Species Status Assessment Report
Bleached Sandhill Skipper
(*Polites sabuleti sinemaculata)*

Version 1.1

Credit: L. Enders USFWS

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Pacific Southwest Region

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U.S. Fish and Wildlife Service. 2024. Species status assessment report for the bleached sandhill skipper (*Polites sabuleti sinemaculata*), Version 1.1. March 2024. Pacific Southwest Region. 100 pp.

EXECUTIVE SUMMARY

We conducted a species status assessment (SSA) to assess the viability of the bleached sandhill skipper (*Polites sabuleti sinemaculata*). We define viability as the ability of a species to maintain populations in the wild over a biologically meaningful timeframe. We characterized bleached sandhill skipper viability over time by assessing its ability to withstand environmental, genetic, and demographic stochasticity and disturbances (resiliency), catastrophic events (redundancy), and novel changes in its biological and physical environment (representation). Bleached sandhill skipper viability is fostered by maintaining the demographic and genetic health of its populations and preserving potential connections between populations.

Biology and habitat requirements: The bleached sandhill skipper is a small-sized, narrow endemic butterfly found in Humboldt County, Nevada. It occupies alkali meadows in three likely isolated populations: Pueblo Slough, Gridley Lake, and Rincon Creek. Bleached sandhill skippers require available and nutritious food plants to reproduce and survive. Rabbitbrushes (*Chrysothamnus* spp. and *Ericameria* spp.) are the primary nectar sources for adults; the availability of non-senescing plants during late summer through fall is essential for adult reproduction and survival. Saltgrass (*Distichlis spicata*) is the presumed sole larval hostplant, providing food and shelter for larvae and presumably shelter for pupae; the availability of nutritious saltgrass plants throughout the fall is essential for larvae growth, development, and survival. These food plant species are dependent on shallow groundwater. Lastly, all butterfly life stages—egg, larvae, pupae, and adult—require suitable microclimate, including suitable temperatures and moisture levels.

Bleached sandhill skippers are poikilothermic, meaning that their body temperature is controlled by ambient temperature, which controls critical physiological functions and behaviors, such as respiration, immunity, metabolism, growth and development, fecundity, flight ability, dispersal, oviposition, feeding, and diapause. Moisture conditions are also an important determinant of butterfly survival, especially in desert areas. The optimal range of temperature and moisture levels is unknown for bleached sandhill skipper, but as a desert occupant, it likely experiences conditions close to its upper thermal and moisture limits under normal conditions, leaving little buffer to cope with increasingly warming and drying conditions. Studies from a number of other insects, including butterflies, across broad geographic areas show significant fitness (growth, development, fecundity, and survival) consequences as temperatures exceed upper thermal limits.

Methods: We assessed bleached sandhill skipper viability by evaluating the historical and current condition (e.g., abundance, population growth rates, habitat quality) of its populations and identifying the primary influences leading to the subspecies’ current condition. Next, we derived population-specific plausible lower and upper projections for each influence and created composite scenarios by combining all lower bound projections (Scenario A) and all upper bound projections (Scenario B) and described the likely population response under each composite scenario. Finally, we used these results to assess viability consequences over time. The primary influences include livestock grazing, groundwater pumping, geothermal development, and climate change. Pulling from available data on thermal limits, we used 35 - 38 C (95 - 100 F) thresholds to assess the risk of non-lethal fitness consequences and 38 - 41 C (100 to 105 F) thresholds to assess the risk of lethal consequences over time. Given its annual lifecycle, a few extreme heat events in a single year can substantially impact reproductive success and reduce abundance, and possibly, lead to extirpation. Key uncertainties and the viability implications of our assumptions are described at the end of the SSA report.

Results: At Pueblo Slough, butterfly counts have steeply declined (97%) since 2014, suggesting a declining trend in abundance. There are only single data points for Gridley Lake and Rincon Creek. Gridley Lake counts were similar to Pueblo Slough, while Rincon Creek counts were considerably lower. Data are too limited to assess quality of saltgrass and rabbitbrushes, but information suggests that the health of the overall vegetation community has declined at Pueblo Slough and Gridley Lake. Microclimate suitability is also likely declining, owing to warming and drying conditions over the last 20 years. Grazing is likely having only minor population-level impacts at Pueblo Slough and no impacts at Gridley Lake and Rincon Creek. Groundwater pumping is increasing depth-to-groundwater across, or up gradient from, all three populations. Climate change is negatively affecting fitness and habitat conditions of all three populations and is likely the dominate driver of bleached sandhill skipper abundance and habitat conditions.

To assess the future condition of the subspecies, we evaluated the impacts of the threats both singly and in combination under composite Scenario A (composite of all lower bound threat projections) and Scenario B (composite of all upper bound threat projections). For Pueblo Slough, a proposed geothermal development project was included in both scenarios. Climate change was projected out to 2099 and continues to be the dominant threat facing bleached sandhill skippers at all three populations. Where applicable, groundwater pumping is projected out to 2099 and will exacerbate climate change-induced drying conditions. Grazing was projected out to 2045 and geothermal development to 2030; although individually they are likely to have no to minor impacts, in combination with climate change and groundwater pumping, these sources will add to, or further compound effects from, the drying conditions.

As population abundances decline due to direct impacts from climate change and indirect impacts to habitat, bleached sandhill skippers will reach a point where demographic and genetic stochasticity interact synergistically with environmental stochasticity, further reducing population size and genetic diversity, triggering a self-reinforcing extirpation vortex. It is unknown whether any of the three populations are presently near or in an extirpation vortex, but it appears inevitable into the future without population adaptation. Bleached sandhill skippers adaptive capacity, however, is likely constrained by its relatively low genetic diversity and its inflexible upper thermal limits. Both conditions suggest little potential for population adaptation given the magnitude and rapid change in climate conditions projected in the near-term (2030), mid-term (2050), and far-term (2099) future.

Viability synopsis: Bleached sandhill skipper viability requires multiple, healthy populations (abundant and strong growth rates). Until recently, bleached sandhill skipper populations had sufficient abundances and growth rates to withstand unfavorable environmental conditions despite its narrow geographic extent and low among-site heterogeneity. Over the last 10 years, however, bleached sandhill skipper abundance has been declining at Pueblo Slough, most likely due to climate change and groundwater pumping. Gridley Lake and Rincon Creek populations have limited population data, but because of their proximity and low among-site heterogeneity, they are likely experiencing and responding similarly to the rising temperatures and drying conditions.

With declining population health (low abundances) coupled with small geographic extent and low among-site heterogeneity, the subspecies now possesses limited ability to withstand inherent stochasticity (environmental, demographic, and genetic), catastrophic events (e.g., heat waves and droughts), and changing environmental conditions (e.g., chronic increases in temperatures, drying conditions, changing abundances of natural enemies, novel pathogens). The plausible future includes increasing temperatures and drying conditions over the near-term and markedly intensifying at mid-century and beyond under the higher impact scenario. In response, population declines will be exacerbated, further reducing the bleached sandhill skipper's ability to sustain itself, while concurrently, impairing the subspecies' ability to withstand stochasticity and catastrophic events. Moreover, declining population health constrains bleached sandhill skipper's seemingly low evolutionary potential (owing to the inferred limited ability to shift its range and its low within and among population genetic diversity), thereby exacerbating declines in the subspecies' resiliency and redundancy over time. Accordingly, our results suggest increasing, though unquantifiable, extirpation risks at all three populations in the near-term under both scenarios and accelerating by mid-century under the higher impact scenario given the rapidly increasing number of extreme heat events.

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VERSIONING UPDATES

The changes from version 1.0 (December 2023) to version 1.1 (March 2024) did not change the SSA framework or implementation of the SSA framework. Minor editorial changes were made throughout the SSA. We also included new citations provided by Ormat Nevada Inc. (email received on March 5, 2024) regarding bleached sandhill skipper data collected in 2023. We have included this information and provided the new citations where appropriate.

CHAPTER 1 – INTRODUCTION AND ANALYTICAL FRAMEWORK

This report summarizes the results of a species status assessment (SSA) conducted by the U.S. Fish and Wildlife Service (Service) for the bleached sandhill skipper (*Polites sabuleti sinemaculata*) and is intended to provide the biological support for the decision on whether the subspecies warrants listing under the Endangered Species Act of 1973, as amended (ESA) and subsequent decisions if added to the list of endangered and threatened species. Importantly, the SSA Report is not a decisional document by the Service; rather it provides a review of available information strictly related to the biological status of the bleached sandhill skipper. 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 appropriate opportunities for public input.

The purpose of the SSA is to assess the viability of the subspecies in light of current and future threats and conservation efforts, collectively referred to as influences. We define viability as the ability to maintain populations in the wild over time and is assessed using the conservation biology principles of resiliency, redundancy, and representation (3Rs, adapted from Shaffer and Stein 2000, pp. 308–311; Wolf et al. 2015, entire).

Resiliency is the ability of a species to withstand environmental stochasticity or normal, year-to-year variations in environmental conditions such as temperature and rainfall; periodic disturbances within the normal range of variation such as fire, floods, and storms; and demographic stochasticity, chance variation in demographic rates such as mortality and fecundity (Redford et al. 2011, p. 40). Therefore, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions.

Redundancy is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population health and for which adaptation is unlikely (Mangel and Tier 1993, p. 1083). Examples include extreme droughts or temperatures, extreme storms, fire, invasive species, and epidemics.

Representation is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments—referred to as adaptive capacity—is essential for viability, as species need to continually adapt to their continuously changing environments (Nicotra et al. 2015, p. 1269). Species adapt to novel changes in their environment by either [1] moving to new, suitable environments or [2] by altering their physical or behavioral traits (phenotypes) to match the new environmental conditions through either plasticity or genetic change (Nicotra et al. 2015, p. 1270; Beever et al. 2016, p. 132). The latter (evolution) occurs via the evolutionary processes of natural selection, gene flow, mutations, and genetic drift (Crandall et al. 2000, pp. 291; Zackay 2007, p. 1; Sgrò et al. 2010, p. 327).

In our SSA, we assess all three facets to the best of our ability based on available data. We first describe the species biological and ecological needs at the individual, population, and species levels (Chapter 2). We then evaluate the subspecies' historical and current condition of its populations (Chapter 3) and identify the primary influences leading to the subspecies' current condition (Chapter 4). Next, we describe future population-specific projections for the primary influences (Chapter 5) and the overall population responses given combined effect of the primary influences (Chapter 6). Lastly, we evaluate the viability consequences over time given the projected future conditions of the species and describe the key uncertainties underlying our analysis and the viability consequences of each (Chapter 7).

In conducting our analyses, we reviewed and collected information from peer-reviewed literature, unpublished reports, government reports, expert input, land management policies and directives. We contacted subject matter experts and reviewed and incorporated aerial imagery and Geographic Information Systems (GIS) data. We identified uncertainties and data gaps in our assessment of sources of threats influencing the subspecies' past, current, and future conditions.

CHAPTER 2 – SUBSPECIES BIOLOGY AND ECOLOGICAL NEEDS

In this chapter, we provide biological information about the bleached sandhill skipper, including its taxonomic history, morphological description, distribution, and life history. We then describe the resource needs of individuals, populations, and the subspecies.

2.1 Taxonomy

The bleached sandhill skipper (*Polites sabuleti sinemaculata*) is one of 13 named subspecies of the sandhill skipper. George Austin described this subspecies from specimens taken from the area of Pueblo Slough in 1985 (Austin 1987, pp. 7–9). The bleached sandhill skipper is a valid taxon listed in the Integrated Taxonomic Information System (ITIS n.d.). The taxonomy for this subspecies is provided in Table 1. This subspecies is also known as the Denio sandhill skipper.

Table 1. Taxonomy of P. s. sinemaculata (Austin 1987, pp. 7–9).

Kingdom:	*Animalia*
Phylum:	*Arthropoda*
Class:	*Insecta*
Order:	*Lepidoptera*
Family:	*Hesperiidae*
Genus:	*Polites*
Species:	*sabuleti*
Subspecies:	*sinemaculata*

2.2 Subspecies Description

The bleached sandhill skipper can be distinguished from other sandhill skipper subspecies based on the unusually pale coloration of the wings that give the subspecies a 'bleached' appearance (Austin 1987, p. 8). George Austin described the bleached sandhill skipper as "…by far the most distinctive of the *P. sabuleti* subspecies" (Austin 1987, p. 8). Austin described *P. s. sinemaculata* as having wing markings typical of other sandhill skippers with a deeper and brighter dorsal orange color, but that overall, *P. s. sinemaculata* is paler than any other subspecies as both sexes lack or have very pale serrated marginal dark areas that are found on the other *P. sabuleti* subspecies (Austin 1987, p. 8). Additionally, both sexes are large in size compared to other *P. sabuleti*; males have an average forewing length of 12.6 millimeters (mm) (0.5 inch (in)), while females' average forewing length is 14.0 mm (0.6 in) (Austin 1987, p. 8).

