot Ridge | Medium | Low | High | Low | High | High | Unknown | Unknown | 5.5 | High |
| Independence Pass | Medium | Low | High | Medium | High | High | Medium | Medium | 5.8 | High |
| Square Top | Medium | Unknown | High | Unknown | High | High | Low | Low | 5.2 | Medium |
| Guanella Pass | Medium | Unknown | High | Unknown | High | High | Low | Low | 5.2 | Medium |
| Loveland Pass | Medium | Unknown | High | Unknown | Medium | High | Low | Low | 5.1 | Medium |
| Byers Peak | Medium | Low | High | Medium | High | High | Medium | Medium | 5.7 | High |
| Flat Tops | Medium | Low | Unknown | Medium | High | Medium | Unknown | Unknown | 4.5 | Medium |
| Mt. Yale | Medium | Low | High | Medium | High | High | Medium | Medium | 5.7 | High |
| Mt. Zirkel | Medium | Low | High | Low | Medium | Medium | Unknown | Unknown | 4.4 | Medium |
| Sangre de Cristos | Low | Very Low | High | Low | Medium | Medium | Unknown | Unknown | 4.2 | Medium |
| Snowy Range, Wyoming-Extirpated | Medium | Unknown | Unknown | Low | Medium | **X** | X | X | X | X |
| Mesa Seco | Medium | Very Low | High | Medium | High | High | Medium | Medium | 5.7 | High |
| Emerald Lake | Medium | Low | High | Medium | High | High | Medium | Medium | 5.7 | High |
| Ophir | Medium | Low | High | Medium | High | High | Medium | Low | 4.7 | Medium |
| Southern San Juans | Medium | Low | High | Medium | High | High | Unknown | Medium | 5.7 | High |
| New Mexico (Culebra, Wheeler Peak, Northern Pecos) | Unknown | Very Low | High | Low | Low | Very Low | Very Low | Very Low | 2.1 | Very Low |

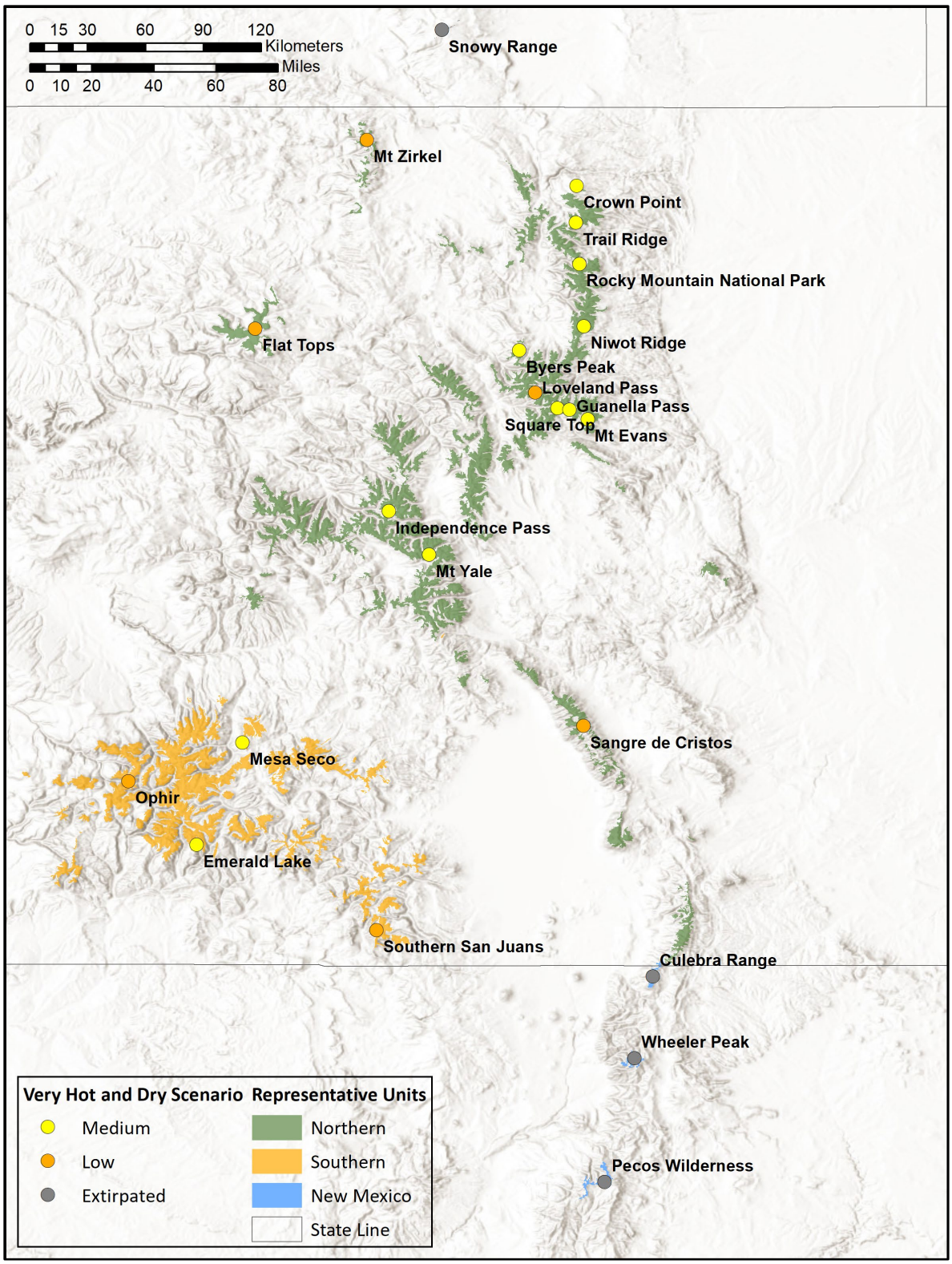


Figure 11. Future conditions for southern white-tailed ptarmigan under the Very Hot and Dry Future Scenario.

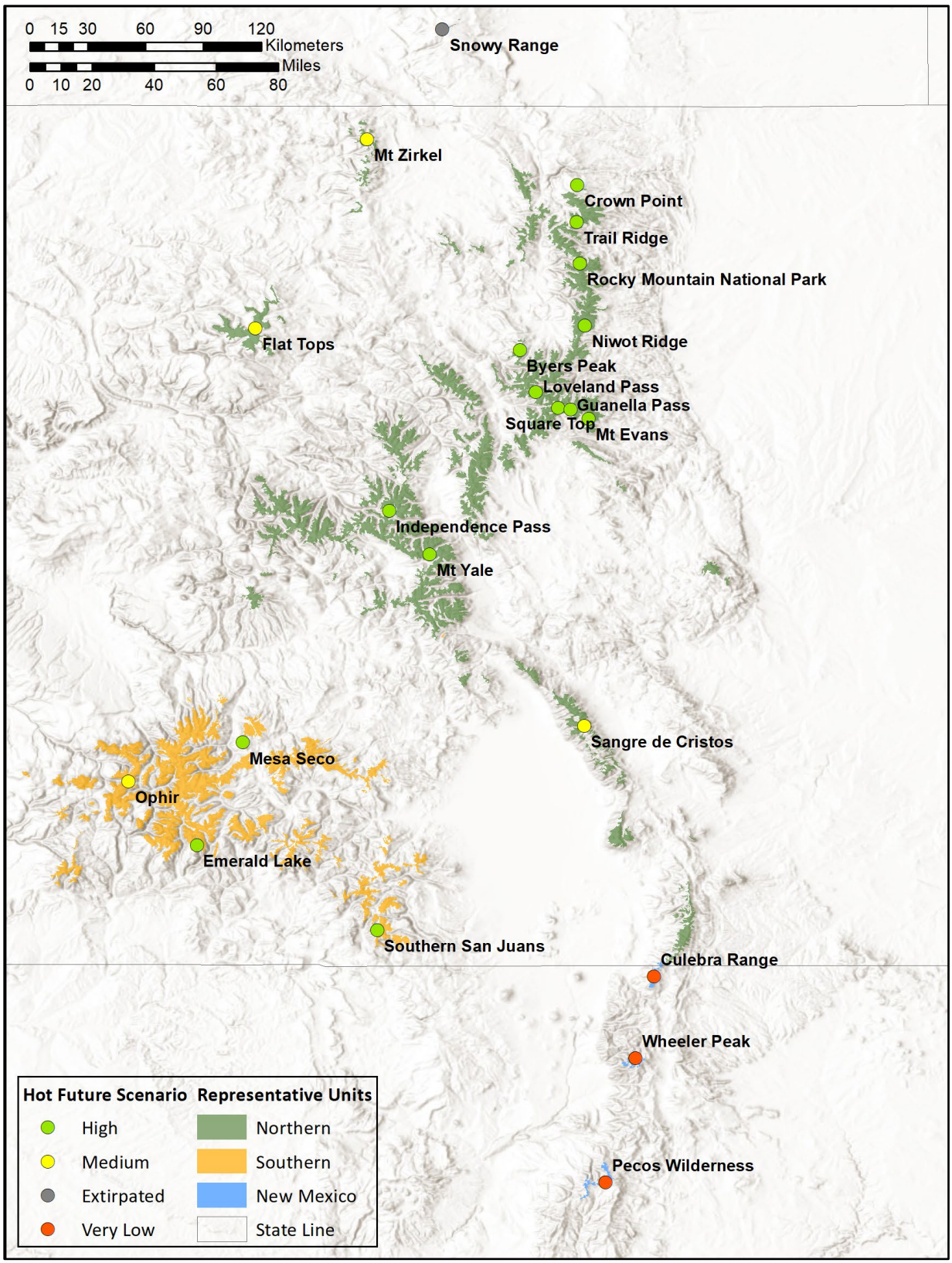

Figure 12. Future conditions for southern white-tailed ptarmigan under the Hot Future Scenario.

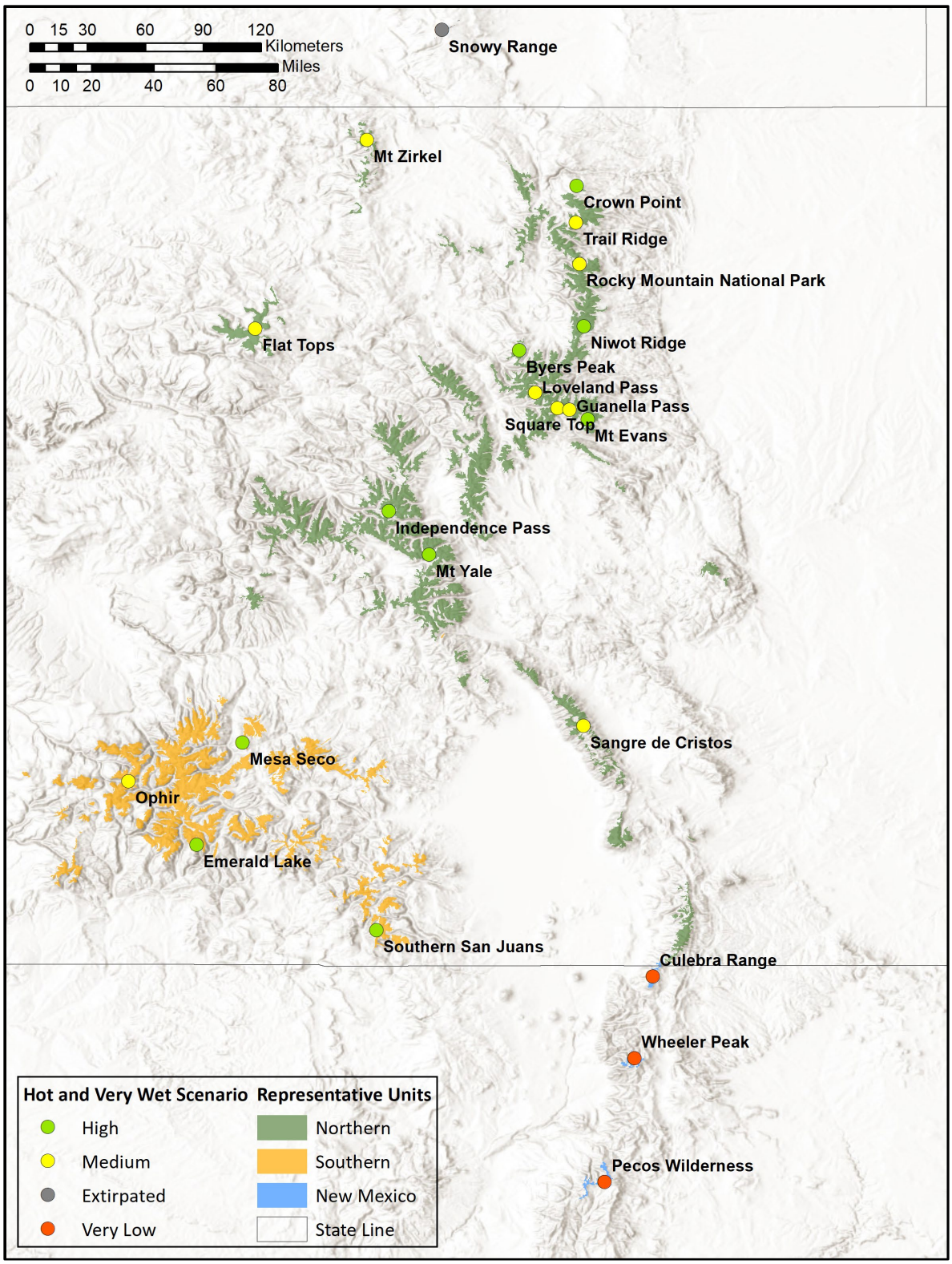


Figure 13. Future conditions for southern white-tailed ptarmigan under the Hot and Very Wet Future Scenario.

### 4.4 Summary of Analysis

Currently, 14 of 19 AUs are in High condition, 3 AUs are in Medium condition, 1 AU is in Very Low condition, and 1 AU is presumed extirpated. We anticipate that of the 18 extant AUs, 17 will remain occupied under all scenarios, and 18 will remain occupied under Future Scenarios 2 and 3. In this analysis, resiliency for all of the AUs is expected to decrease under Future Scenario 1 due to substantially hotter and drier climate conditions. We also expect a decrease in redundancy and representation under Future Scenario 1 due to the loss of the New Mexico representative unit, which represents an increased risk to the subspecies under Scenario 1. Under Future Scenario 2, we expect that resiliency will be maintained similar to current conditions for all AUs with the exception of the Ophir AU, which declines under this scenario. Under Future Scenario 3, we anticipate reductions in resiliency across 5 AUs due to reductions in several habitat and demographic factors as a result of reductions in snowpack leading to reductions in brood-rearing habitat and subsequent impacts to both adult female survival and chick survival influencing population growth. Redundancy and representation are expected to be maintained under Future Scenarios 2 and 3. Therefore, risk to the subspecies generally stays the same as current condition by year 2050 under Future Scenarios 2 and 3 (Table 16).

Table 16. Summary of overall condition scores for current condition and three future scenarios by year 2050 by analytical unit. Analytical units assigned an "X" are considered extirpated. See text for explanation on methodology for calculating an overall condition score.

| **Analytical Unit** **(Shading identifies the representative unit: green = northern; tan = southern; blue = New Mexico)** | **Overall Current Condition Score** | **Future Scenario 1: Very Hot and Dry** | **Future Scenario 2: Hot** | **Future Scenario 3: Hot and Very Wet** |
|---|---|---|---|---|
| Crown Point | High | Medium | High | High |
| Mt. Evans | High | Medium | High | High |
| RMNP/Trail Ridge | High | Medium | High | Medium |
| Niwot Ridge | High | Medium | High | High |
| Independence Pass | High | Medium | High | High |
| Square Top | High | Medium | High | Medium |
| Guanella Pass | High | Medium | High | Medium |
| Loveland Pass | High | Low | High | Medium |
| Byers Peak | High | Medium | High | High |
| Flat Tops | Medium | Low | Medium | Medium |
| Mt. Yale | High | Medium | High | High |
| Mt. Zirkel | Medium | Low | Medium | Medium |
| Sangre de Cristos | Medium | Low | Medium | Medium |
| Snowy Range, Wyoming-Presumed Extirpated | **X** | **X** | **X** | **X** |
| Mesa Seco | High | Medium | High | High |
| Emerald Lake | High | Medium | High | High |
| Ophir | High | Low | Medium | Medium |
| Southern San Juans | High | Low | Medium | High |
| New Mexico (Culebra, Wheeler Peak, Northern Pecos) | Very Low | **X** | Very Low | Very Low |

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## **Appendix A**: Southern White-tailed Ptarmigan future projection model: predicting future status and viability

### Summary

We used a modified population projection model developed by Colorado Parks and Wildlife (hereafter, CPW) to simulate the future status of southern white-tailed ptarmigan throughout its range. The CPW model was a population matrix model developed to evaluate population dynamics of ptarmigan at six survey sites (three in the Northern population and three in the Southern population). The model incorporated data on survival and reproduction collected from 2013 through 2016 (Seglund et al. 2018). The model incorporated the results of the data analysis directly by using the posterior distributions from the Markov Chain Monte Carlo (MCMC) analysis to simulate parametric uncertainty and temporal variance. We modified CPW's model to include variability in quasi-extinction threshold and in the immigration rate between breeding sites. Seglund et al. (2018) used a fixed extinction threshold set at two individual female ptarmigan, meaning that if the number of females at a site fell to two or fewer, the abundance at that site would be reset to zero for that replicate. Other researchers have used a higher quasi-extinction threshold of 10, so we allowed the quasi-extinction threshold to vary to incorporate this uncertainty (Wann 2017). We also incorporated immigration variability into our modified simulation model to reflect the range of values simulated in Seglund et al. (2018, p. 68). The incorporation of additional uncertainty and variability in our simulations resulted in higher predicted extinction probabilities than those presented in Seglund et al. (2018). The inclusion of a variable quasi-extinction threshold and variable immigration rate in our modified modeling scenario resulted in a median quasi-extinction probability of approximately 0.12 for the Northern population at 50 years into the future, meaning that there is on average a 12% chance that the species will be extinct in the northern portion of it range within 50 years. The Southern population appears to have lower extinction risk with near zero probability of extinction within 50 years and low probabilities within 100 years (Figure 4).

### Model Description

CPW designed a simulation model to project southern white-tailed ptarmigan populations into the future (Seglund et al. 2018, pp. 37-92). The model was a female only, two-stage life history model that projected juveniles and adults with a post–breeding census, meaning that the model predicted population size for each year after the breeding season (Figure 1).

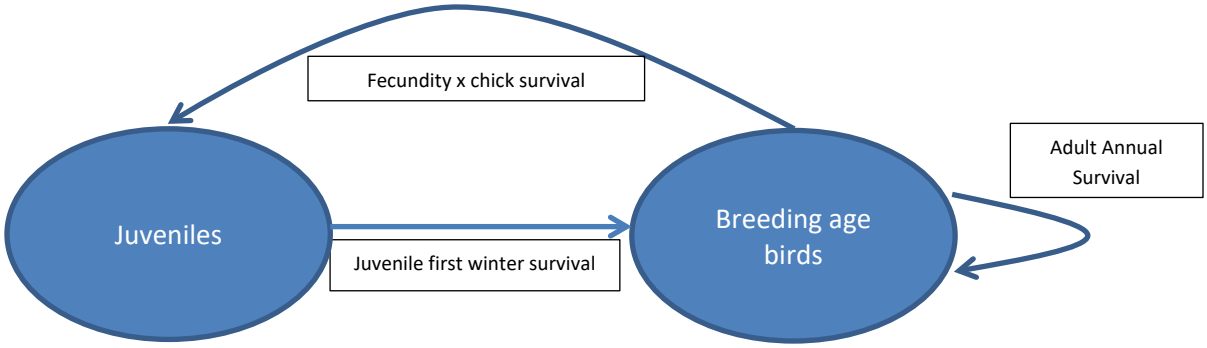



**Figure 1.** Conceptual diagram of white-tailed ptarmigan life-cycle dynamics

The life history diagram was converted into a matrix population projection equation as follows:

$$\begin{bmatrix} N_{chick,t+1} \\ N_{adult,t+1} \end{bmatrix} = \begin{bmatrix} S_{chick,t}F_t & S_{adult}F_t \\ S_{chick,t} & S_{adult,t} \end{bmatrix} \begin{bmatrix} N_{chick,t} \\ N_{adult,t} \end{bmatrix}$$

where $N_{chick}$ is number of chicks, $N_{adult}$ is number of adults, F is fecundity, $S_{chick}$ is annual survival of chicks, and $S_{adult}$ is annual survival of adults, $t$ is the current year time step, and $t+1$ is the one year forward time step.

The productivity terms in the top row were multiplied by the survival term to account for the post breeding dynamics that breeding birds have to first survive their first year before recruiting into the breeding population (Kendall et al. 2019, p. 34). In the model code, provided by CPW, the projection equations were written out as algebraic functions rather than a matrix projection equation:

Projecting juveniles each year:

$$N_{j,t+1} = N_{j,t} \times S_{j,t} \times F_t + N_{A,t} \times S_{A,t} \times F_t$$

and projecting adults:

$$N_{A,t+1} = N_{j,t} \times S_{j,t} + N_{A,t} \times S_{A,t}$$

These different formulations are equivalent and only amount to a difference in coding preferences. The post-breeding modeling formulation meets the suggested approach by Kendall et al. (2019) in a recent paper noting four common modeling errors in population projection models.

The population parameters in the model were based on data collected and analyzed by CPW researchers and staff for the years 2013-2016. They used radio telemetry data to estimate true survival rates of adults and juveniles on a monthly basis then converted the monthly survival to annual survival (i.e., 12 months). To model fecundity, they used a modified Noon and Sauer (e.g., Noon and Sauer 1992 pp. 457-458, McGowan and Ryan 2011, p. 3131) approach:

$$F_{s,t} = \left(BP * NS_{s,t} * Clutch\ Size + BP * \left(1 - NS_{s,t}\right) * RN * NS_{s,t} * Clutch\ Size\right) * 0.5$$

where "BP" was breeding propensity, "NS" was nest survival, and "RN" was renesting probability. The productivity was multiplied by 0.5 assuming a 50:50 sex ratio at hatching to account for a female only model.

*Model uncertainty and stochasticity*

Most parameters were modeled as stochastic variables. The model program drew the parameter values directly from the MCMC analysis posterior distributions. For survival and fecundity

values, the model randomly chose one year of available data to represent temporal variation in the parameters. Initial population abundance values and age distributions were also based on the estimates from the empirical data (Seglund et al. 2018, pp. 37-92).