2.3 Range and Distribution

The bleached sandhill skipper is known from three locations within the Bog Hot Valley drainage system in Humboldt County, Nevada: Pueblo Slough, Gridley Lake, and Rincon Creek (Figure 2.1) (Austin 1987, p.8; Stantec 2016, pp. 14–15; Stantec 2020, p. 9; Center for Biological Diversity (CBD) 2022, pp.10-15, Jahner 2023, pp. 3, 9-10; Osborne 2023a, pp.4-9, Osborne 2023b, p.5-12). We assume that these three locations are distinct populations. Although a small amount of gene flow may be occurring, it is unlikely that the number of dispersers is sufficient to influence population dynamics given the bleached sandhill skipper's inferred low dispersal tendency (see discussion in Section 2.4).

Recent survey efforts to identify additional populations of bleached sandhill skipper in Humboldt County, Nevada and Harney County, Oregon have not yielded positive results. The neither the subspecies nor the nominate species were found; at a few locations individuals of related subspecies, or individuals with intermediary characteristics, were discovered (Center for Biological Diversity (CBD) 2022, p.15, Jahner 2023, p.2; Osborne 2023a, pp.4-9, Osborne 2023b, p. 8-12).

The type locality, Pueblo Slough, is the alkali meadow surrounding Baltazor Hot Spring within Pueblo Slough (Austin 1987, p. 8). This population is found on private lands and lands managed by the Bureau of Land Management (BLM). At Gridley Lake, bleached sandhill skippers are found around the lake margins in an alkali meadow community. This population is approximately 21.5 kilometers (km) (13.4 miles (mi)) southwest of Pueblo Slough and is found on private lands and lands managed by the BLM. At Rincon Creek, bleached sandhill skippers are found along the extent of an alkali meadow. This population is located approximately 7.8 km (4.8 mi) west of Pueblo Slough and is found on lands managed by the Sheldon National Wildlife Refuge. This population is also referred to as "Bog Hot Springs" population; however, individuals have been found near both the cold and warm springs but have not been found at Bog Hot Springs proper.

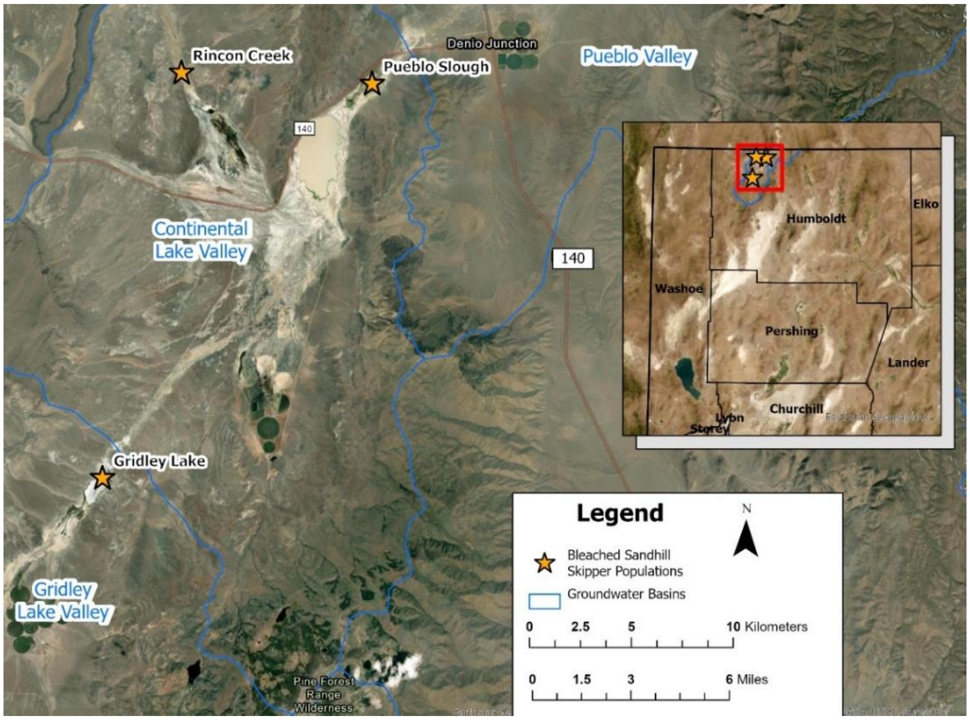

Figure 2.1. The three known bleached sandhill skipper populations (stars) and associated groundwater basins: Continental Lake Valley and Gridley Lake Valley.

2.4 Annual lifecycle

The bleached sandhill skipper has an annual life cycle and is presumably univoltine (having one adult flight period per year; Austin 1987 p. 8, Stantec 2016, p. 7, Stantec 2020, p.10). The specific timing and expression of life history characteristics of the bleached sandhill skipper subspecies have not been studied in detail, but its phenology (Figure 2.2) is likely similar to other *P. sabuleti* subspecies and univoltine skipper species found in similar habitat communities such as the Carson wandering skipper (*Pseudocopaeodes eunus obscurus*).

Life stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
adult								■■	■■	■		
egg								░■	■■	■░		
larva									░	░░	░░	
pupa	░░	░░	░░	░░	░░	░░	░░	░			░░	░░

Figure 2.2. Presumed lifecycle chart for the bleached sandhill skipper. The sequence of life stages and the timing of the adult stage are known, the precise timing (duration) of immature stages is unknown (depicted as lighter shading).

Like other subspecies of *P. sabuleti*, adult bleached sandhill skippers lay eggs on the presumed larval hostplant, saltgrass (Austin 1987, p. 8). In a different subspecies of multivoltine sandhill skippers in Yakima Valley, Washington, eggs laid in August-September hatch after about one week and larvae (caterpillar stage) begin feeding on the hostplant, progressing through instars, possibly as many as five (Newcomer 1966, pp. 244–245). Pupation (chrysalis stage of metamorphosis) occurs just before winter (Newcomer 1966, p. 244). Based on other *P. sabuleti* subspecies, bleached sandhill skipper likely overwinters in the pupal stage as well (Scott 1986, p. 443), meaning that individuals must progress through each of the larval instars prior to the onset of unfavorable conditions. While in the pupal stage, the skipper undergoes complete metamorphosis, with adults emerging mid-August through early October (Austin 1987, p. 8, Stantec 2020 p. 9, Arid West 2023, p. 7, 8, 10). During the flight period, adults feed on nectar of rabbitbrushes, mate, and oviposit (females lay eggs) on saltgrass. Little is known about its dispersal habits but given the following evidence, it is likely that bleached sandhill skipper has low dispersal tendency. Bleached sandhill skippers are morphologically differentiated from the other subspecies of *P. sabuleti* (Austin 1987, p. 8) and have among the lowest genetic diversity of the 11 sampled subspecies (Jahner 2023, pp. 3–4); the three populations are also genetically differentiated (Jahner 2023, pp. 3, 9–10). All of which suggest limited gene flow, and thus dispersal, is minimal. Additionally, the combination of small wing size and large thorax, coupled with short generation time (univoltine) and short adult flight period further suggests low dispersal habits (Scott 1986, pp. 42–43, 425; Sekar 2011, pp. 179–182).

2.5 Ecological Resource Needs

In this section, we briefly describe the habitat of the three populations and the key viability needs at the individual, population, and species levels.

The bleached sandhill skipper occupies alkali meadows, which are found within topographically low extents, with vegetation that is often groundwater dependent, referred to as phreatophytic (Figure 2.3). The dominant vegetation at the three sites include saltgrass (*Distichlis spicata*) and rabbitbrushes, including white-flowered rabbitbrush (*Ericameria albida*), rubber rabbitbrush (*Ericameria nauseosa*) and yellow rabbitbrush (*Chrysothamnus viscidiflorus*).

Figure 2.3. Pueblo Slough (left), Gridley Lake (middle), and Rincon Creek (right)

Pueblo Slough is an approximately 404-hectare (ha) (1000-acre (ac)) alkali meadow, with a relatively intact native plant community. The plant community has a dense growth of saltgrass interspersed with three species of rabbitbrushes found around the periphery of the slough/meadow (Stantec 2016, p. 2). Baltazor Hot Springs, a geothermally fed spring system, occurs within Pueblo Slough at an elevation of approximately 1280 meters (m) (4200 feet (ft)).

Gridley Lake is an ephemeral lake, which may be a dry playa in some years, with an alkali meadow community dominated by saltgrass and rabbitbrushes along the edges. The habitat area is approximately 227 ha (560 ac) (Osborne 2023a, pp. 4–5). Three Springs, Gridley Springs, and Warm Springs are a series of springs found on the northern, southern, and northeastern extent, respectively, of Gridley Lake at elevations of approximately 1341 m (4400 ft.).

Rincon Creek is an alkali meadow dominated by greasewood (*Sarcobatus vermiculatus*) and yellow rabbitbrush with a saltgrass understory (no other rabbitbrushes have been documented). The habitat extent is not fully known but may be approximately 97 ha (240 ac), based on survey efforts in 2015, extending from Bog Hot Springs north 3.2 km (2 mi) past the warm and cold springs along Rincon Creek drainage (Stantec 2016, pp. 9, 16). This location has greater topographic variation, with elevations ranging from approximately 1304–1317 m (4280–4320 ft.).

The viability the bleached sandhill skipper depends on specific individual, population, and species-level needs. We describe these needs below and provide a diagram for reference (Figure 2.4)

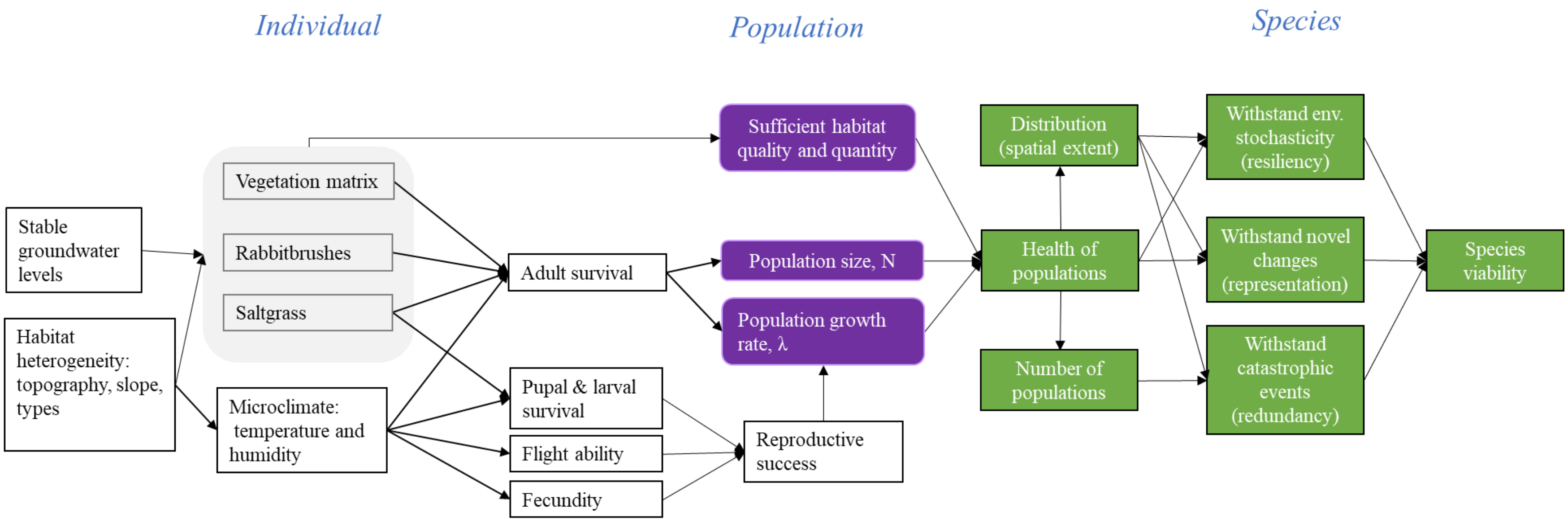

Figure 2.4. Conceptual model of the bleached sandhill skipper viability.

Individual-level needs

Bleached sandhill skippers require sufficient food, shelter, and suitable microclimate conditions throughout the year. The resources required vary by life stage and the timing of resource availability is critical for successful reproduction and survival. We list the key resource needs for individuals in Table 2.1 and describe these needs below.