Although CPW was unable to estimate immigration, they simulated varying levels of density-dependent immigration. Movement of ptarmigan among suitable habitats is supported by genetic analyses (Langin et al. 2018), and it is known that individual birds can disperse up to approximately 50 kilometers; sufficient distance to disperse between breeding sites. CPW implemented five simulation scenarios, one with no immigration between sites and four with increasing levels of fixed immigration rates. In their model, immigration rate varied only among scenarios and within a scenario it varied as a function of abundance, but there was not randomized deviations from the prescribed function:

$$Immigrants_t = N_t \times \exp(imm \times N_t)$$

$$N_{A,t+1} = N_{j,t} \times S_{j,t} + N_{A,t} \times S_{A,t} + Immigrants_t,$$

where $N_t$ is the annual abundance and *imm* is the mean immigration rate. For this SSA analysis, we modified this model to incorporate randomized variation in the overall immigration rate instead of using specific scenarios. We further randomized annual deviations from the mean immigration rate. Our process incorporated parametric uncertainty in immigration probability so that each model replicate had a different mean value drawn from a uniform distribution with the lowest CPW scenario as the lower bound of the randomized draws and the highest CPW as the upper bound of the distribution. The model then drew an annual value of immigration by drawing from a normal distribution with the mean set at the replicate value and standard deviation set at 10% of the mean value:

$$Immigrants_{i,t} = N_t \times \exp(imm_{i,t} \times N_t),$$

where:

$$imm_{i,t} \sim Normal(imm_i, (imm_i \times 0.1)),$$

Where *i* indicates the model replicate and *t* indicates the year in the simulation. Thus the *imm* value input into the abundance dependent immigration calculation varied by replicate and by year in our simulations.

We also modified the CPW model to reflect uncertainty in the quasi-extinction threshold. CPW set the quasi-extinction threshold at two individual females, meaning that if the population at a site declined to two individual females or less, the abundance was reset to 0 and that site was considered extinct. The resulting population size of 0 was then propagated to the overall population when the abundances were extrapolated across the range. In all but the lowest immigration simulation scenario, the number of individuals immigrating into a site exceeded the two individual threshold (Seglund et al. 2018, p. 68, Figure 11), so sites almost never went below the quasi-extinction threshold. In a separate analysis and population model, Wann (2017) built a population viability analysis based on long-term data from Rocky Mountain National Park and used a quasi-extinction threshold of 10 females at a site. Given the general uncertainty of what quasi-extinction thresholds are for any population, we built a function to randomize the extinction threshold across replicates. We drew a value from a uniform random distribution

between two and 12 and rounded the draw to the nearest whole number, so that each replicate had a different point at which a population would be considered extinct (Figure 2).

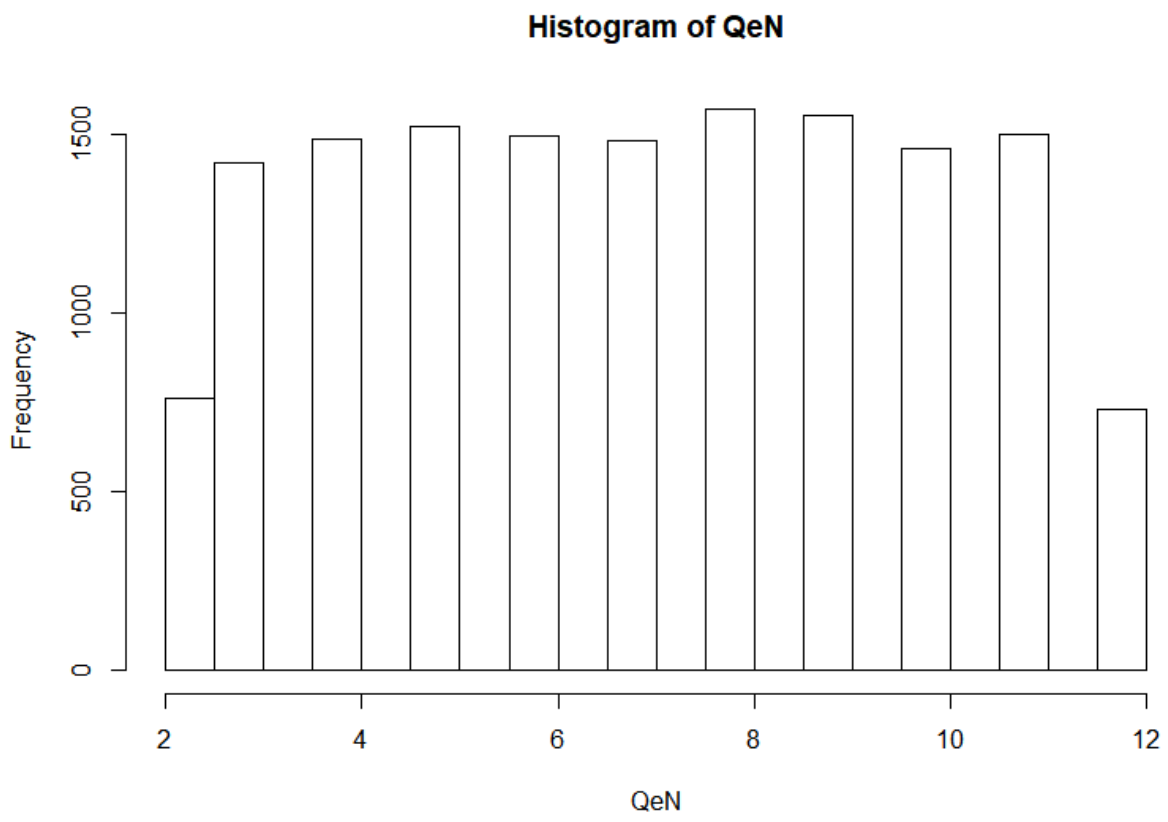



**Figure 2.** Histogram of randomized quasi-extinction thresholds drawn from a uniform distribution and rounded to the nearest whole number.

*Simulation scenarios*:

We ran two sets of scenarios with the model described above. One scenario with no immigration of individuals between modeled populations and one scenario with the randomized immigration functions described above. Each scenario had 15,000 replicates determined by the parameter draws from the MCMC analysis results and under each scenario the population was projected 100 years into the future (starting in 2018).

**Results**

*No immigration scenario*

All scenarios exhibited higher extinction probabilities than the simulations reported by CPW (Seglund et al. 2018, p. 84, Table 6). This was expected given the variable quasi-extinction threshold implemented in our simulations. With no immigration between breeding sites, median extinction probability in the northern population at 50 years was 0.35 and was 0.48 at 100 years (Table 1, Figure 3), meaning that there was a median predicted 35% chance that the northern

population will be extinct in 50 years and a median predicted 48% chance that the northern population will be extinct in 100 years.

The southern population had lower extinction probability than the northern population likely because survival estimates were higher in that portion of the range, according to the CPW estimates (Seglund et al. 2018, p. 78, Figure 18). With no immigration between breeding sites, extinction probability at 50 years was 0.07 and at 100 years was 0.13 (Table 1, Figure 3), meaning that there was a median predicted 7% chance that the southern population will be extinct in 50 years and a 13% chance that the southern population will be extinct in 100 years. The extinction probability for both populations to go extinct simultaneously was 0.02 at 50 years and 0.07 at 100 years (Table 1).

*With immigration scenario*

For our simulations with randomized immigration rates and variable quasi-extinction threshold, median extinction probability in the northern population at 50 years was 0.12 and was 0.17 at 100 years (Table 1, Figure 3), meaning that there was a median predicted 12% chance that the northern population will be extinct in 50 years and a median predicted 17% chance that the northern population will be extinct in 100 years, even with consideration of immigration into breeding sites.

The southern population had lower extinction probability than the northern population, again, likely because survival estimates were higher in southern portion of the range, according to the CPW estimates (Seglund et al. 2018, p. 78, Figure 18). With consideration of immigration into between breeding sites, extinction probability at both 50 years and 100 years was 0.0 (Table 1, Figure 3), meaning that there was a median predicted 0% chance that the population will be extinct in the southern portion of the range in 50 years and 100 years, although it should be noted that the upper quantile (i.e., the upper bound of the 95% C.I.) was 0.03 or 3%, meaning that there is a 2.5% chance that extinction probability is 3%. The extinction probability for both populations to go extinct was 0.0 at both 50 years and 100 years, but the upper quantile was 0.02 or 2% (Table 1).

**Table 1**: Median probability of quasi-extinction and the 2.5 ("Lower quantile") and 97.5 percentiles ("Upper quantile"; equivalent to a 95% confidence interval) for the Northern and Southern populations and for the entire state with and without consideration of immigration into breeding populations.

| | | 50 years | | | 100 years | | |
|---|---|---|---|---|---|---|---|
| | Population | Lower quantile (%) | Median quasi-extinction probability (%) | Upper Quantile (%) | Lower quantile (%) | Median quasi-extinction probability (%) | Upper Quantile (%) |
| No Immigration | North | 15 | 35 | 64 | 23 | 48 | 77 |
| | South | 0 | 7 | 27 | 1 | 13 | 40 |
| | Statewide | 0 | 2 | 14 | 0 | 7 | 24 |
| With Immigration | North | 3 | 12 | 26 | 6 | 17 | 31 |
| | South | 0 | 0 | 3 | 0 | 0 | 3 |
| | Statewide | 0 | 0 | 2 | 0 | 0 | 2 |

**Figure 3.** Median probability of quasi-extinction (dark line) and the 2.5 and 97.5 percentiles (shaded area; equivalent to a 95% confidence interval) for the northern (lighter gray) and southern (darker gray) populations with no immigration between sites.

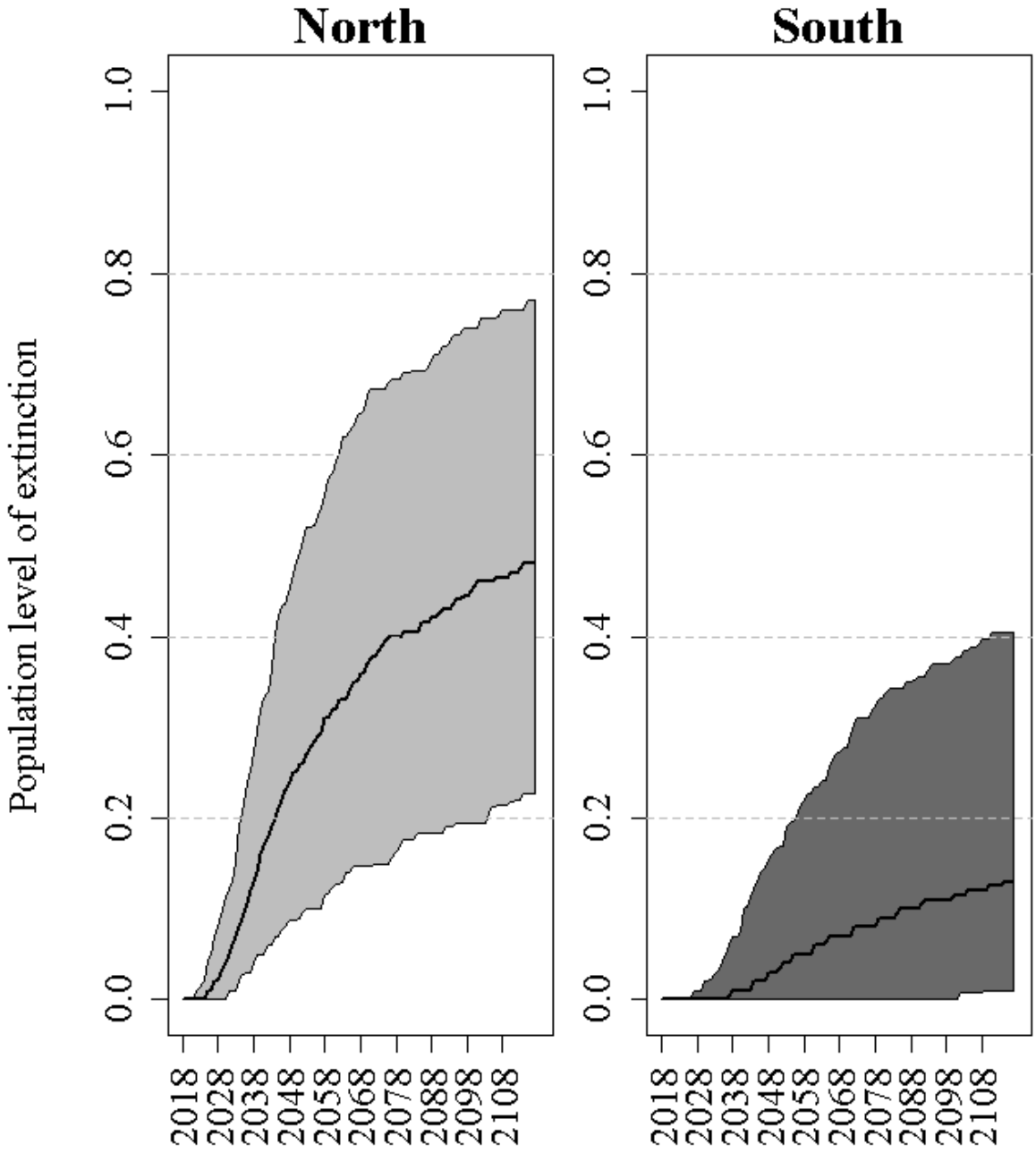
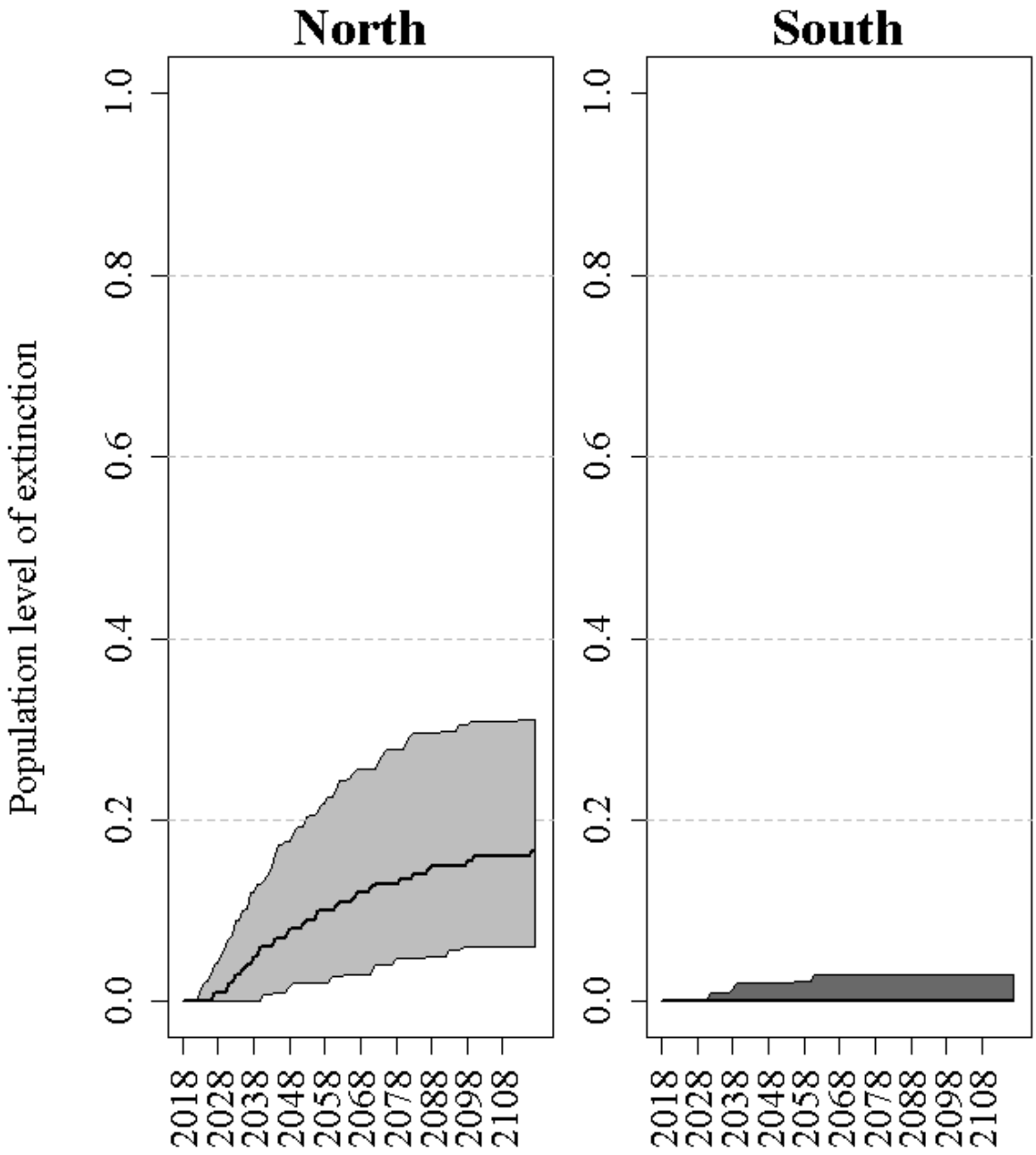


**Figure 4.** Median probability of quasi-extinction (dark line) and the 2.5 and 97.5 percentiles (shaded area; equivalent to a 95% confidence interval) for the northern (lighter gray) and southern (darker gray) populations with randomized immigration between sites.



**Conclusion**

Our models incorporated higher levels of uncertainty than previous simulation models, specifically with respect to immigration rates between breeding sites and quasi-extinction thresholds. The quasi-extinction threshold is a theoretical point at which a population becomes so small that it enters what is called "the extinction vortex," and total extirpation is certain beyond that point (Morris and Doak 2002). The extinction vortex accounts for issues that arise for very small population sizes, such as inbreeding depression or low density Allee effects (e.g., inability to find a mate), which likely occur for most populations (Morris and Doak 2002). However, the population size at which these negative effects create an extinction vortex is unknown. Population models use quasi-extinction thresholds to mimic the effect of an extinction vortex without having to model the complexities of inbreeding depression or Allee effects, but using a threshold that is too low or too high can have significant implications for interpretation of model outputs and subsequent management decisions. Here we chose to use a function that accounted for our uncertainty regarding at what population size the extinction vortex occurs and introduced variable quasi-extinction thresholds among replicates.

We also modified the immigration components of the CPW model to introduce more uncertainty. Immigration is a critical component of southern white-tailed ptarmigan population dynamics, but thus far, no study has accumulated sufficient data to directly estimate the probability or rate of movement between breeding sites. Because of these added uncertainties and variability, our predicted extinction probabilities were higher than those presented in the CPW report (Seglund et al. 2018, p. 83), but our predicted extinction risks with no immigration into breeding sites were similar to those reported by CPW.

**Appendix B**: Cause and Effects Tables

| PREDATION | Assessment | Summary |
|---|---|---|
| **SOURCE(S)** | *What are the ultimate actions causing the stressor?* | Increasing numbers of generalist predators. |
| **- Activity(ies)** | *What is actually happening on the ground as a result of the action? I.e. what are the specific sources of the actions?* | Disturbances related to recreation and development can result in an increase in generalist predators. |
| **STRESSOR(S)** | *What are the changes in environmental conditions on the ground that may be affecting the species?* | Potential increased nest and chick predation. |
| **- Exposure of Stressor(s)** | *When and where does the stressor overlap with the resource (life history and habitat needs)?* | Predation largely impacts the nesting and brood-rearing periods and can impact all analysis units. Small percentage of females on nests are depredated. |
| **- Immediacy of Stressor(s)** | *Are the stressors happening in the past, present, and/or the future? What's the timing and frequency?* | Predation is a natural part of the population dynamics for white-tailed ptarmigan. It is possible that generalist predators can increase due to increased recreation and development in the alpine. |
| **Affected Resource(s)** | *What are the resources that are needed by the species that are being affected by this stressor?* | Nest and brood survival |
| **Changes in Resource** | *Specifically, how was the resource changed?* | No evidence that predation has increased. Level of predation in recent study is similar to previous studies (Seglund et al. 2018, p. 122). |
| **Response/effect to Stressors: INDIVIDUALS** | *What is the effect on individuals of the species to the stressor? (May be by life stage)* | Complete loss of eggs or partial to complete loss of broods. Occasional loss of females on nests<br>**Conclusion on Individuals:** Yes. Predation can affect individual WTPT, their nests, and broods through direct mortality.<br>**Uncertainty/Assumptions:** No evidence that predation is elevated above natural population dynamics at any AU in CO. |
| **POPULATION & SPECIES EFFECTS** | *How do individual effects translate to population- and species-level effects?* | |
| | *What is the magnitude of this stressor in terms of species viability?* | |
| **Effects of Stressors: POPULATIONS [RESILIENCY]** | *What are the effects on population characteristics (lower reproductive rates, reduced population growth rate, changes in distribution, etc.)?* | High predation years can lead to reduced reproductive output and increased external recruitment. |
| **SCOPE** | *What's the geographic extent of the stressor relative to the range of the species/populations?* | No other information or evidence that any populations of WTPT are currently experiencing elevated levels of predation. |

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| **Effects of Stressors:** | *What are the expected future changes to the number of populations and their distribution on the landscape?* | Increased recreation and development could increase the number of generalist predators in the alpine in the future, but it is not expected to reduce the redundancy or representation of WTPT. |
| **[REDUNDANCY]** | *Number and distribution of populations.* | No evidence that predation will affect the number and distribution of populations now and into the future beyond natural population dynamics. |
| **[REPRESENTATION]** | *What changes to the genetic or ecology diversity in the species might occur?* | No changes to the genetic and ecological diversity of the species is expected due to predation. |
| **SUMMARY** | | No evidence that predation has affected resiliency beyond natural population dynamics now and into the future. We do not expect reductions in redundancy or representation now or into the future. |

| MINING/TRACE HEAVY METALS | Assessment | Summary |
|---|---|---|
| **SOURCE(S)** | *What are the ultimate actions causing the stressor?* | Mining of ore deposits |
| **- Activity(ies)** | *What is actually happening on the ground as a result of the action? I.e. what are the specific sources of the actions?* | Mine tailings dumped into rivers, large waste piles left on the surface, abandoned mines. Mining mobilizes naturally occurring heavy metals in the soil, such as cadmium. |
| **STRESSOR(S)** | *What are the changes in environmental conditions on the ground that may be affecting the species?* | Increased contamination of ground and surface water, increased uptake of heavy metals by plants. Increased cadmium from mining runoff can be deposited downstream. Cadmium can accumulate and biomagnify in willow. |
| **- Exposure of Stressor(s)** | *When and where does the stressor overlap with the resource (life history and habitat needs)?* | For sites located within the Mineral Ore Belt, increased cadmium levels in willow. Influences WTPT most in winter and spring, when primary food is willow. |
| **- Immediacy of Stressor(s)** | *Are the stressors happening in the past, present, and/or the future? What's the timing and frequency?* | Mining in the mineral ore belt began in the 1860s. Although the number of active mines has decreased, the effects of mining continue now and into the future. |
| **Affected Resource(s)** | *What are the resources that are needed by the species that are being affected by this stressor?* | Willows, a critical food source. |
| **Changes in Resource** | *Specifically, how was the resource changed?* | Cadmium is biomagnified in willow. |
| **Response/effect to Stressors: INDIVIDUALS** | *What is the effect on individuals of the species to the stressor? (May be by life stage)* | Juveniles, Subadults, Adults: Birds are affected by accumulation of cadmium. Toxic levels of cadmium in kidneys can result in renal damage. Most kidney damage observed in overwintering females. Kidney damage can lower calcium levels resulting in bone weakness and fractures.<br>**Conclusion on Individuals**: Bioaccumulation of cadmium can affect individual WTPT. Exposure is possible throughout the mineral ore belt of CO.<br>**Uncertainty/Assumptions:** Only populations in the Animas River watershed in the San Juans have been studied. No known impacts to fitness. No information on the impacts of trace metals in other parts of CO. |
| **POPULATION & SPECIES EFFECTS** | *How do individual effects translate to population- and species-level effects?* | |
| | *What is the magnitude of this stressor in terms of species viability?* | |
| **Effects of Stressors: POPULATIONS [RESILIENCY]** | *What are the effects on population characteristics (lower reproductive rates,* | Preliminary findings from Larison etal. 2000. Adult survivorship could be reduced as cadmium accumulation increases with age, resulting in kidney damage and bone weakness. Females appear to be more affected than males because they typically |