Vegetation matrix

Bleached sandhill skippers occupy healthy alkali meadow communities dominated by saltgrass (the sole larval foodplant) and rabbitbrushes (the primary adult nectar source). These communities may contain other phreatophytic species such as greasewood, iodine bush (*Allenrolfera*), saltbushes (*Atriplex* ssp.), Sandberg's bluegrass (*Poa secunda*), seepweed (*Sueda* ssp), and alkali cordgrass (*Spartina gracilis*). Alkali meadows are found in valley bottoms and other areas with shallow water tables and alkaline soils. Small changes in topography create a gradation of species composition, owing to differences in water and salinity tolerances. Saltgrass has shallow root system and is more salt tolerant than rabbitbrushes, so typically, in alkali meadows, saltgrass is found lower, closer to groundwater and intergrades with rabbitbrushes as depth-to-groundwater increases and alkalinity decreases. Changes in water chemistry, temperature, or volume can influence the quality and quantity of bleached sandhill skippers' food and hostplant resources.

The bleached sandhill skipper habitat is located within phreatophytic vegetation communities (The Nature Conservancy (TNC) 2022a, p. ES-6), meaning composed of groundwater dependent vegetation. Phreatophytic vegetation are plants, trees, and shrubs that have roots that tap into groundwater or can draw water from groundwater to their roots. Saltgrass and rabbitbrush are phreatophytic plants, although both may also use meteoric water (precipitation) in some conditions (e.g., Kray et al 2021, p. 32–33, TNC 2022a, pp. 1–3). The maximum depth from which phreatophytic plants can effectively draw water is dependent on their root system. Based on studies of a similar vegetation community in Owens Valley, California, the maximum effective rooting depth may be around 2.5 m (8.2 ft.) (Elmore et al. 2006, p. 776), although the rooting depth is species-specific (see Saltgrass section below). Depth-to-groundwater also affects the soil chemistry, especially alkalinity. Thus, changes in groundwater levels (and precipitation patterns and vegetation stressors such as livestock grazing, which we discuss in Chapter 4) can affect the composition of the vegetation community and can detrimentally impact bleached sandhill skippers food and hostplant resources (see Saltgrass and Rabbitbrush sections below).

Saltgrass (the sole larval hostplant)

More than any other factor, saltgrass is essential to the bleached sandhill skipper's life cycle. Each stage of the bleached sandhill skipper's life cycle relies on saltgrass and is presumed to be the sole larval hostplant (Austin 1987, p. 8). The density or cover of saltgrass needed for the bleached sandhill skipper is unknown. The quality (health) of saltgrass is important as green plants during the larval stage are more nutritious (due to increased moisture content) and likely more edible. Saltgrass is a halophyte found along coastlines as well as inland sites across North America (Hansen et al. 1976, p. 635). It is adapted to grow in salty soils with salt glands that extrude salt from the leaves (Hansen et al. 1976, p. 645). Across the Great Basin, saltgrass is typically found in valley bottoms or along riparian corridors where there is a shallow water table and evaporation exceeds precipitation. Maximum rooting depths is approximately 0.6 –2.7 m

(2.0 to 8.0 feet) (Meinzer 1927, p. 19; TNC 2018, p.1). Laboratory experiments found saltgrass biomass to be the highest when groundwater is constant and when the rooting zone is approximately 1.0 m (3.3 ft.) below the surface and producing only half as much biomass when groundwater fluctuated annually between 1.0–4.0 m (3.3–13.1 ft.) (Naumburg et al. 2005, p. 735).

Rabbitbrush (the primary nectar source)

The rabbitbrushes are the primary nectar plants for adults (Austin 1987, p. 8, Stantec 2020, p. 10), and thus the quantity and quality of rabbitbrushes are essential for reproduction and survival of bleached sandhill skippers. No other flowering plants have been observed during their flight period (Austin 1987 p. 8, Stantec 2016, pp. 6–7, Stantec 2020, p. 10), with a single exception[1]. Depending upon weather conditions, rabbitbrushes flower from July–October (Calflora 2023, p.1). As phreatophyte species, rabbitbrushes have roots that collect water from the water table, and thus, changes in the depth-to-water table will affect the density of rabbitbrushes. Rabbitbrushes have a maximum rooting depth of approximately 1.0–2.5 m (3.3–8.2 ft.) (TNC 2018, p. 1). Rabbitbrushes can survive seasonal groundwater fluctuations better than phreatophyte species with shallower root systems but have lower alkalinity tolerances than saltgrass(Groeneveld 1994, p. 7-1; Patten et al. 2008, p. 404-406).

Microclimate suitability and habitat heterogeneity

Bleached sandhill skippers are poikilothermic, meaning that their body temperature is controlled by its microclimate (the abiotic environmental conditions within a few meters of their activity area), namely temperature (Harvey et al. 2023, p. 3, Jaworski and Hilszczanski 2013, p. 346). Insect body temperature regulates critical physiological functions and behaviors such as respiration, immunity, metabolism, growth, development, fecundity, flight, dispersal, oviposition, feeding, and diapause, and thus strongly influences organisms' reproduction and survival (Gonzalez-Tokman 2020, p. 811; Palumbo 2011, p. 1; Harvey et al. 2020, p. 6687). The response of insects to increasing ambient temperatures involves a complex interaction of neurological and biochemical functions. Generally, warmer temperatures accelerate development, which is not necessarily beneficial (Klockmann et al. 2017, p. 8; Gonazalez-Tokman 2020, p. 811; Zhao and Wang 2021, p. 4). Under increasing temperatures, metabolic rates and oxygen demand increase, leading to faster development, which in turn results in smaller adult body size and mass, and consequently, fewer eggs produced (reduced fertility) (Klockmann et la. 2017, p. 8; Gonazalez-Tokman 2020, p. 811; Zhao and Wang 2021, p. 4; Bristow et al. 2023, p. 8-9). Faster development can also lead to mismatch phenology with their hostplants. Additionally, when temperatures exceed specific limits (hereafter referred to as thermal limits), insects produce heat shock proteins to protect other heat sensitive proteins. These heat shock proteins are costly to produce and eventually lead to impaired muscular function, complete shut-down (reversible coma), and death (Harvey et al. 2020, p. 6687). Exposure to extreme temperatures for even a limited time can lead to a breakdown of metabolic functions and death (Harvey et al. 2020, p. 6689).

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[1] In 2014, during one survey period, adults were observed on lanceleaf goldenweed (*Pyrocoma lanceolata)* (Stantec 2015, p. 14). This species was not observed flowering in other years.

The optimal temperatures for physiological health vary by species and location (Hoffman et al. 2013, p. 937, Table 1; Kingsolver et al. 2013, p. 1421), but the temperature range triggering significant fitness consequences (i.e., thermal limits) for a multitude of species across a vast geographical expanse is remarkably narrow (Addo-Bediako et al. 2000, p. 742; Sunday et al. 2011, p. 1823; Hoffman et al. 2013, p. 937). For most butterfly species, significant reproductive and survival consequences during the active season (when life stages are growing, developing, and feeding) are triggered between 35 C (95 F) and 41 C (105 F), with immature stages more sensitive than adults at the lower end of the range (examples provided in Appendix, Table A1). These thermal limits shift downward when high daytime temperatures are coupled with high night-time temperatures (Zhao et al 2014, p. 774), owing to the need for respite from daytime temperature stress (Nail et al. 2015, p. 99; Halsch et al. 2021, p. 3; Harvey et al. 2023, pp. 14–15). For example, monarch larval mortality was higher when daytime temperatures of 38 C (100 F) coincided with night-time temperatures of 34 C (93 F) than when night-time temperatures cooled to below 34 C (93 F) (Nail et al. 2015, pp. 99, 104, 107). In species with short life cycles or reproductive periods— for example, univoltine butterflies like the bleached sandhill skipper—even brief periods of high temperatures can profoundly impact their reproductive success (Harvey et al. 2020, p. 6689).

Fitness (reproduction and survival) consequences from temperature stress in the early larval stages carry-over to latter stages without further exposure (Klockmann et al. 2017, p. 6; Harvey et al. 2023, p. 5). For example, *Bicyclus anynana*, a tropical butterfly, exposed to 37 C (99 F) temperatures during the egg stage had lower larval and pupal survival and smaller adult body mass, which in turn can compromise fitness components such as stress tolerance and reproduction (Klockmann et al. 2017, p. 6). These detrimental fitness consequences were exacerbated when individuals were exposed twice (in the egg and hatchling stage) to heat stress events (Klockmann et al. 2017, p. 6).

Temperature is also a key determinant of survival during the inactive period (overwintering or diapause stage). Diapause initiation, maintenance, and termination is controlled by a complex, intricate interaction of photoperiod, temperature, and moisture (Leather et al. 1995, p. 27). Temperature strongly affects the timing of diapause induction, with night-time temperatures appearing most influential (Leather et al. 1995, pp. 34–36). Successful overwintering requires larvae to develop to the requisite diapausing stage at precisely the correct time of year; that is, to reach the instar phase where individuals are sensitive to diapause initiation cues (Leather et al. 1995, pp. 25). Failing to reach the correct stage results in death (Leather et al. 1995, p. 149). Additionally, many insect species have critical thresholds below which temperatures must occur for a minimum number of hours to trigger diapause induction (Leather et al. 1995 pp. 34–36). These thresholds vary among species and locales. For example, <15 C (59 F) for at least 9.5 hours was needed for 50% of corn borer insects to enter diapause, while in a wasp species no diapause occurred when temperatures were below 13-23 C (55-73 F) for fewer than 10 hours (Leather et al. 1995, pp. 35–36). Temperature is also a strong determinant for maintenance and termination of diapause (Leather et al. 1995, pp. 47, 55). Premature warm temperatures trigger breaks in diapause, potentially exposing individuals to harsh and lethal conditions (Leather et al. 1995, p. 42; Klockmann and Fischer 2019, p. 150) or prematurely depleting energy reserves and reducing survival (Zhao and Wang 2021, p. 6). Data show that a small temperature change—even for brief periods—can substantially impact diapause energetics and fitness (Hahn and

Denlinger 2011, p. 114). One week of unusually warm temperatures of 16 C (61 F), for example, reduced *B. anynana* survival rates by 37% (Klockmann et al. 2019, p. 155).

Moisture conditions are also an important determinant of survival, especially in desert areas (Chown et al. 2011, p. 1071; Palumbo 2011, p. 1; Norhisham et al. 2013, p. 1). Insects obtain water through their food supply, but moisture levels influence insect growth and behavior by affecting the insect's ability to regulate water loss. Response to changing moisture levels varies by species and life stage (Norhisham et al. 2013, p. 4); generally, however, at low levels (e.g., relative humidities < 20–40%), fecundity decreases and desiccation risk increases (Woods and Singer 2000, pp. 594, 602; Norhisham et al. 2013, pp. 4–5). Diapausing individuals lose a significant amount of their body water content, and thus moisture is a limiting survival factor and a primary determinant of desiccation risk for overwintering pupae (Leather et al. 1995, p. 171). Pupae have a large surface area-to-volume ratio and are immobile, leaving them especially prone to dry conditions and desiccation (Leather et al. 1995, p. 4). Beyond lethal effects, dehydration in pupae can lead to adult deformities that impede their flight ability, and thus their feeding and oviposition success. Irrespective of the life cycle stage, development will be delayed until moisture conditions are favorable (Leather et al. 1995, p. 56). This being said, we have little knowledge with respect to moisture requirements and desiccation risks for desert lepidoptera.

Microclimate conditions are also influenced by the surrounding habitat (vegetation types and structure, topography, aspect, and slope). A mix of vegetation types, topographies, slopes, and aspects (referred to as habitat heterogeneity) creates a diversity of microclimates of which adults can use to optimize their fitness and the fitness of their offspring, as well as providing refugia during extreme events such as heat waves and strong, severe rainfall events (Harvey et al. 2020, p. 6688). Temperature extremes may also indirectly impact insects through their larval hostplants. Extended exposure to high temperatures may affect plant growth, resulting in early senescence of plants, leading to a reduction in nutritional value and production of toxic compounds (Harvey et al. 2020, p. 6690). Changing temperature may also affect nectar characteristics of a plant (such as volume and sugar content), which can affect nutritional value for bleached sandhill skipper (Scaven and Rafferty 2013, pp. 421–422; Takkis et al. 2015, entire; McCombs et al. 2022, entire). Habitat heterogeneity can directly and indirectly influence fitness of all life stages.