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| | *reduced population growth rate, changes in distribution, etc.)?* | winter at lower elevations than males, and willow comprises more of their diet. Predicted higher rates of juvenile recruitment due to elevated mortality rates of adults in contaminated populations. Predicted lower breeding densities among contaminated populations. Skewed sex ratios, favoring males due to the effects on adult females. |
| **SCOPE** | *What's the geographic extent of the stressor relative to the range of the species/populations?* | In CO, study has been restricted to areas within the Animas Watershed. |
| **Effects of Stressors:** | *What are the expected future changes to the number of populations and their distribution on the landscape?* | Although some evidence of population-level reductions in resiliency in areas near Silverton in the San Juans, no evidence of skewed sex ratios, skeletal abnormalities, or unusual female mortality rates exists at other sites across CO in the Mineral Ore Belt (Hoffman 2006, p. 47). |
| **[REDUNDANCY]** | *Number and distribution of populations.* | No evidence that species-level redundancy has been reduced. Nor do we expect redundancy to be reduced into the future due to mining. |
| **[REPRESENTATION]** | *What changes to the genetic or ecology diversity in the species might occur?* | No evidence that the effects of cadmium on WTPT will affect genetic or ecological diversity of the species. Nor do we expect representation to be reduced into the future due to mining. |
| **SUMMARY** | | Some evidence that historical mining impacted the resiliency near Silverton in the San Juans. However, no other evidence of reductions in resiliency. Future changes to the number of populations and their distribution due to mining/trace metals is not expected. |

| HUNTING | Assessment | Summary |
|---|---|---|
| **SOURCE(S)** | *What are the ultimate actions causing the stressor?* | Hunting of WTPT |
| **- Activity(ies)** | *What is actually happening on the ground as a result of the action? I.e. what are the specific sources of the actions?* | Harvest of individual WTPT |
| **STRESSOR(S)** | *What are the changes in environmental conditions on the ground that may be affecting the species?* | Direct take of individual WTPT |
| **- Exposure of Stressor(s)** | *When and where does the stressor overlap with the resource (life history and habitat needs)?* | Hunting season occurs in the fall when birds are congregated in flocks. As a result, hunters could harvest their daily bag limit from a single flock. Most hunting is concentrated in easily accessible areas near roads and urban areas. These sites include Loveland Pass, Square Tops, Niwot Ridge, Independence Pass, Guanella Pass, Byers Peak, Mt. Evans, and Crown Point. |
| **- Immediacy of Stressor(s)** | *Are the stressors happening in the past, present, and/or the future? What's the timing and frequency?* | Past, present, and future. Annual fall hunting season. |
| **Affected Resource(s)** | *What are the resources that are needed by the species that are being affected by this stressor?* | None. Hunting results in direct take of individual WTPT. |
| **Changes in Resource** | *Specifically, how was the resource changed?* | No impact on resources. Hunting pressure has likely declined in some areas. |
| **Response/effect to Stressors: INDIVIDUALS** | *What is the effect on individuals of the species to the stressor? (May be by life stage)* | Direct loss of juvenile, subadult, and adult birds.<br>**Conclusion on Individuals:** Yes. Hunting can affect individual WTPT juveniles, subadults, and adults directly. Exposure in CO is potentially range-wide, but is concentrated in easily accessible areas near roads and trails. No hunting in NM. |
| **POPULATION & SPECIES EFFECTS** | *How do individual effects translate to population- and species-level effects?* | |
| | *What is the magnitude of this stressor in terms of species viability?* | |
| **Effects of Stressors: [RESILIENCY]** | *What are the effects on population characteristics (lower reproductive rates, reduced population growth rate, changes in distribution, etc.)?* | Impacts to population dynamics can occur in areas that are easily accessible by hunters (i.e., close to roads/urban centers). |
| **SCOPE** | *What's the geographic extent of the stressor relative to the range of the species/populations?* | In CO, 8 of 18 analysis units experience some hunting pressure. All sites are in the Northern representative unit. No hunting in NM. |

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| **Effects of Stressors:** | *What are the expected future changes to the number of populations and their distribution on the landscape?* | The number of individuals harvested across the range of S WTPT is relatively low due to limited access to habitat. Population trend data suggest that hunting had a population impact to resiliency on Mt. Evans before the 1994 hunting closure. However, populations have shown increasing trends since 1994, even though many band returns come from birds taken beyond the closure. |
| **[REDUNDANCY]** | *Number and distribution of populations.* | Currently, hunting does not appear to be reducing the resiliency of any analysis units in CO. There is no hunting in NM. Prior to 1994, hunting at Mt. Evans may have impacted the resiliency of that site, but a partial hunting closure appears to have ameliorated that impact, as population trends have increased since 1994. There are no impacts to redundancy currently. We do not expect impacts to redundancy into the future. |
| **[REPRESENTATION]** | *What changes to the genetic or ecology diversity in the species might occur?* | Hunting is not expected to impact genetic or ecological diversity at the species level. |
| **SUMMARY** | | Historically, the resiliency at Trail Ridge was impacted due to hunting. Currently, hunting is not resulting in population-level impacts to resiliency. WTPT have not experienced a reduction in redundancy or representation. Hunting is expected to continue into the future but is not expected to impact the resiliency, redundancy or representation of WTPT. |

| RECREATION | Assessment | Summary |
|---|---|---|
| **SOURCE(S)** | *What are the ultimate actions causing the stressor?* | People recreating in southern white-tailed ptarmigan alpine habitats, particularly when the recreation is conducted off of established highways, roads, and trails (off-road/off-trail recreation). |
| **- Activity(ies)** | *What is actually happening on the ground as a result of the action? I.e. what are the specific sources of the actions?* | Hiking, biking, off-highway vehicle use, snowmobiling, snow biking, skiing, trash, unleashed dogs |
| **STRESSOR(S)** | *What are the changes in environmental conditions on the ground that may be affecting the species?* | Potential decreases in the quality and quantity of alpine vegetation due to crushing or trampling, and potential decreases in soft snow used for winter roosting due to compaction. Additionally potential erosion and drying of habitats due to compaction and trampling, especially where recreation is concentrated or occurs off-trail. Additionally, recreation may increase noise due to increased human presence and increase predation of white-tailed ptarmigan, whether by dogs brought into the alpine or human-commensurate predators. Based on anecdotal observations, these stressors may result in disturbance, fleeing, and potential emigration of individual southern white-tailed ptarmigan, and in rare cases, mortality. |
| **- Exposure of Stressor(s) and Individuals** | *When and where does the stressor overlap with the resource (life history and habitat needs)?* | Individual southern white-tailed ptarmigan may be exposed to recreation at any time of the year, but especially during the summer and winter when alpine habitats are a popular destination for outdoor recreationists. Potential exposure is largely concentrated near existing highways, roads, and trails, and where alpine habitats are relatively easy to access and close to densely populated metropolitan areas, such as the urban Front Range corridor of Colorado. Specifically, exposure of southern white-tailed ptarmigan to recreation can occur in their winter, breeding, and brood-rearing areas during the winter, spring, and summer, and breeding subadults and adults and brood-rearing hens may be exposed during the spring and summer. Exposure to individuals can occur rangewide, but exposure is likely concentrated along established and popular roads and trails that are near metropolitan areas. |
| **- Immediacy of Stressor(s)** | *Are the stressors happening in the past, present, and/or the future? What's the timing and frequency?* | Recreation has occurred in the past and it is currently occurring to varying degrees in all of the AUs year-round, depending on accessibility. Currently and into the future, the northern AUs likely experience the most recreation due to their proximity to Colorado's Front Range corridor. Recreation, as estimated by the number of visitors to alpine habitats and based on anecdotal observation by researchers working in the alpine, is increasing and will likely continue to increase into the future as human populations grow and outdoor recreation in the alpine continues to be popular. |
| **Affected Resource(s)** | *What are the resources that are needed by the species that are being affected by this stressor?* | Potential effects to willows used by southern white-tailed ptarmigan to feed and shelter throughout the year, other alpine vegetation used for feeding, and soft snow for roosting (shelter) in the winter. |

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| **Changes in Resource** | *Specifically, how was the resource changed?* | By trampling and crushing willows and other alpine vegetation, compacting snow, depositing trash, and increasing noise, recreationists may temporarily or permanently reduce the quality and quantity of southern white-tailed ptarmigan habitats. Dogs that accompany recreationists my also disturb or kill individuals. Anecdotal observations suggest that the number of recreationists and associated noise, dogs, and trash, have increased at two AUs (Ophir and Independence Pass), although there is no conclusive evidence to indicate that this increased use significantly reduced the habitat resources available to individual white-tailed ptarmigan at these or any of the AUs. |
| **Response/effect to Stressors: INDIVIDUALS** | *What is the effect on individuals of the species to the stressor? (May be by life stage)* | Recreation can affect individual southern white-tailed ptarmigan through disturbance, displacement, and in rare cases, mortality. In the winter, adults and juveniles may be disturbed temporarily or permanently by snowmobiles (either directly through disturbance, or indirectly through the compaction of snow or loss of willow used for shelter and feeding). In the summer, all life stages could be affected indirectly through loss of habitat and directly through temporary or permanent disturbance.<br><br>Recreation may disturb and cause temporary displacement of individual southern white-tailed ptarmigan. For example, in response to recreation, individual southern white-tailed ptarmigan may flush and disperse from feeding, roosting, and loafing areas when disturbed by humans recreating in or near alpine habitats. This disturbance may cause the individual southern white-tailed ptarmigan to divert energy from normal breeding, feeding, and sheltering activities. In general, this disturbance and the resulting displacement is largely temporary, and the individual may return to the area when the disturbance subsides. Additionally, if recreation tramples, crushes, or compacts willows, soft-snow, and other vegetation, these resources may be temporarily or permanently unavailable to individuals in that area. Prolonged disturbance to individuals or to habitats may cause individuals to move permanently away from an area, as was observed anecdotally by researchers at the Ophir AU when radio-collared females moved from the study area to adjacent suitable habitat, presumably because of a localized concentration of hikers. Finally, recreation may result in the death of individual southern white-tailed ptarmigan if individuals are crushed by vehicles or killed by dogs that accompany recreationists. Researchers observed dogs chasing and disturbing breeding birds and dogs killed a southern white-tailed ptarmigan chick at Independence Pass (Seglund et al. 2018, p. 91).<br><br>Although there are no published studies that directly link recreation to individual-level effects to southern white-tailed ptarmigan, effects have been observed anecdotally, primarily at locations near established and popular outdoor recreation destinations, such as Guanella Pass, Trail Ridge Road, and Independence Pass. Researchers working in alpine habitats have observed and commented that individual white-tailed ptarmigan may be disturbed or displaced by recreation, and in rare cases individuals may be |