Population-level needs

Resilient populations are able to withstand and recover from random environmental, genetic, and demographic events that may temporarily reduce overall population abundance or vital rates. Generally speaking, resilient populations are demographically, genetically, and physically healthy (Redford et al. 2011, entire):

- demographically healthy populations have high abundance and robust survival, reproductive, and growth rates
- genetically healthy populations have large effective population sizes (N_e), high genetic diversity, and gene flow between populations
- physically healthy populations have individuals with good body condition

We have little information available to determine the specific population-level needs of the bleached sandhill skipper, but we can apply basic population biology tenets. Bleached sandhill skipper populations, owing to their poikilothermic physiology, can experience swings in abundance year-to-year in response to variable environmental conditions. During favorable conditions, survival and reproductive rates are high and population abundance increases; conversely, when environmental conditions are unfavorable, survival and reproductive rates are low and population numbers decrease. Thus, to successfully recruit over time, populations must be capable of withstanding large swings in population sizes (N). Specifically, they need high abundance (N) and robust population growth rates. Large population size (N) minimizes the likelihood of adverse events (whether stochastic or deterministic) from affecting all individuals, i.e., buffers the population during bad years. Large populations also tend to have greater genetic diversity, thereby improving the fitness of its individuals. For the bleached sandhill skipper, large population size likely means abundances in the thousands (based on past survey counts, see Section 3.1). Population growth rate determines the ability of the population to recover from adverse events. In general, average annual growth rates of at least 1.0 are needed for a population to persist, but, for species sensitive to environmental conditions, higher growth rates are needed to overcome large declines that may occur in years of poor conditions. Given bleached sandhill skippers sensitivity to environmental conditions, its populations require strong growth potential (population growth rates, $\lambda > 1.0$).

Population abundance and population growth rates are limited by the quantity and quality of the habitat and by connectivity among habitat patches. Bleached sandhill skipper populations require high quality and quantity of habitat patches of saltgrass and rabbitbrushes that are embedded in a vegetation matrix with few or minor barriers to dispersal. Additionally, habitat heterogeneity is likely beneficial to bleached sandhill skipper populations as it creates a diversity of microclimates thereby providing available suitable microclimate conditions during favorable and unfavorable conditions within and across years. Thus, habitat heterogeneity can provide microclimatic refugia during adverse years**.** For example, the warmest and driest parts of a habitat patch may provide optimal microclimate conditions in cooler years while being inhospitable during warmer or drier than normal years. It is generally believed that risk of population extirpation decreases with increasing within-population habitat heterogeneity (Hanski 1997, p. 90; Bladon et al. 2020, p. 2442).

In summary, population health—ability to successfully recruit over time—requires robust demography (large N and strong λ) and genetic health (large effective N and gene flow), as well as sufficient good quality habitat (i.e., abundance of high-quality hostplants and nectar resources embedded within a well-connected, heterogeneous phreatophyte community with a diversity of microclimates) to support a healthy demography (Table 2.1).

Subspecies-level needs

The ecological requisites at the subspecies level include having a sufficient number and distribution of healthy populations to ensure it can withstand environmental, demographic, and genetic stochasticity (resiliency), catastrophic events (redundancy), and novel biological and physical changes in its environment (representation). We describe bleached sandhill skipper requirements for resiliency, redundancy, and representation below, and summarize the key aspects in Table 2.1.

Resiliency

Resiliency is fostered by having healthy populations across spatially heterogeneous conditions. Healthy populations (robust abundances, population growth rates, quality habitat) are better able to withstand and recover from environmental variability and stochastic perturbations than those populations that are less demographically or genetically healthy. Additionally, resiliency is promoted by maintaining among-site habitat heterogeneity (i.e., differences in climate, slopes, aspects, topography, and plant community among its populations), as it helps guard against regional environmental stochasticity-induced population synchrony by ensuring that all populations do not experience poor years (e.g., hot, dry years) concurrently and to the same degree (Thomas and Hanski 1997, p. 385). Lastly, resiliency depends on maintaining connectivity between populations and also with potentially suitable yet unoccupied areas. Connectivity can foster population-level genetic diversity (heterozygosity) via gene flow (even at low levels), provide demographic rescue following population decline or extirpation, and facilitate dispersal and colonization of new areas.

Bleached sandhill skipper, however, is a narrow endemic with seemingly little among-site heterogeneity and limited gene flow (Jahner 2023, pp. 3–4, 9–10). Thus, its resiliency depends upon maintaining high population abundances and large effective population sizes to withstand environmental, demographic, and genetic stochasticity, as well as sufficient quantity of good quality habitat with diverse microclimates to support healthy demographics (high abundance and robust growth rates).

Redundancy

Redundancy, the ability to withstand catastrophic events, is best achieved by maintaining multiple, healthy populations across a broad and heterogeneous area. Maintaining multiple populations is critical to the subspecies' survival as extirpation of a population would significantly lower redundancy, greatly increasing its risk of extinction to both catastrophic and non-catastrophic events. Maintaining high population abundance reduces the likelihood of all individuals being exposed to the same catastrophic events, thereby affording protection against population extirpation. As a narrow endemic with little among-site heterogeneity, bleached sandhill skipper redundancy is completely dependent on maintaining (restoring) robust population sizes at its three known populations, as well as preserving (restoring) connectivity between populations.

Representation

Representation, the ability to withstand novel changes in abiotic and biotic conditions, is influenced by two interacting processes: dispersal and alteration of its traits. Dispersal allows motile species to shift to areas containing suitable habitat, while alteration of traits enables species to respond to novel conditions via plasticity or natural selection (i.e., evolutionary adaptation) (Thurman et al. 2020, entire).

Aspects of the bleached sandhill skipper life history both facilitate and constrain its ability to withstand novel changes. Bleached sandhill skippers have a short generation time, which allows for rapid adaptation to changes. It is also a habitat specialist, is a diet specialist, and is univoltine with a strict phenology and inflexible upper thermal limits. Habitat and diet specialists, relative to generalists, are less likely to locate suitable habitat conditions and are typically poor dispersers, further constraining their ability to track suitable habitat conditions (Hill et al. 2021, p. 2118). Being univoltine, as opposed to multivoltine, limits population growth potential and thus slows response time to change. Having an inflexible lifecycle (strict timing of the life stages) constrains its tolerance for changes in phenology (e.g., must reach the pupal stage prior to the onset of cold weather). Similarly, inflexible upper thermal limits constrain its ability to tolerate when temperatures go beyond those limits. In addition to these constraining life history traits, bleached sandhill skippers occupy areas with little among-site climate and habitat heterogeneity, which constrains natural selection via fewer heterogeneous selective forces acting on the populations. This in turn limits the number of unique local adaptations thereby minimizing options for evolutionary response to changes in their environment. Thus, as a specialist species with limited dispersal ability, the bleached sandhill skipper is unlikely shift its range large distances in response to changing environmental conditions. Instead, its ability to withstand changing conditions requires an in-situ response. Given the constraints imposed by its life history (e.g., tight phenology, upper thermal limits), the bleached sandhill skipper's viability in the face of changing conditions primarily rests with preserving among and within population genetic diversity, which requires maintaining large effective population sizes (to avoid loss of genetic diversity due to genetic drift and inbreeding), preserving (restoring) connectivity between populations (to foster gene flow and movement of potentially adaptive alleles), and preserving habitat heterogeneity (to facilitate natural selection)(Forester et al. 2022, pp. 508–509).

Table 2.1. The ecological requisites for bleached sandhill skipper viability

Level	Requirement	Why it is needed	Associated 3Rs
Individual	Habitat (all stages): salt desert scrub, alkali meadow	Matrix of healthy saltgrass and rabbitbrushes and associated vegetation community at appropriate cover and successional stages	Resiliency
	Food (larval & adult): saltgrass and rabbitbrushes	Diet specialists: rabbitbrushes are the primary nectar source for adults; saltgrass is presumed to be the sole hostplant and larval foodplant	Resiliency
	Microclimate (all): temperature and moisture	Owing to poikilothermy, all stages require specific thermal and moisture conditions to ensure proper growth rates and timing	Resiliency
Population	Habitat: abundant density of saltgrass and rabbitbrushes and high plant species diversity	Support 1000s of individuals and promote habitat heterogeneity thereby supporting microclimate diversity so populations can withstand and rebound from random environmental, genetic and demographic events.	Resiliency Redundancy
	High levels of fecundity (number of eggs)	Maintain population size; allows for maintenance of genetic diversity and improves efficacy of natural selection	Resiliency Representation
	High survival rates	Maintain population size	Resiliency Representation
	High population size, N and effective population size, Ne	1000s of adults to withstand and recover from unfavorable years, sufficient density of conspecifics to find mates, and to avoid deleterious effects from genetic drift and inbreeding depression; improves efficacy of natural selection	Resiliency Representation
	High annual population growth rate, λ	Long-term λ greater than 1 to recover from adverse environmental conditions	Resiliency
Subspecies	Habitat heterogeneity	Guard against synchronous population dynamics across populations due to regional environmental stochasticity; facilitate adaptation via natural selection	Resiliency Representation
	Multiple large populations	Fosters ability to sustain populations given natural variability and catastrophic events	Resiliency Redundancy

Level	Requirement	Why it is needed	Associated 3Rs
	Genetic diversity	Maintains ability to adapt to environmental changes; minimizes fitness impacts of inbreeding	Resiliency Representation
	Connectivity	Fosters genetic diversity via introducing new alleles and guarding against genetic drift	Resiliency Representation

2.6 Summary of Ecological Needs

The bleached sandhill skipper is a small-sized, narrow endemic butterfly found in Humboldt County, Nevada. It occupies alkali meadows in three likely isolated populations: Pueblo Slough, Gridley Lake, and Rincon Creek. Bleached sandhill skippers require available and nutritious food plants, including rabbitbrushes and saltgrass, to reproduce and survive. Rabbitbrushes are the primary nectar (food) sources for adults; the availability of non-senescing plants during late summer through fall is essential for success adult reproduction and survival. Saltgrass is the presumed sole larval hostplant, providing food and shelter for larval (caterpillar) and pupal stages, and thus, the availability of nutritious saltgrass plants throughout the fall is essential for larvae growth, development, and survival. Additionally, all life stages–egg, larvae, pupae, and adult– require suitable microclimate, i.e., temperatures and moisture levels. Bleached sandhill skippers are poikilothermic, meaning that their body temperature—and consequently, critical physiological functions and behaviors—is controlled by ambient temperature. Although the optimal range of temperature is unknown, substantial fitness (reproduction and survival) consequences are likely triggered when temperatures exceed 35 - 41 C (95 - 105 F) (Table A1).

Bleached sandhill skipper populations, owing to their poikilothermic physiology, can experience large swings in abundance year-to-year in response to environmental conditions. Thus, to successfully recruit over time, populations need large population sizes (likely 1,000s) and robust population growth rates ($\lambda > 1.0$). Populations also require large effective population sizes and gene flow to maintain genetic health and evolutionary potential. Bleached sandhill skipper populations also require high quality and quantity of habitat to support a robust demography. The amount of habitat required is unknown, but we know that suitable habitat means non-senescing patches of saltgrass and rabbitbrushes embedded within a healthy alkali meadow vegetation community with few dispersal barriers.

The subspecies' viability ultimately depends on its ability to withstand environmental, demographic, and genetic stochasticity (resiliency), catastrophic events (redundancy), and novel biotic and abiotic changes in its environment (representation). Bleached sandhill skipper resiliency is facilitated by maintaining healthy populations across spatially heterogenous conditions. As a narrow endemic with little among-site heterogeneity, its redundancy is completely dependent on maintaining high abundances in each of the three known populations, as well as preserving potential connections between populations. As a habitat and diet specialist, with inflexible upper thermal limits and a strict phenology, its adaptive capacity (representation) primarily rests with preserving the amount of among and within population genetic diversity, meaning having large effective population sizes (to minimize the impacts of genetic drift and inbreeding) and preserving gene flow to allow for movement of potentially adaptive alleles.

CHAPTER 3 – HISTORICAL AND CURRENT CONDITION

In this chapter, we describe the historical and current demographic (abundance and trend) and habitat conditions at the three known bleached sandhill skipper populations. The historical (defined here as <2010) period provides the baseline condition from which we evaluate changes in bleached sandhill skipper viability over time, while the current (2010–2020) period is the starting point for analyzing the future viability of bleached sandhill skipper.

3.1. Historical to Current Abundance and Trends

Prior to 2010, anecdotal information suggests that "thousands" of bleached sandhill skippers occupied Pueblo Slough, but that a population decline was observed (estimated 2007-2008) (WildEarth Guardians 2010, p. 15). We were unable to find further supporting evidence. We have no other historical abundance data for Pueblo Slough, Gridley Lake, or Rincon Creek populations.

Since 2010, periodic standardized surveys (visual encounter techniques resulting in numbers of individuals counted) have been conducted at Pueblo Slough (Service and BLM 2014, entire; Service and BLM 2022, entire)[2]; count data are available for six out of the last ten years. The population counts were in the 1000s through 2019 but since 2021 counts have been in the low hundreds (Figure 3.1). Generally, at least 10 years of survey data is needed to confidently discern population trend (Didham et al. 2020, p. 109), the steep and mostly consistent (little inter-annual variability) decline in counts suggest that the Pueblo Slough population is declining; meaning that despite interannual variability, a dominating, underlying deterministic decline is in process.

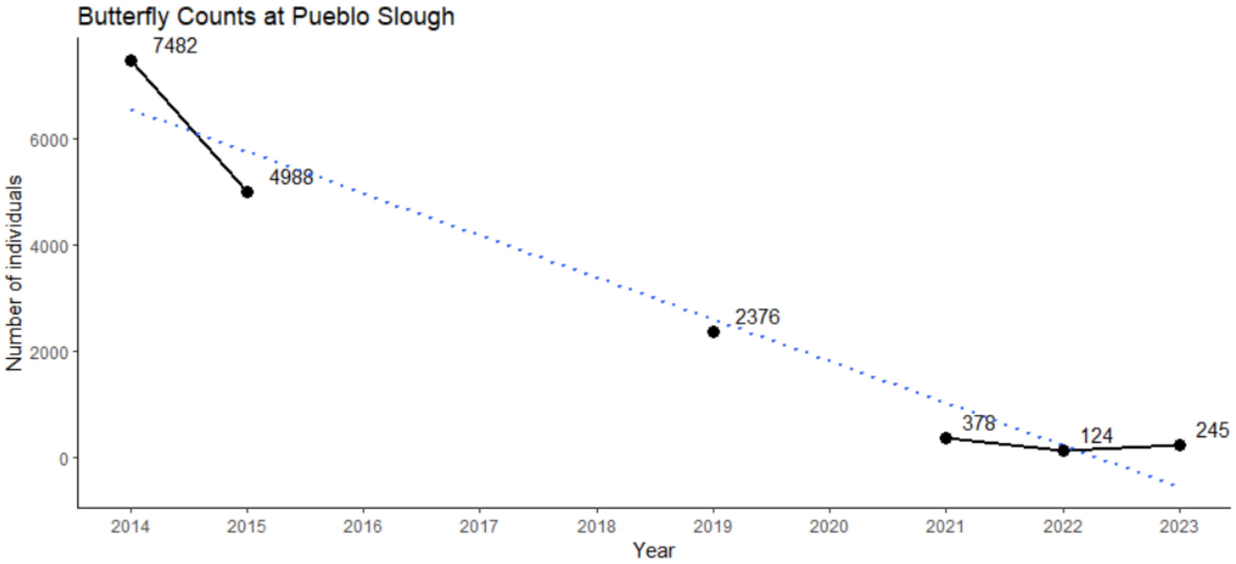

Figure 3.1. Number of individuals counted during standardized transect surveys at Pueblo Slough (Stantec 2015, Table 6, p. 14; Stantec 2016, Table 2, p. 9; Stantec 2020, Table 4, p. 10; Arid West

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[2] We reviewed survey protocols and field notes to assess level of effort between survey years and found survey effort was greater in recent surveys based on a longer daily survey window.

2022, Table 7, p. 10; 2023, Table 7, p.11; Stantec 2023, p.2). Trend line: linear model in R using Tidyverse, ggplot2, and Viridis packages.

At Gridley Lake, standardized surveys were conducted in 2023 with a total of 313 bleached sandhill skippers counted (Stantec 2023, p. 2). At Rincon Creek, standardized surveys were conducted in 2015, with a total of 78 individuals were counted (Stantec 2016, p. 16) and the number observed per mile ranged from <1–12 butterflies. With single data points for both Gridley Lake and Rincon Creek populations, we cannot estimate the population abundance nor population trend. The available data, however, suggest that Gridley Lake population abundance is similar to Pueblo Slough, and Rincon Creek may be smaller than the other two, based on the concurrent surveys completed at Pueblo Slough (Stantec 2016, p.7–8; Stantec 2023, p.2). We have no further abundance data for these populations.

3.2. Historical to Current Habitat Conditions

Bleached sandhill skipper population health (abundance and population growth rate) depends upon the quantity of good habitat, i.e., the abundance of high-quality hostplants and nectar resources embedded within a well-connected, heterogeneous phreatophyte community with a diversity of microclimates. To assess the habitat conditions for the three populations, we evaluated the vegetation matrix, the quantity and quality of saltgrass and rabbitbrushes, and the microclimate suitability.

Vegetation matrix

To assess the health of the vegetation matrix we evaluated two different metrics: extent of phreatophyte area and late summer normalized vegetation difference index[3] (NVDI).

We assessed the change in the extent of phreatophyte area in the groundwater basins within which populations are found: Pueblo Slough and Rincon Creek populations are found within Continental Lake Valley groundwater basin, and Gridley Lake population is found within Gridley Lake Valley groundwater basin (See Figure 2.1 for groundwater basins). We found 32% decline in Continental Lake Valley and 9% increase in Gridley Lake Valley from 1963 (Sinclair 1963, p. 15) to 2019 (Table 3.1; Desert Research Institute (DRI) 2021, p. 13; Albano 2023, pers. comm.). However, it is unclear whether differences are due to differences in methods used in the two studies or a true change. The Sinclair analysis was a coarse analysis, while the contemporary analysis was more fine scale with modern data sources. In Continental Lake Valley, vegetation was historically described as predominantly greasewood—a facultative phreatophyte (i.e., a species that partially depends on groundwater), but now about 45% of vegetation is classified as Sparse Vegetation or Big Sagebrush Shrubland and Steppe, suggesting a vegetation community that is no longer dominantly composed of phreatophyte species (DRI 2021, p. 43). This finding suggests a reduce extent of phreatophyte vegetation in Continental Lake Valley today compared to historical conditions. Gridley Lake Valley indicates a slight increase in extent of phreatophyte vegetation; however, much of this change may be due to increased agricultural crops (Albano 2023, pers. comm.).

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[3] Normalized vegetation difference index measures the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs.). Values range from -1 to +1, with values near zero indicating bare soil and higher positive values of NDVI ranging from sparse vegetation (0.1–0.5) to dense green vegetation (0.6 and above). Generally, higher NDVI values means healthier vegetation.

Table 3.1. Acres of phreatophyte vegetation in 1963 (Sinclair 1963, p. 15) and 2019 (DRI 2021, p. 13; Albano 2023, pers comm.).

Groundwater Basin	Hectares (acres) 1963	Hectares (acres) 2019	Percent change
Continental Lake Valley	11,634 (28,750)	7,967 (19,686)	-32%
Gridley Lake Valley	1,659 (4,100)	1,811 (4,474)	+9%

We evaluated the trend in NVDI to assess the change in the health (vigor) of the vegetation matrix. At Pueblo Slough, NVDI values have declined across large portions, with significant declines in two areas, since the mid-1980s (DRI 2021, pp. 48–49). The magnitude and confidence in the decline varies across this area, but a pattern of declining vegetation health exists (Figure 3.2).

At Gridley Lake, NVDI values are generally declining (DRI 2021, p. 45), although in areas along the lake margins NVDI values are increasing. The change along the lake margins may be due to declining lake levels (CBD 2022, p. 27), as vegetation growth will occur in previously submerged areas. This pattern is consistent with a drying system. The magnitude and confidence in the decline varies across this area, but a pattern of declining vegetation health exists (Figure 3.2).

At Rincon Creek, NVDI values are stable to slightly increasing in three small areas but are declining across the larger extent of Rincon Creek (north and upgradient of the population). The magnitude and confidence in this decline varies across this area, but a pattern of declining vegetation health exists, with declines clearer in the northern extent of this population (Figure 3.2).

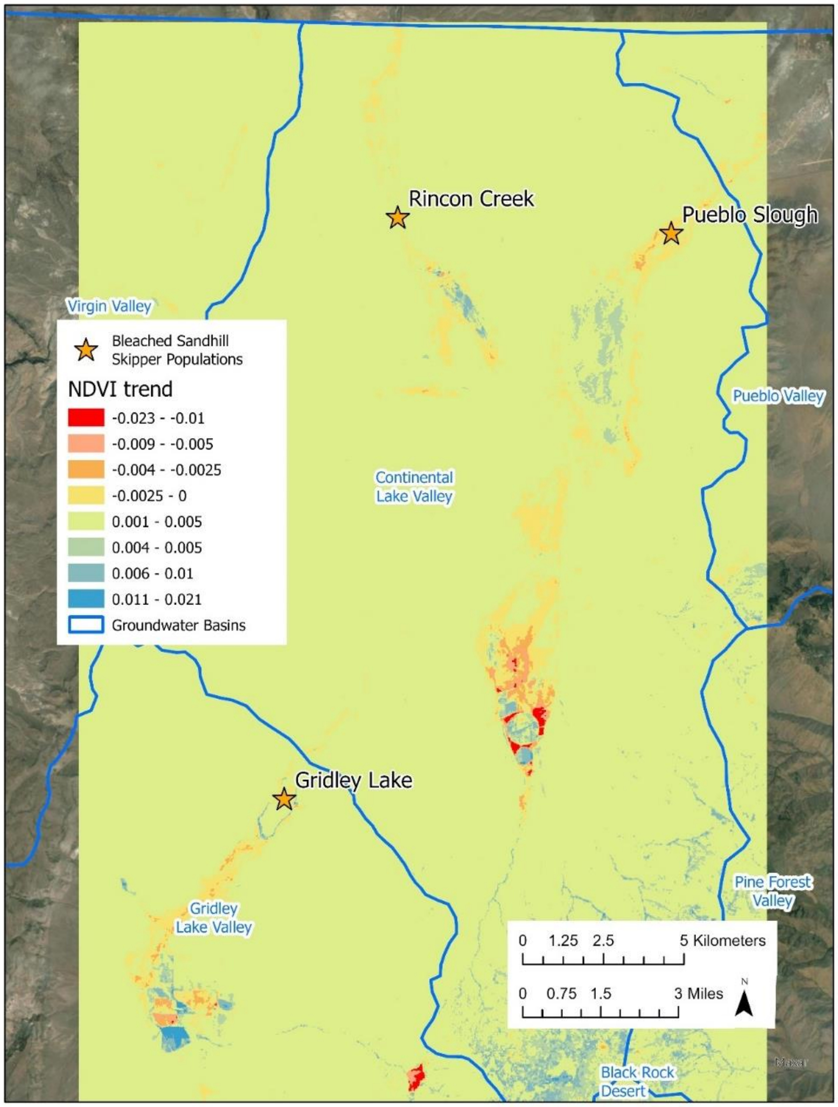

Figure 3.2. NVDI trend for the 3 known bleached sandhill skipper locations (DRI 2021, p.45). Negative trend (red to yellow) indicates decreased health, and likely drying, of the system. Positive trend (green to blue) indicates increased health and likely increased wetness of the system.

Hostplant and larval foodplant: saltgrass

There are no data pertaining to the quality and quantity of saltgrass at Pueblo Slough prior to 2021. Currently, saltgrass occupies 227 ha (560 ac). Of that, 186 ha (460 ac) was described as "carpeted with minimal bare ground" (Arid West 2022, pp. 11–12). In the remaining 41 ha (100 ac) saltgrass is scattered with mostly bare ground interspersed between grass clusters. The quality (indicated by the height and proportion of seed heads) of the saltgrass varies among years in response to grazing intensity (see Chapter 4 Grazing), and as such, we do not have sufficient information to assess whether the extent or quality of saltgrass at Pueblo Slough has changed over time. The depth-to-groundwater is unknown at Pueblo Slough, but evidence suggest that groundwater levels are declining (see Chapter 4, Groundwater pumping). An increase in depth-to-groundwater may affect the overall moisture and soil suitability for saltgrass thereby reducing its abundance.

At Gridley Lake and Rincon Creek, we have no data on saltgrass, other than general presence. However, similar to Pueblo Slough, well and NDVI data suggest groundwater levels are declining, thus we expect saltgrass abundance to also be declining (see Chapter 4 Groundwater pumping).