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| | | crushed by vehicles or killed by dogs. We are aware of one instance of mortality due to a vehicle and one mortality of a chick by a dog, and have several reported observations of southern white-tailed ptarmigan being temporarily or permanently displaced from local areas due to concentrated recreation along existing highways, roads, and trails. Additionally, radio-collared females may have left the Ophir AU for adjacent suitable habitat in response to heavily concentrated hikers. |
| **POPULATION & SPECIES EFFECTS** | *How do individual effects translate to population- and species-level effects?* | |
| | *What is the magnitude of this stressor in terms of species viability?* | |
| **Effects of Stressors: POPULATIONS [RESILIENCY]** | *What are the effects on population characteristics (lower reproductive rates, reduced population growth rate, changes in distribution, etc.)?* | In general, any negative effects to wintering and breeding areas may reduce overwintering survival and reproductive success of southern white-tailed ptarmigan within an AU. If disturbance were to exceed individual-level effects, large numbers of southern white-tailed ptarmigan could be forced to emigrate outside of an AU, which could in turn reduce the abundance of the AU. We have anecdotal observations that suggest that recreation may have resulted in population-level effects to resiliency at two AUs, the first from large numbers of hikers at the Ophir AU and the second from snowmobiles at the Snowy Range AU. First, researchers speculated that declines in abundance at the Ophir AU may have been partially the result of southern white-tailed ptarmigan emigrating from the study area for an adjacent areas of suitable habitat in response to localized increases in the number of hikers. In the northernmost AU, the Snowy Range AU in Wyoming, anecdotal evidence suggests that Heavy off-trail snowmobile use may have contributed to its presumed extirpation. However, we lack conclusive evidence that recreation results in more than effects to individuals, with the primary effect being temporary disturbance and displacement. |
| **SCOPE** | *What's the geographic extent of the stressor relative to the range of the species/populations/AUs? Now and into the future?* | Currently, in CO, 1 of 18 (Ophir) analytical units has seen possible reductions in abundance as birds have dispersed to adjacent suitable habitats, which may have been due to recreation. Snowmobiling may have contributed to extirpation of WY population. Recreation in NM is relatively light compared to CO. We have no conclusive evidence, other than anecdotal evidence at two AUs, that population-level effects are occurring in any other AUs currently. Although the number of recreationists in the alpine is expected to increase in the future, we have no conclusive evidence to suggest that the geographic extent of recreation will increase such that population-level effects occur at other AUs. |
| **Effects of Stressors:** | *What are the expected future changes to the number of populations (or analytical units) and their distribution on the landscape?* | Anecdotal observational evidence suggest that the Ophir AU is experiencing high levels of recreation, which may contributed to the emigration of radio-collared WTPT out of |

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| | | currently occupied habitats to adjacent suitable habitats. However, we have no information regarding population-level impacts indiscriminate recreation on ptarmigan. |
| **[REDUNDANCY]** | *Number and distribution of populations.* | The presumed extirpation of the Snowy Range AU at the northernmost extent of the overall range in Wyoming due, in part, to recreation represents a historical reduction in redundancy for the species. However,18 out of the 19 AUs still remain and their distribution has remained unchanged. Although recreation could reduce the resiliency of additional AUs across the range at AUs near human population centers or where alpine habitats are more accessible, a further reduction to redundancy from additional AU losses is not expected because effects from the stressor will likely remain to individuals and not affect the resiliency of the AU. |
| **[REPRESENTATION]** | *What changes to the genetic or ecology diversity in the species might occur?* | Historically, recreation may have contributed to the presumed extirpation of the southern white-tailed ptarmigan from the Snowy Range AU, the northernmost AU and the only AU in Wyoming, although we have no conclusive evidence other than anecdotal observations that snowmobiles may have been that cause. It is unknown whether the Snowy Range AU provided any diversity or adaptive capacity for the subspecies, but its northern extent and lower elevation may have provided some ecological diversity.<br><br>Currently, recreation does not affect the number or distribution of AUs (redundancy) or the diversity of the subspecies across the AUs (representation).<br>In the future, more hikers at the Ophir AU could result in increased disturbance and permanent dispersal, and as a result reduce its resiliency, although we have no conclusive evidence other than anecdotal observations that recreation resulted in population-level effects at any of the AUs. A hypothesized reduction in resiliency at the Ophir AU would not be expected to reduce species-level representation. |
| **SUMMARY** | | Recreation historically reduced the redundancy of the species by one AU, and may have reduced species-level representation due to the loss of the Snowy Range AU at the northern extent of the species' overall range in Wyoming. Currently, this stressor may directly and indirectly affect individual ptarmigan, by killing or altering the behaviors of individual ptarmigan or reducing the quality or quantity of the habitat resources. However, this stressor has not reduced the resiliency of the remaining 18 AUs and has not affected species-level redundancy or representation because 18 AUs remain. In the future by 2050, this stressor is likely to increase across all AUs, based largely on the projected increases to human populations, with larger increases in alpine habitats that are easily accessible or closer to metropolitan areas. In the remaining 18 AUs, effects from this stressor will likely remain confined to individuals, although there may be some reductions in AU resiliency. Future reductions in representation are not expected from this stressor. |

| GRAZING | Assessment | Summary |
|---|---|---|
| **SOURCE(S)** | *What are the ultimate actions causing the stressor?* | Livestock management. Expansion of native ungulate populations. |
| **- Activity(ies)** | *What is actually happening on the ground as a result of the action? I.e. what are the specific sources of the actions?* | Sheep grazing. Elk browsing. |
| **STRESSOR(S)** | *What are the changes in environmental conditions on the ground that may be affecting the species?* | Increased trampling of vegetation, increased erosion, decreased plant species important to WTPT, increased disturbance, particularly during brood rearing. |
| **- Exposure of Stressor(s)** | *When and where does the stressor overlap with the resource (life history and habitat needs)?* | Sheep grazing occurs primarily in the San Juans and overlaps with the brood-rearing period. Elk browsing is impacting willow habitats in the alpine, including in the winter, particularly in areas where elk concentrate. |
| **- Immediacy of Stressor(s)** | *Are the stressors happening in the past, present, and/or the future? What's the timing and frequency?* | The number of sheep grazing in the alpine was much higher historically and was largely unregulated. Sheep are grazed more sustainably now and grazing will likely continue into the future. Sheep graze the alpine during the brood-rearing period, primarily in the San Juans, although some sheep grazing does occur in the Flat Tops. Sheep grazing occurred historically in New Mexico and in the Snowy Range in Wyoming but no longer occurs. Some records that the Pecos Wilderness was severely overgrazed by domestic sheep, historically. Elk numbers peaked in and around Rocky Mountain National Park (RMNP) in the 1990s and early 2000s, impacting willow habitats in the park. |
| **Affected Resource(s)** | *What are the resources that are needed by the species that are being affected by this stressor?* | Willows and forbs. |
| **Changes in Resource** | *Specifically, how was the resource changed?* | Reduced growth and vigor of willow, reduced availability of willow above the snow in winter. Reduced cover and frequency of willow (Braun et al. 1991). |
| **Response/effect to Stressors: INDIVIDUALS** | *What is the effect on individuals of the species to the stressor? (May be by life stage)* | **Chicks, Juveniles, Subadults, Adults**<br>Loss of willow may impact chick, juvenile, subadult, and adult ptarmigan food sources. Sheep graze forbs important to hens with broods. Disturbances related to sheep grazing may impact brood-rearing habitat and can separate chicks from hens.<br>**Conclusion on Individuals**: Grazing can affect individual WTPT. Sheep grazing in late summer can impact chicks, juveniles, subadults, and adults through loss of forbs and direct disturbance. Elk browsing can impact winter habitat for juveniles, subadults, and adults. Sheep grazing is most prevalent in the San Juans. Anecdotal evidence of possible impacts to hens with broods at Mesa Seco in the San Juans. Elk grazing reached its highest levels in and around RMNP |

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| | | 20-30 years ago, but numbers are currently below population objectives. Willow habitats are still recovering, and recovery may be slow in some areas. **UNCERTAINTY/ASSUMPTIONS:** Evidence of grazing impacts are largely anecdotal. Unknown how much historical sheep grazing has impacted WTPT habitat in Wyoming, New Mexico, and Colorado. |
| **POPULATION & SPECIES EFFECTS** | *How do individual effects translate to population- and species-level effects?* | |
| | *What is the magnitude of this stressor in terms of species viability?* | |
| **Effects of Stressors: POPULATIONS [RESILIENCY]** | *What are the effects on population characteristics (lower reproductive rates, reduced population growth rate, changes in distribution, etc.)?* | Declines in populations at Trail Ridge coincided with high elk numbers, but the direct relationship is unknown. Historical sheep grazing may have impacted the abundance of WTPT in New Mexico and Wyoming. |
| **SCOPE** | *What's the geographic extent of the stressor relative to the range of the species/populations?* | In CO, at least 3 of 18 analysis units experience grazing impacts. The effects of elk grazing may be primarily restricted to Trail Ridge, particularly in areas where elk concentrate. Sheep grazing primarily occurs in the San Juans, but also occurs in the Flat Tops. In particular, Mesa Seco is impacted annually by sheep grazing. |
| **Effects of Stressors:** | *What are the expected future changes to the number of populations and their distribution on the landscape?* | Populations of WTPT at Trail Ridge have seen declines in abundance, but the cause is unknown. In other CO sites, unknown how sheep grazing will affect populations and distributions. Historically, sheep grazing may have impacted populations and habitats of WTPT in New Mexico and Wyoming. |
| **[REDUNDANCY]** | *Number and distribution of populations.* | Historical sheep grazing may have affected abundance of WTPT populations in New Mexico at the southern extent of the range. It is unknown if sheep grazing has impacted populations of WTPT in CO. High elk numbers impacted WTPT habitats, particularly at Trail Ridge, in the 1990s and early 2000s, and this may have influenced abundance of WTPT at this AU. The impacts to resiliency due to grazing are largely unknown, and there has been no loss of redundancy due to grazing. In the future, we do not expect impacts to redundancy. |
| **[REPRESENTATION]** | *What changes to the genetic or ecology diversity in the species might occur?* | Historically, possible impacts to resiliency of WTPT in New Mexico at the southern extent of the range, but no loss of representation. Currently, there are no impacts to representation from grazing. In the future, we do not expect impacts to representation. |
| **SUMMARY** | | Historically, possible impacts to resiliency of WTPT in New Mexico at the southern extent of the range, but no loss of representation. Effects to resiliency will likely remain at the individual level now and into the future. We do not expect any future reductions to redundancy or representation. |