Nectar sources: rabbitbrushes

At Pueblo Slough, in 2014 white rabbitbrush communities were estimated at 34 ha (85 ac) (Stantec 2015, pp. 11–12). In 2021, white rabbitbrush communities were estimated at 57 ha (141 ac) with 95% of this area noted as low density white rabbitbrush (Arid West 2022, p. 11). In 2014, yellow/rubber rabbitbrush cover was not estimated. In 2021, yellow/rubber rabbitbrushes was estimated at 21 ha (53 ac), with 72% of this area noted as low density (Arid West 2022, p. 11). No significant changes in rabbitbrush extent were noted in 2022 (Arid West 2023, p. 13). Due to the difference in estimate approaches in 2014 to 2021, we cannot assess changes. Overall, despite regional declines the phreatophyte community signaling potentially deteriorating conditions, we do not have sufficient evidence to make reliable conclusions about the condition of rabbitbrushes at Pueblo Slough.

We lack data for condition of rabbitbrushes at Gridley Lake and Rincon Creek. Rincon Creek currently does not have white-flowered rabbitbrush or rubber rabbitbrush (Stantec 2016, p. 14), but it is unknown whether that was always the case. Based on this information, we do not have sufficient information to assess whether the extent or quality of rabbitbrushes has changed over time.

Microclimate suitability and habitat heterogeneity

Within-site habitat heterogeneity exists at all three population sites. For example, at all sites, perennial springs provide consistent sources of water, which may provide microclimate refugia in dry years. At Pueblo Slough, and possibly Gridley Lake, nectar plants include white, yellow, and rubber rabbitbrushes, providing a diversity of nectar sources. This diversity likely ensures available nectar sources among years, as timing, density, and quality of a species vary with yearly environmental conditions (i.e., conditions favoring species differently). A diversity of nectar sources may also extend the within-season duration of nectar availability. At Rincon Creek and Gridley Lake, there is minor topographic relief, thereby providing some diversity of microclimates, and thus refugia, during unfavorable conditions within and among years. There is little among-site heterogeneity.

However, microclimate suitability is likely declining across bleached sandhill skipper range owing to warming and drying conditions. Average annual temperatures have increased almost 1 C (2 F) over the last century (Garfin 2014, p. 464), and every part of the southwestern U.S. experienced higher average temperatures between 2000 and 2020 than the long-term average (1895–2020) (EPA 2023, p.3). Moreover, our analysis of trends in temperatures and moisture levels in Humboldt County, indicates increasingly warmer and drier conditions, and increasing trend in the number of extreme heat events, at the three populations (Chapter 4). Given the extent of warming and drying that has occurred, it is unlikely that the mediating effects conferred by within-site habitat heterogeneity are sufficient to compensate for the magnitude of warming and drying that has occurred, and thus, microclimate suitability is likely declining at all three sites.

3.3 Summary of historical and current conditions

At Pueblo Slough, only anecdotal population data is available prior to 2014. Butterfly counts have steeply declined (97%) since standardized surveys began in 2014, with counts in the low 100s since 2021. Although the count data do not provide an abundance estimate, the decline from 1000s of butterflies to 100s butterflies suggests that the population size is now much smaller than it had been prior to 2014. These data also suggest a declining population trend. Data are too limited to assess whether the extent and health of saltgrass and rabbitbrushes have changed over time. Saltgrass extent is currently 227 ha (560 ac), within which it is dominant vegetation in the majority of this area; the extent of rabbitbrushes is much smaller (78 ha) (193 ac), within which is it found in low density in the majority (>72%) of this area. Notably, data suggest that the extent and health of the vegetation matrix, the community in which these essential resources are embedded, appear to be declining across the region, although the magnitude of the declines cannot be reliably determined. Given the magnitude of warming and drying conditions over the last 20 years, microclimate suitability of Pueblo Slough has likely declined.

At Gridley Lake, the current butterfly count is in the low 100s; no data are available to discern population trend. Declining NDVI values suggest that the health of the phreatophyte community has declined, although we cannot reliably estimate the magnitude of change in either the health or extent of the phreatophyte community. Similarly, we have no information on the extent and quality of saltgrass and rabbitbrushes. Given the magnitude of warming and drying conditions over the last 20 years, microclimate suitability has likely declined.

At Rincon Creek, the only population data are from 2015, at which point the total count was 78 butterflies; based on the 2015 counts at Pueblo Slough, Rincon Creek population is likely smaller. No data are available to discern population trend. NDVI data suggest that the health of the phreatophyte community is stable or slightly increasing in some areas around perennial springs and declining in areas away from the springs. Specifically at the warm and cold springs, vegetation condition may have increased slightly due to reduction in grazing (See Rincon Creek in Section 4.1). Information is too limited to reliably estimate the magnitude of change in either the health or extent of the phreatophyte community. We have no information on the extent and quality of saltgrass and rabbitbrushes. Given the magnitude of warming and drying conditions over the last 20 years, microclimate suitability has likely declined at Rincon Creek.

CHAPTER 4 – PAST AND CURRENT ASSESSMENT OF PRIMARY INFLUENCES

In this Chapter, we describe the primary influences of bleached sandhill skipper's population health (abundance, trend, and habitat conditions) from the past to the present: grazing, groundwater pumping, and climate change. These four influences have the opportunity to negatively impact the subspecies and its habitat and therefore are collectively called threats. We describe how each may influence bleached sandhill skipper directly or indirectly through its habitat. We are not aware of conservation actions benefitting the species; however, we discuss the impact of existing regulatory mechanisms.

4.1 Livestock Grazing

The BLM manages the vast majority of lands at Pueblo Slough and Gridley Lake and livestock grazing is permitted in both areas by the BLM. Rincon Creek is mostly within the Sheldon National Wildlife Refuge and grazing is not permitted within the Refuge. We recognize that different grazing intensities and management practices can affect areas differently, and as such the effects at each site must be evaluated independently based on site characteristics and grazing management practices. Livestock grazing may negatively impact the bleached sandhill skipper through changes in the vegetation matrix and consumption of plants, ground compaction, increased spread of invasive grasses, reduction of nectar plants (food) and saltgrass abundance (hostplant), and consumption or trampling of all life stages (Fleischner 1994, p. 631; Belsky et al. 1999, pp. 8-11; Filazzola et al. 2020, p. 1304).

Wildhorses and burros are managed within the McGee Mountain Herd Management Area, which is located approximately 1.3 km (0.8 miles) from Gridley Lake population and 8.0 km (5.0 miles) from Rincon Creek population. While we found records of burros and horses in or near these populations (BLM 2014, p. 1, Ludwig 2023, pers. comm.), we do not have sufficient information to further analyze excessive use by horse and burros as a potential threat.

Heavy grazing is considered incompatible with the conservation of some butterflies (Sanford 2006, p. 401; Selby 2007, pp. 3, 29, 33, 35), and any grazing in arid habitats may reduce insect abundance (Debano 2006, pp. 2554–2555; Bussan 2022, p. 368). However, rotational grazing or light grazing, can be beneficial to butterflies (Bussan 2022, pp. 364–366, 368). Rotational grazing includes moving cows around to give the plant community more time to recover between grazing periods, and includes a seasonal rest period, where cows are kept off the pasture when either plants or butterflies are particularly more vulnerable to grazing (Swanson 2015, p. 10; Bussan 2022, p. 360). Alkaline meadows are susceptible to grazing stress and it is recommended to have deferred grazing or rest at least one out of every three years (Natural Resources Conservation Service 2023, pp. 3, 6).

Grazing can directly affect bleached sandhill skipper's nectar plants and hostplants through consumption. Cows do not preferentially eat rabbitbrush and saltgrass, but rabbitbrush and saltgrass are some of the dominant browse available at the three populations, and cows will eat what is available even if not preferred, especially when this remains the greenest forage in the pasture. Loss of nectar plants and hostplants can reduce the overall quality and quantity of available habitat. These plant resources need adequate recovery time from grazing for regrowth to ensure those resources are adequate during the adult flight period, when adults lay eggs, and during the caterpillar stage.

Grazing at the end of the adult flight period, and in the weeks following, may result in caterpillars getting trampled or consumed by cows because caterpillars are feeding on saltgrass at this time. Grazing during the pupa stage (overwintering) may also result in trampling. However, pupae are in silk nests at the base of plants, which may provide some protection to trampling if it is cushioned by the surrounding plant material. Grazing during the pupal overwintering stage likely has the least impact because trampling is the only concern during this life stage (Service 2014, p. 2). These potential effects are likely commensurate to a point, when the vegetation and bleached sandhill skipper populations are healthy but may become additive when populations experience additional environmental or demographic stresses.

Pueblo Slough

Pueblo Slough population is located within an active grazing allotment (Pueblo Mountain Allotment) administered by the BLM. The Pueblo Mountain Allotment (NV00046) was authorized in 2015, with a 10-year term that expires in 2025 (BLM 2015a, entire). The allotment is split into seven pastures with the Pueblo Slough population located in the Continental Pasture. Grazing in the Continental Pasture is currently authorized for 258 cows from July 16 to August 15 or October 1 to October 31 each year (BLM 2015a, p. 10). Grazing management for this pasture has generally been permitted under this prescription since 2015 (BLM 2015a, entire).

The grazing windows from 2015 to 2023 were as follows:

2015 = July 16 – August 15
2016 to 2018 = Oct 1 – October 31
2019 = July 16 – August 15
2020 = voluntary nonuse
2021 to 2023 = July 16 – August 15

From 1999 to 2014, the Continental Pasture was authorized for 258 cows from August 1 to August 31, on a three-year rotation with cattle grazing occurring two out of every three years, allowing one year for rest (BLM 2015b, p. 7). The BLM noted that the change from this grazing schedule that included a year of rest, to grazing every year, would result in an increase in grazing pressure on the system (BLM 2015b, pp. 51, 60, 71). In 2012, the pasture was not heavily grazed, and the habitat looked to be in good condition (Lawson 2012, pers. comm.). Additional data in 2013 and 2015 did not note utilization objectives being exceeded (BLM 2013a, entire; BLM 2015c, entire). Utilization objectives are the measure of forage consumed by livestock; which, if exceeded, may result in damage to the vegetation. In 2022, the overall condition of the saltgrass meadow was observed to have fewer grazing impacts than the prior year (Arid West 2022, p. 17), with taller saltgrass plants and abundant seedheads on grasses (Arid West 2022, p. 17).

The grazing system from 1999 to 2014, implemented a rest year every three years to allow the vegetation system time to recover. However, grazing occurred during a sensitive window of just prior to and during early adult flight period, which allowed for consumption of nectar and hostplants, with limited window for hostplant regrowth. The grazing system in place since 2015 does not include designated rest years for the system to recover and allows for grazing during the sensitive periods (summer/fall). In addition, while this grazing system avoids the majority of the adult flight period, it still allows for impacts during nectar development, during a very limited window for hostplant regrowth, and consumption and trampling during caterpillar stage. Thus, we assess that the current grazing system is likely having minor adverse impacts on the population.

Gridley Lake

Gridley Lake population is located within an active grazing allotment (Alder Creek Allotment) administered by the BLM. The Alder Creek Allotment (NV00051) was authorized in 2015 with a 10-year term that expires in 2025 (BLM 2015d, entire). The allotment is split into eight pastures with the Gridley Lake population located in the Gridley Lake Pasture. Grazing in the Gridley Lake Pasture is currently authorized for 349 cattle from April 15 to June 15 in odd years and for 308 cattle from November 1 to February 28 in even years (BLM 1994, p.9). Grazing management for this pasture has generally been permitted under this prescription since 1987 (BLM 1994, p. 4; BLM 2015d, entire). The Final Multiple Use Decision for this allotment in 1994 indicated that utilization objectives were being met for this pasture at that time (BLM 1994, p. 10). In July 2014, Gridley Lake Pasture was evaluated for drought impacts, but none were observed at the time (BLM 2014, p. 2). Wild burros were observed on site, though no negative impacts were noted due to the burros (BLM 2014, p. 1).

This grazing system provides rest to the system by grazing in different seasons (spring and winter) every other year and occurs during the pupal overwintering stage. This grazing system allows for the nectar resources to develop and gives time for hostplants to regrow. And, since it is outside of the adult flight period, this grazing system is less likely to result in consumption or trampling during caterpillar stage. We conclude that grazing is not negatively impacting the population.

Rincon Creek

There have been no valid claims of livestock grazing rights or privileges on Sheldon National Wildlife Refuge since 1994 and feral horses were removed in 2014 (Service 2012, p. 4-3, Ludwig 2023, pers. comm.). However, unfenced portions of the Refuge may be subject to unauthorized horse, burro, or livestock grazing from adjacent BLM or private lands (Ludwig 2023, pers. comm.). The southern portion of Rincon Creek population is located south (outside) of the Refuge boundary fence, and may be accessible to unauthorized grazing. With exclusion of grazing within the Refuge and only a limited portion of the skipper population subject to possible unauthorized grazing, and no evidence of it occurring, we conclude that grazing is not negatively impacting the population.