| CLIMATE CHANGE | Assessment | Summary |
|---|---|---|
| **SOURCE(S)** | *What are the ultimate actions causing the stressor?* | Increased atmospheric $CO_2$ and other greenhouse gases. |
| **- Activity(ies)** | *What is actually happening on the ground as a result of the action? I.e. what are the specific sources of the actions?* | Increasing daily minimum and maximum temperatures; increase in winter/spring precipitation; possible changes in the frequency, timing, and intensity of monsoonal moisture/summer afternoon thunderstorms; increased dust on snow; changes in snowpack and length of the snow season. |
| **STRESSOR(S)** | *What are the changes in environmental conditions on the ground that may be affecting the species?* | Warmer winter temperatures; Earlier spring snowmelt; changes in plant phenology; advancing treeline and increasing tree densities into the alpine; changes in snow quality; changes to hydrology that will affect willow; changes in alpine plant communities. |
| **- Exposure of Stressor(s)** | *When and where does the stressor overlap with the resource (life history and habitat needs)?* | Across the range of S WTPT. Earlier breeding; earlier hatch dates; phenological mismatch with breeding and food availability; impacts on snow roosting sites in winter; partial loss of alpine habitat as trees encroach; impacts on willow important for winter and spring foraging; impacts to summer/brood-rearing foraging habitat (forbs). |
| **- Immediacy of Stressor(s)** | *Are the stressors happening in the past, present, and/or the future? What's the timing and frequency?* | Some evidence of impacts to nesting with warming temperatures currently. Climate change impacts are likely to increase into the future. Can impact year-round habitats. Uncertainty surrounding future precipitation, plant phenology, treeline advancement. |
| **Affected Resource(s)** | *What are the resources that are needed by the species that are being affected by this stressor?* | Willow, alpine vegetation, soft snow for roosting, late-lying snowfields, monsoonal moisture/summer precipitation. |
| **Changes in Resource** | *Specifically, how was the resource changed?* | Changes in the timing of nesting with warming temperatures has been observed at three AUs. |
| **Response/effect to Stressors: INDIVIDUALS** | *What is the effect on individuals of the species to the stressor? (May be by life stage)* | If breeding does not align with the availability of forage, chick survival may be lower due to phenological mismatch with resource abundance. Impacts to individuals have been observed at 3 AUs: Mt. Evans, Trail Ridge, and Mesa Seco. |
| **POPULATION & SPECIES EFFECTS** | *How do individual effects translate to population- and species-level effects?* | |
| | *What is the magnitude of this stressor in terms of species viability?* | |
| **Effects of Stressors: POPULATIONS [RESILIENCY]** | *What are the effects on population characteristics (lower reproductive rates, reduced population growth rate, changes in distribution, etc.)?* | Lowered chick survival may reduce overall reproductive success and population growth. |

| | | |
|---|---|---|
| **SCOPE** | *What's the geographic extent of the stressor relative to the range of the species/populations?* | Range-wide. |
| **Effects of Stressors:** | *What are the expected future changes to the number of populations and their distribution on the landscape?* | Hotter and drier conditions may impact AUs with limited habitats (e.g., New Mexico), resulting in reductions to redundancy and representation. |
| **[REDUNDANCY]** | *Number and distribution of populations.* | No historical or current reductions to redundancy. Potential loss of AUs with more limited habitat that may reduce redundancy. |
| **[REPRESENTATION]** | *What changes to the genetic or ecology diversity in the species might occur?* | Potential loss of local adaptations in the New Mexico AU to warmer temperatures and precipitation. |
| **SUMMARY** | | Given currently available climate scenarios, we expect that climate change may reduce resiliency for at least some AUs and may reduce the redundancy and representation of AUs that currently have limited habitat (New Mexico). |

## **Appendix C:** Dynamic Global Vegetation Models

To fully explore potential future viability for the southern white-tailed ptarmigan, we considered the use of dynamic global vegetation models (DGVMs) as a tool to inform our evaluation of future condition for the habitat factors that we identified as needs for the southern white-tailed ptarmigan. DGVMs simulate shifts, or future changes, in broad categories of vegetation classes in response to climate change. However, there are a variety of limitations associated with using DGVMs. DGVMs represent vegetation as generalized and simplified types, such as tundra, coniferous forest, and grassland, so that results of the model can be applied at a global scale (Bachelet et al. 2015, p. 4549). Additionally, DGVMs provide results at coarse spatial resolutions (e.g., 4 kilometers [2.5 miles]) and do not incorporate fine-scale ecosystem processes (Bachelet et al. 2017, p. 272). Another potential limitation of their utility to evaluate future viability for the southern white-tailed ptarmigan is that the climate data used in these models includes limited observations above 3,000 meters (9,850 feet) and almost no observations above 3,500 meters (11,500 feet) (Rangwala and Miller 2012, p. 534). Further, DGVMs are developed using simplified relationships of complex biotic and abiotic mechanisms that influence the distribution and dynamics of vegetation, potentially oversimplifying complex ecosystems processes that influence potential future vegetative change. As a result, such a coarse grain analysis can overpredict the loss of habitat and underestimate the potential for suitable habitat under future changes in climate (Barbet-Massin et al. 2010, p. 884; Forester et al. 2013, p. 1491). DGVMs do not incorporate factors such as slope and aspect, cold air drainage, and canopy cover that influence variation in climate and in turn impact species distributions at fine spatial scales (Slavich et al. 2014, p. 953). Because of the topographic complexity in alpine systems, the inclusion of topoclimatic effects into models of vegetation distribution is necessary to project how vegetation will respond to climate change (Slavich et al. 2014, p. 958), particularly in mountainous regions (Dobrowski 2011, p. 1033; Bueno de Mesquita et al. 2018, p. 11). Given these limitations, we proceeded cautiously before applying DGVMs to the predicted range of the southern white-tailed ptarmigan.

For the southern white-tailed ptarmigan, we examined the DGVM MC2 (Bachelet et al. 2015, Bachelet et al. 2017) run with a suite of plausible climate futures that corresponded to the three GCMs used to develop the future climate projection scenarios for the subspecies' predicted range. The DGVM under all three climate futures showed a near complete conversion of alpine tundra to coniferous forest by mid-century (years 2041 to 2070) within the range of the southern white-tailed ptarmigan (Figures 1-4). This conflicted with our understanding of the magnitude of potential loss of southern white-tailed ptarmigan habitats by 2050 due to climate change, so we questioned the use of these models to evaluate plausible future condition for the southern white-tailed ptarmigan.

The complete conversion of alpine tundra to coniferous forest projected by the DGVM MC2 would mean that treeline in the southern Rocky Mountains would need to advance by more than 2,500 feet (762 meters) by mid-century, which is highly unlikely given the past, current, and anticipated trends of treeline progression for the region (Rondeau et al. 2012, p. 6, Fink et al. 2014, p. 9) and other areas of the Rocky Mountains (Davis et al. 2020, p. 15). The potential future conversion of alpine tundra to coniferous forest depends on a number of climatic and non-climatic factors, including soil type, microclimate, tree species composition, and topography

(Germino et al. 2002, p. 164; Dullinger et al. 2004, p. 250; Harsch and Bader 2011, p. 589). Therefore, although we expect reductions in either the quality or quantity of alpine habitats within the range of the southern white-tailed ptarmigan due to climate change by year 2050, we do not expect a complete loss of alpine tundra under any future scenario, whether from treeline advancement or any other factor. Given their underlying limitations, we believe that the DGVM evaluated for this analysis does not accurately project future habitat conditions for the southern white-tailed ptarmigan by mid-century. Therefore, we did not use DGVMs in our analysis of future viability for this subspecies. Instead, we relied on demographic and ecological data for the southern white-tailed ptarmigan collected over several decades as well as expert input to help evaluate the future condition for the southern white-tailed ptarmigan under three climate-based future scenarios that captured the range of uncertainty associated with global climate change (Chapter 4).

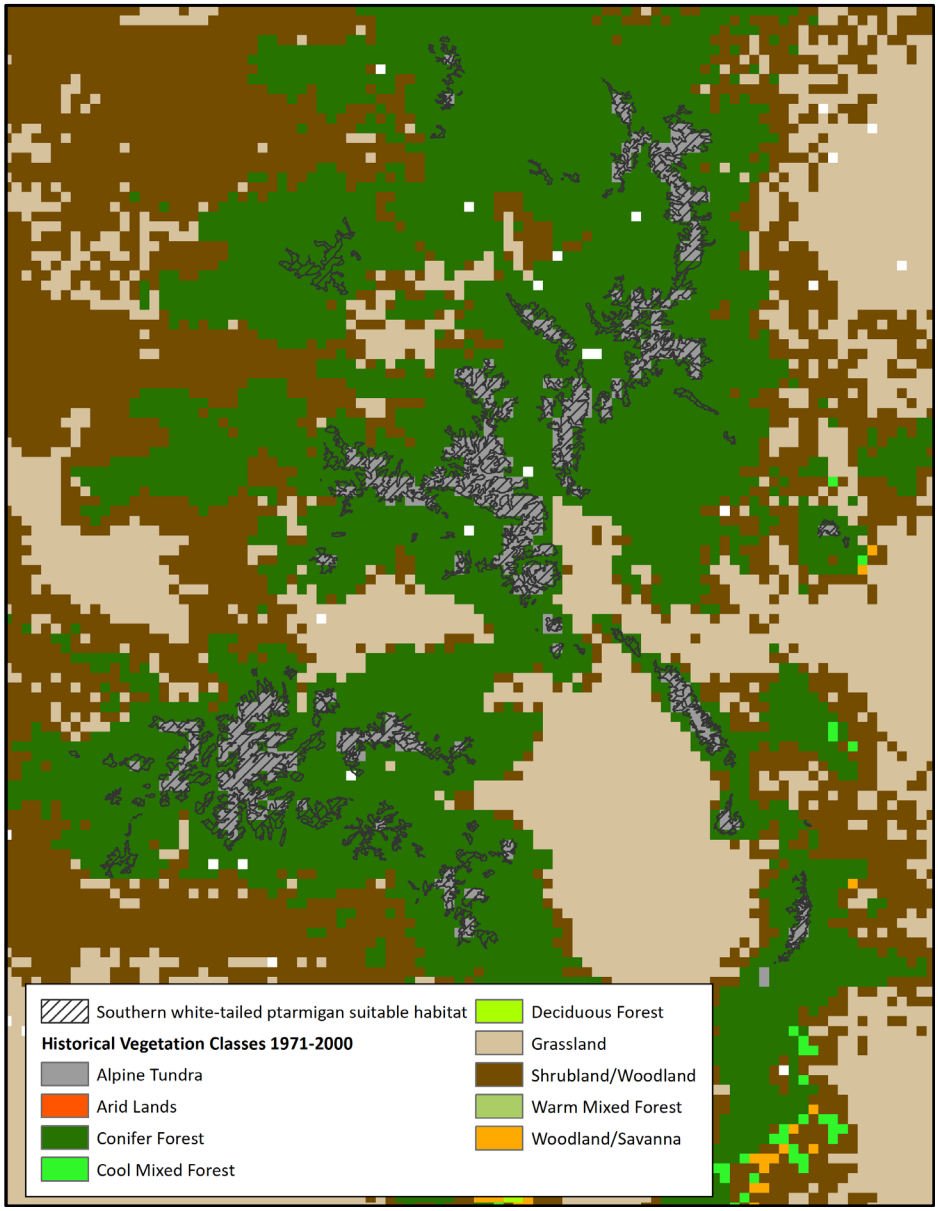


Figure 1. Simulated historical vegetation distribution (1971 to 2000) within predicted range of the southern white-tailed ptarmigan (Colorado only).