4.2 Groundwater pumping

Bleached sandhill skippers are found across two different groundwater basins. The Pueblo Slough and Rincon Creek populations are found within Continental Lake Valley groundwater basin and the Gridley Lake population is found within Gridley Lake Valley groundwater basin (Figure 2.1). Pumping of groundwater occurs in these basins for many uses, but the vast majority is for irrigation of agricultural crops (NDWR 2023a, p.1; NDWR 2023b, p.1).

In Nevada, groundwater rights set the amount of groundwater that can be withdrawn from a groundwater source and are allocated to users based on perennial yield. Perennial yield is defined as ‘‘the amount of usable water of a groundwater reservoir that can be withdrawn and consumed economically each year for an indefinite period of time … without causing depletion of the groundwater reservoir’’ (Nevada Division of Water Planning 1999, pp. 5–6). In other words, perennial yield is often set to be equal to or less than natural aquifer recharge. Groundwater extraction that exceeds aquifer recharge may result in surface or groundwater level decline, spring drying and degradation, or the loss of aquatic habitat (Zektser et al. 2005, pp. 396–397). Over appropriated groundwater basins are subject to groundwater drawdown and associated impacts to groundwater dependent ecosystems (Aldous & Gannett 2021, p. 10).

Simply comparing permitted groundwater or surface water rights to the perennial yield of a hydrographic area is inadequate to determine if a site or biotic entity will be impacted as additional factors influence vulnerability (Southern Nevada Water Authority (SNWA) 2011, p. 5). There needs to be hydraulic connectivity between groundwater pumping and the site. If there is no hydraulic connectivity, a site will not be impacted. A site may only be lightly impacted if the distance to pumping is great or if low transmissivity lithologies separate the site from the area of pumping. Hydraulic connectivity is influenced by hydrogeologic conditions (groundwater flow systems, groundwater flow paths, flow direction, flow barriers, etc.) (SNWA 2011, p. 5). The manner and purpose of the water right use can also influence potential impacts from groundwater or surface withdrawal (SNWA 2011, p. 6). A permit for agricultural use will not consume the entire amount since a portion is returned to the groundwater system through irrigation itself or through the inefficiency of the conveyance system (SNWA 2011, p. 6).

In addition to above, it should also be noted that evapotranspiration of phreatophytic communities (and evaporation of playas) is often used to establish perennial yield; thus groundwater use at a rate equal to the perennial yield may result in degradation of these communities over time (Bredehoeft 2002, p.343; TNC 2022a, p. 7). The severity of the effect increases with increasing proximity of the wells pumping to the phreatophytic communities (Bredehoeft 2002, pp. 344–345). For the two groundwater basins discussed below, perennial yield was determined based on evapotranspiration rates of phreatophytic communities and with the objective of “salvaging natural discharge” by withdrawing water to “below the root zone of the low value phreatophytes, which consume most of the natural discharge” (Sinclair 1963, pp. 15–16). Thus, this limitation applies to our discussion below. Similarly, groundwater pumping that causes a decline in aquifer levels can result in groundwater dependent ecosystems drying out, even if a large volume of groundwater is still stored in the aquifer (Parker et al. 2020, p. 312).

Saltgrass and rabbitbrush, because of their shallow root systems, can survive seasonal groundwater fluctuations better than some wetland species but can be harmed by long-term declining or fluctuating water tables (Greonveld 1994, entire; Manning 1999, entire; Elmore et al. 2006, pp. 775–776; Patten et al. 2008, p. 8). A long-term decline in groundwater supply may shift the vegetative community from ground water dependent plants to more upland species that rely on precipitation rather than groundwater (Patten et al. 2008, p. 10) or to successional dead-ends where further disturbance results in bare soils dominated by non-native species (Manning 1999, p. 236).

It should be noted that we consider these population locations to be groundwater dependent ecosystems, supported by shallow groundwater. However, meteoric water (precipitation) and perennial springs also contribute water at all three populations. We do not have information to understand the relative contribution of each of these water sources to the systems and they are likely interrelated to a small or large degree (e.g. precipitation helps feed recharge to shallow groundwater).

Continental Lake Valley and Gridley Lake Valley Groundwater Basins

In this section we evaluate the perennial yield (the maximum amount of groundwater that can be withdrawn each year over the long term without depleting the groundwater reservoir) and pumpage (actual amount withdrawn) for the groundwater basins within which the three bleached sandhill skipper populations are found. We also report the appropriated water for basins (as a frame of reference and which will be important in the future projections chapter). We review groundwater level data available using significance analysis (TNC 2022b, entire), estimates of groundwater trend in phreatophyte communities (TNC 2022c, p.1), and discuss this information in concert with NDVI data also available (DRI 2021, entire) to assess past and current impacts to bleached sandhill skipper and its habitat.

It should be noted that the northern extent of Continental Lake Valley, Rincon Creek drainage area, is in Oregon. From a hydrological perspective, this area contributes to the basin, but from a regulatory perspective is not included in Nevada's oversight. It appears from Sinclair (1963, Plate 1) that the perennial yield estimate for Continental Lake Valley included the extent in Oregon.

Pueblo Slough

The Pueblo Slough population is found in the Continental Lake Valley groundwater basin. Hydrologic flow for this population would generally be from the southwest to the northeast. The perennial yield for this basin is 13,568,280 cubic meters (11000 acre-feet) (NDWR 2023a, p.1), 97% of the groundwater basin is appropriated (NDWR 2023a, p.1), and average pumpage for the last three years of data available is 22% of perennial yield (Figure 4.1) (NDWR 2013, Appendix A; 2017, p.32; 2021, p.32). As the current pumpage is below the perennial yield, groundwater pumping may not currently be a concern. However, water use and recharge patterns vary within a large basin (Bredehoeft 2002, pp. 344–345) and perennial yield may be overestimated in this basin (DRI 2021, p.12). See additional discussion below.

While we do not have depths-to-groundwater measurements within habitat at Pueblo Slough, we can look at well data available elsewhere in the basin. There are 12 wells within Continental Lake Valley groundwater basin with sufficient data to determine significant trend of depth-to-groundwater (TNC 2022b, p.1). Of those 12, five have a significant negative trend, meaning an increase in depth-to-groundwater, and seven had no significant trend. The five with significant trend are all to the southeast of Crain Creek within Alder Creek drainage, which are hydrologically upgradient from Pueblo Slough population (Figure 4.2) (the seven northwest of Crain Creek are described below in the Rincon Creek subsection). These five wells cover a range of time frames. One of those wells has data from 2006 to 2014 shows an average decrease of 0.52 m (1.72 ft) per year (total decrease of 4.68 m, 15.48 ft across that time frame); one well with data from 2014 to 2021 shows an average decrease of 0.28 m (0.92 ft) per year (total decrease of 2.24 m, 7.36 ft across that timeframe; two wells with data from 2015 to 2021 show an average decrease of 0.23-0.24 m (0.76-0.79 ft) per year (average total decrease of 1.65 m, 5.43 ft increase across that time frame); and the final well with data from 2006 to 2021 shows an average decrease of 0.67 m (2.19 ft) per year (total of 10.72 m (35.05 ft) decrease over that time frame) (TNC 2022b, p.1). These data indicate that depths-to-groundwater are increasing within the basin and are upgradient to Pueblo Slough, which therefore may affect groundwater depths at Pueblo Slough.

Complimenting these data, TNC modeled shallow groundwater trends in groundwater dependent ecosystems across the state. For the Pueblo Slough population, results showed an increasing depth-to-groundwater trend within portions of the slough. The random forest model is trained using predictor variables from satellite images and climate data and observed groundwater table depths. This estimator was completed at a state-scale and notes that areas such as groundwater dependent playas and lakes may have erroneous results. However, we include the results here as we find them to be consistent with other patterns in the data we reviewed but acknowledge this potential limitation (TNC 2022c, p.1; Byer 2023 pers. comm, entire; TNC 2023, p.2).

Additionally, looking at the NDVI data that were presented in Section 3.2 of this report, the analyses completed by DRI also analyzed the NDVI data adjusting for climate variability, which helps understand potential cause by adjusting for a common, primary driver in NDVI variability over time. The NDVI results in light of climate variability are discussed below in the climate section. At Pueblo Slough, the significant downward trend in NDVI across large portions of the slough remain when the data are adjusted for interannual climate variability (climate adjusted NDVI), indicating that annual weather patterns are not the driver. This suggests that the decline in NDVI is due to other factors such as changing hydrology or grazing impacts (DRI 2021, pp. 48–49; Arid West 2023, pp. 17–18).

Looking at patterns hydrologically upgradient from Pueblo Slough, the climate-adjusted NDVI data shows a decreasing trend in areas of Alder Creek, where the groundwater wells are showing a significant trend of increasing depth-to-groundwater. The trend is nearly continuous from Alder Creek to Pueblo Slough; areas of increase within Continental Lake are likely due to declining lake levels, which has allowed for vegetation growth where none could previously. In addition, the same pattern of decreasing trend is also found at Gridley Lake which is described below. While Gridley Lake is a separate groundwater basin due to a buried impermeable barrier, these groundwater basins are connected by surface flow when groundwater storage increases, as is generally the case in the spring of the year. As groundwater levels decline, connectivity is lost (Sinclair 1963, pp. 5–6). Therefore, these upgradient trends at Alder Creek and Gridley Lake are likely affecting the Pueblo Slough population habitat.

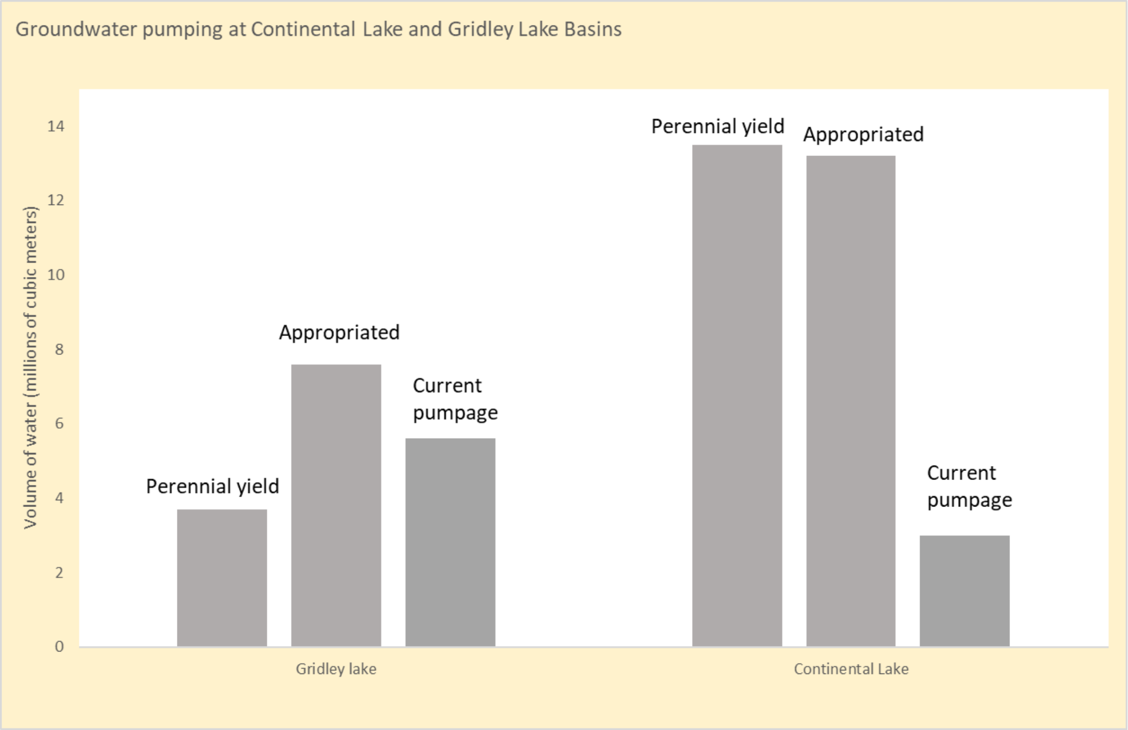

Figure 4.1. Comparing perennial yield, appropriated rights, and current pumpage within Gridley Lake Valley and Continental Lake groundwater basins.