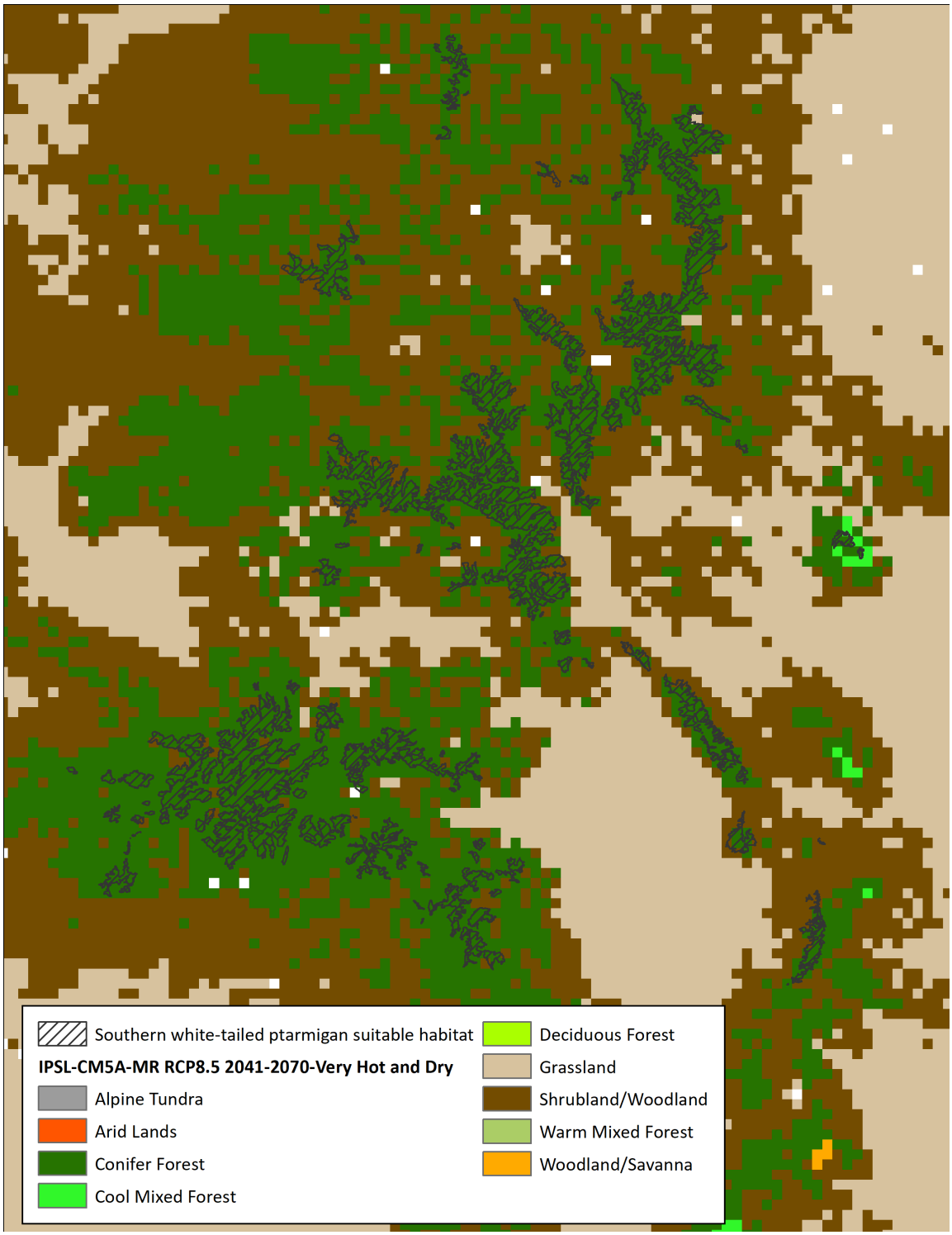

Figure 2. Projected vegetation distribution (2041 to 2070) under the Very Hot and Dry Scenario.

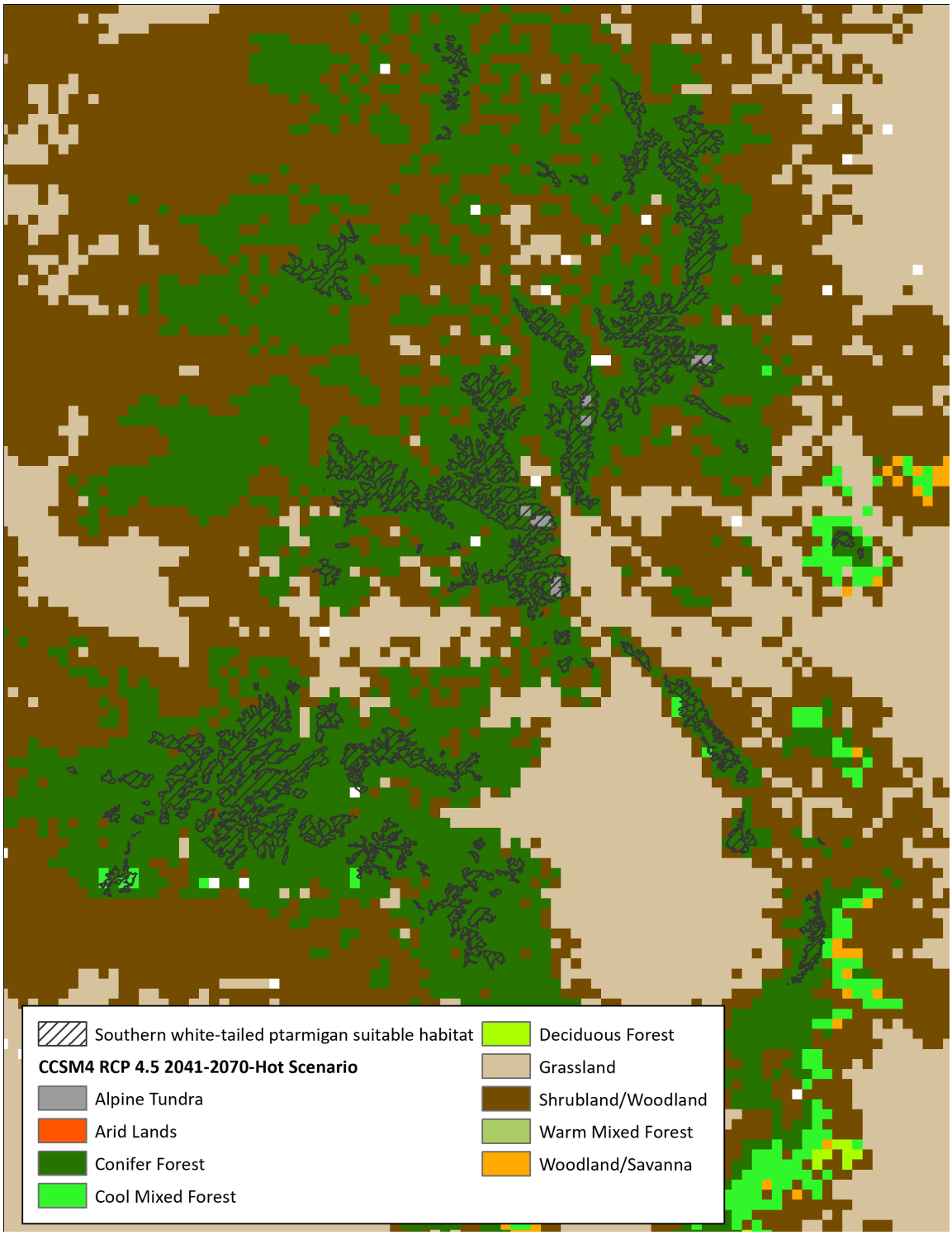

Figure 3. Projected vegetation distribution (2041 to 2070) under the Hot Scenario.

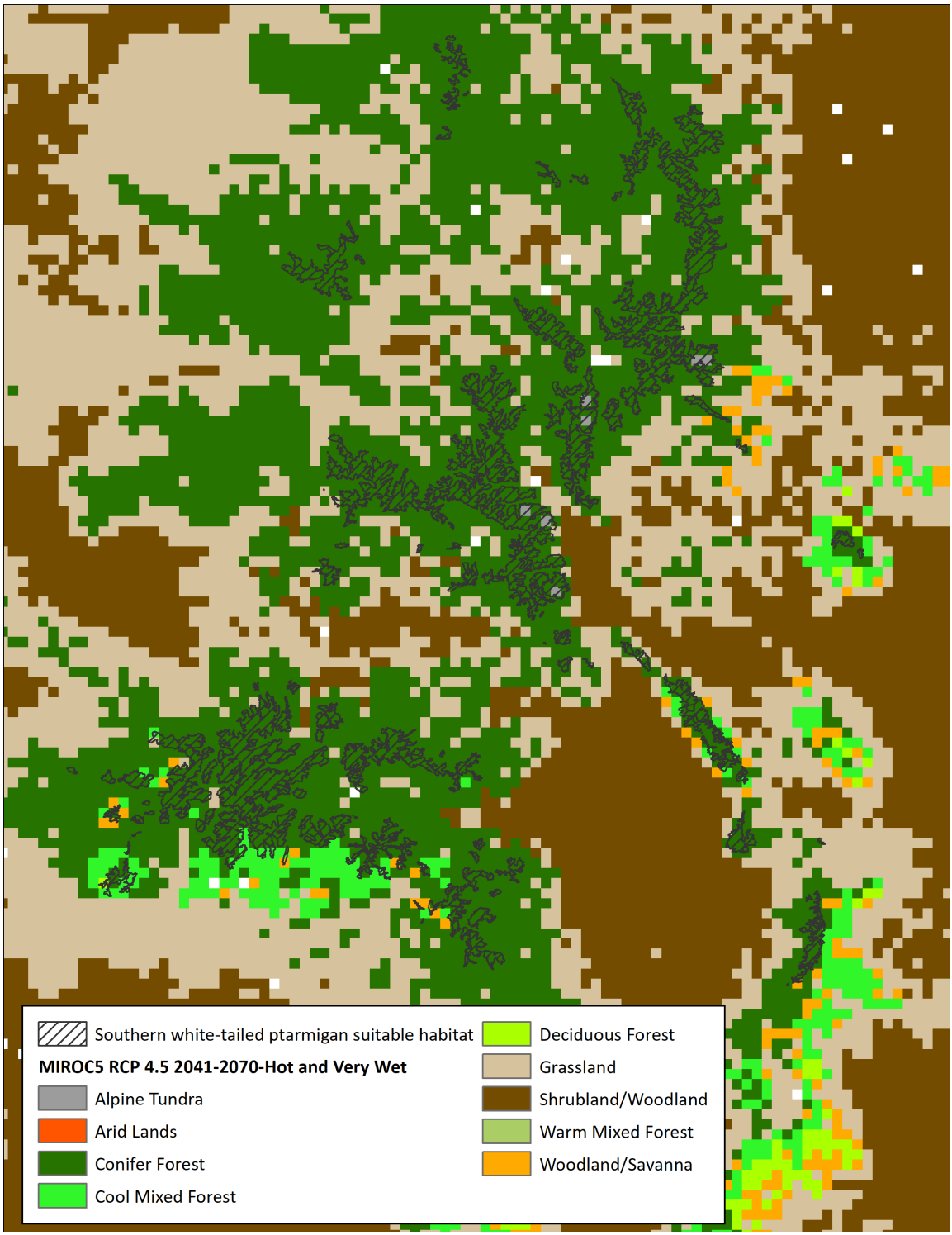

Figure 4. Projected vegetation distribution (2041 to 2070) under the Hot and Very Wet Scenario.