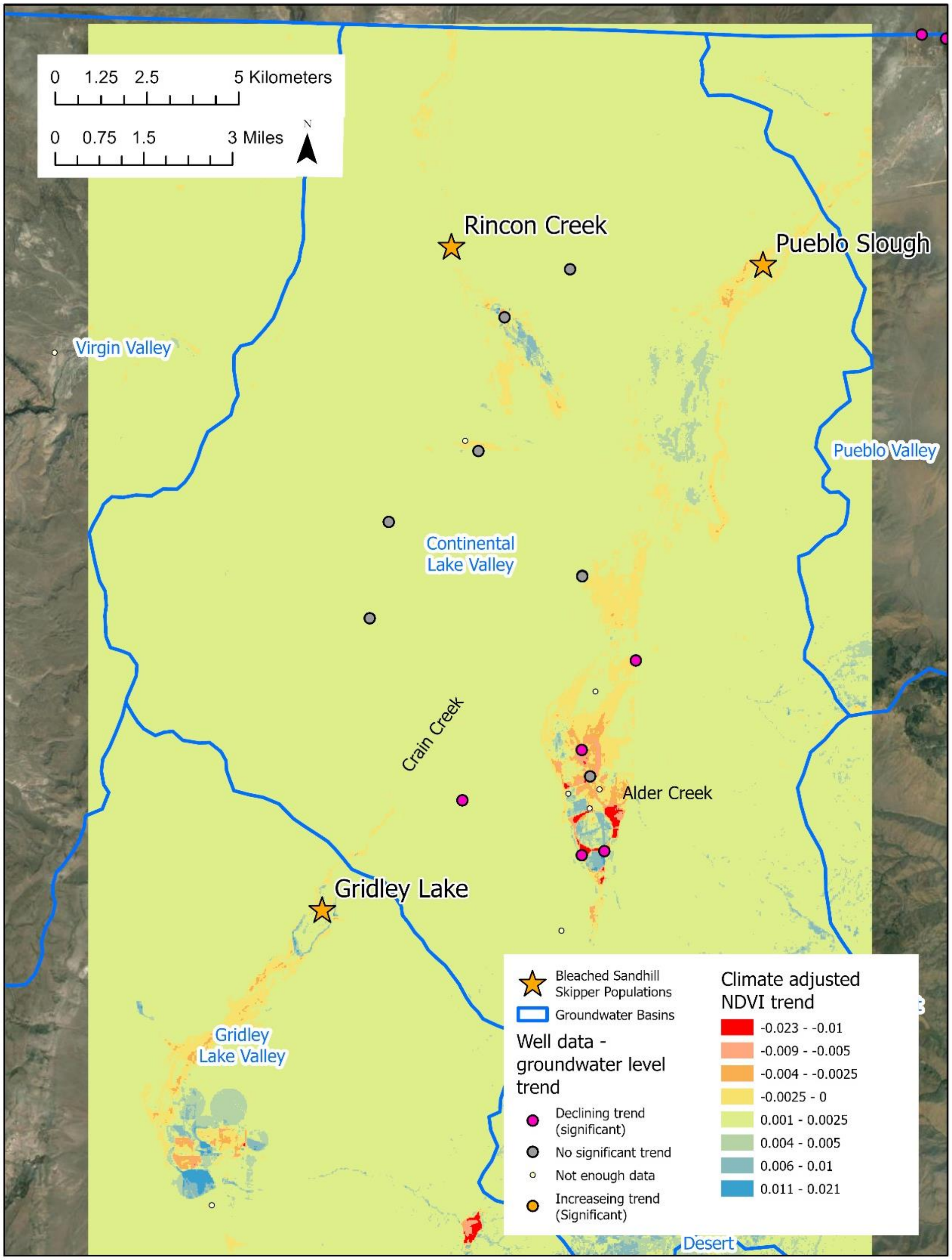

Figure 4.2. Climate adjusted NDVI trend (DRI 2021, p.45) and groundwater level trend from well data (TNC 2022, entire) for the 3 known bleached sandhill skipper locations. Negative trend (red to yellow) indicates decreased health, and likely drying, of the system. Positive trend (green to blue)indicates increased health and likely increased wetness of the system.

Gridley Lake

The Gridley Lake population is found in the Gridley Lake Valley groundwater basin. Hydrologic flow for this population would generally be from the southwest to the northeast. The perennial yield for this basin is 3,700,440 cubic meters (3,000 acre feet) (NDWR 2023b, p.1), 206% of the groundwater basin is appropriated (NDWR 2023b, p.1), and average pumpage for the last three years of data available is 150% of the perennial yield (Figure 4.1) (NDWR 2017, p.32; 2021, p.32; McGowan 2023, pers. comm.). Current pumpage is greater than perennial yield, suggesting impacts to shallow groundwater levels may be occurring in the basin. We do not have depth-to-groundwater measurements within habitat at Gridley Lake, and there are no wells within this basin with sufficient data to determine significant trend of depth-to-groundwater in this basin (TNC 2022b, p.1). However, the shallow groundwater estimates for groundwater dependent ecosystems show an increasing in depth-to-groundwater trend within portions of the population (TNC 2022c p.1). See Section 4.2, subsection Pueblo Slough, for a discussion of the limitations of these estimates.

Additionally, while DRI did not provide discussion on Gridley Lake Valley, their spatial analyses included this extent (DRI 2021, p. 45, Figure 4.2). Climate-adjusted NDVI values show that in areas which are hydrologically downgradient from agriculture fields, have a decrease in NDVI, although areas of agriculture fields and areas along the lake margins NDVI are increasing. The increase in NDVI along the lake margins may be due to declining lake levels, which has allowed for vegetation growth where none could previously. As discussed in Chapter 3, some of the declines are not statistically significant.

Rincon Creek

Rincon Creek population is also located in Continental Lake Valley. Hydrologic flow for this population would generally be from the north to the south. To reiterate what was described above, the perennial yield for this basin is 13,568,280 cubic meters (11,000 acre-feet) (NDWR 2023a, p.1), 97% of the groundwater basin is appropriated (NDWR 2023a, p.1), and average pumpage for the last three years of data available is 22% of perennial yield (Figure 4.1) (NDWR 2013, Appendix A; 2017 p.32; 2021, p.32). As the current use is below the perennial yield, groundwater pumping may not currently be a concern. However, water use and recharge patterns vary within a large basin (Bredehoeft 2002, pp. 344–345) and perennial yield may be overestimated in this basin (DRI 2021, p. 12). In addition, the northern end of Rincon Creek is located in Oregon, and the agricultural fields in that extent are not considered part of the Nevada Continental Lake Valley due to the state boundary. While, we believe the perennial yield estimate (Sinclair 1963, entire) included the area in Oregon, pumpage occurring there would be affecting the Nevada side of the groundwater basin as it is hydrologically upgradient. We were not able to find pumpage data for this extent in Oregon, but total pumpage for Continental Lake Valley is likely higher that what is represented by the Nevada-only data.

Similar to the other populations, there are no depth-to-groundwater measurements within habitat at or upgradient of Rincon Creek; however, we can look at data from the 12 wells within Continental Lake Valley groundwater, as we did for Pueblo Slough. Down gradient of the Rincon Creek population, northwest of Crain Creek, seven wells show no significant trend in changes in depth-to-groundwater (TNC 2022b, p1.). The five wells southeast of Crain Creek are discussed above under Pueblo Slough. There was no relevant well data available from Oregon. However, similar to Pueblo Slough, the shallow groundwater estimates for groundwater-dependent ecosystems show an increasing depth-to-groundwater trend across much of this population for the extent that was modeled (TNC 2022c, p.1). See limitation discussions in Section 4.2, subsection Pueblo Slough, on these estimates.

The climate-adjusted NDVI values are stable to slightly increasing, based on three evaluation areas, although there is high interannual variability, which suggest they are sensitive to climate variation. The trend was statistically significant at two of the three evaluation areas (springs), but no conclusions were given about underlying causes for the trend (DRI 2021, p. 52). These evaluation areas were tightly focused on the warm and cold springs. Notably, livestock grazing ended at Sheldon National Wildlife Refuge in 1994 and wild horses were removed in 2014 (Service 2012, p. 4-3, Ludwig 2023, pers. comm), which may have allowed for increased vegetation health at these springs. Outside the three evaluation areas, climate adjusted NDVI values are declining in the northern portion of Rincon Creek, but not in the southern end, and much of the decline is not statistically significant (Figure 4.2). This suggests that groundwater pumping associated with the agricultural fields in Oregon may be currently affecting the northern extent of this valley.

Synopsis of past and current groundwater pumping on bleached sandhill skipper

Based on the above information, groundwater pumping is likely having minor to moderate impacts on the vegetation matrix health–including the health of saltgrass and rabbitbrushes–at Pueblo Slough and Gridley Lake. Groundwater pumping is likely having no to minor impacts on the vegetation matrix health – including the health of saltgrass and rabbitbrushes – at Rincon Creek.

For Pueblo Slough, current pumpage is below perennial yield, but evidence suggests that perennial yield may not be the best indicator for this population. First, perennial yield may have been over estimated (DRI 2021, p. 12). Second, perennial yield was based on extent of phreatophytic community, thus, if pumpage equals the perennial yield, impacts to the community can occur (Sinclair 1963, p. 15, TNC 2022a, p. 7). Lastly, pumpage is not occurring equally across the basin, but rather, it is concentrated in one area (Alder Creek) (Bredehoeft 2002, pp. 344–345), which is upgradient of Pueblo Slough by approximately 8–9 miles (13–14 km). This coupled with increasing depth-to-groundwater trend (TNC 2022b; TNC 2022c) in Alder Creek drainage and Pueblo Slough, indicate that pumpage is likely greater than recharge. This comports with the NDVI data showing a decrease in vegetation health (DRI 2021, pp. 48–49). In addition, the likely connection between Gridley Lake Valley and Continental Lake Valley (Sinclair 1963, pp. 5–6) suggest that pumping in Gridley Lake Valley may be further exacerbating Pueblo Slough, as that pumping is hydrologically upgradient. Given the increasing depth-to-groundwater levels at several of the wells (0.23 to 0.67 m per year (0.75 ft to 2.2 ft) for several years) in the Alder Creek area, this would have major impacts on vegetation matrix, including saltgrass and possibly rabbitbrush. However, given that the pumping is located several miles away, but that is occurring in two location upgradient and the change in vegetation health is occurring, current groundwater pumping is likely minorly to moderately impacting habitat conditions at Pueblo Slough.

For Gridley Lake, we have information that pumpage, which is located 3.5 miles (5-8 km) upgradient, is exceeding perennial yield by 150%, therefore pumpage is likely affecting phreatophytic community, including bleached sandhill skipper habitat. This is further exacerbated because perennial yield was based on extent of phreatophytic community and pumpage is occurring immediately upgradient, suggesting that pumping at rates equal to perennial yield would not be protective of the habitat. While we do not have well data here, depth-to-groundwater data show a likely increase (TNC, 2022c) and the declining NDVI values indicate a decrease in vegetation health. Given that current pumpage is exceeding perennial yield and pumpage at perennial yield is unlikely to sustain suitable habitat, current groundwater pumping is likely having minor to moderate impacts on habitat conditions at Gridley Lake.

For Rincon Creek, the pumping that is occurring in Continental Lake Valley is hydrologically down gradient. The wells in closest proximity are also hydrologically down gradient and do not show a downward trend. However, there is agricultural pumping in the north end of Rincon Creek in Oregon (approximately 7-8 miles (11-13 km)), which is upgradient from this population. As well, the estimate for trend in depth-to-groundwater does show an increase. In addition, NDVI data show a decrease in vegetation health in the northern extent of Rincon Creek, which is hydrologically downgradient from agricultural fields. While this suggests the same pattern may be playing out at this population, the decrease in vegetation health pattern does not yet extend all the way south through the full extent of the population. We lack information on pumpage upgradient from this population. Thus, current groundwater pumping is likely having no effect to potentially minor effects on habitat conditions at Rincon Creek.

4.3 Climate Change

Findings from a rapidly amassing number of studies over the last decade across latitudes and longitudes around the world indicate high vulnerability of insects to the direct and indirect effects of changing temperature and moisture patterns (Harvey et al. 2023, p. 3; Halsch et al. 2021, p. 1), with butterflies being especially vulnerable (Radchuk et al. 2013, p. 275). These findings are not surprising given the small size and poikilothermic physiology of butterflies, meaning that their body temperature is controlled by abiotic environmental conditions, namely temperature (Jaworski and Hilszczanski, 2013, p. 346; Harvey et al. 2023, p. 3). Insect body temperature affects many critical biological processes influencing individual fitness, such as flight ability, reproductive behavior, fecundity, oviposition, feeding, development, and diapause (Palumbo 2011, entire; Gonzalez-Tokman 2020, p. 811). Similarly, moisture conditions are an important determinant of survival, especially in desert areas (Chown et al. 2011, p. 1071; Palumbo 2011, p. 1; Norhisham et al. 2013, p. 1). Moisture levels influence insect growth and behavior by affecting the insect's ability to regulate water loss. Thus, despite geographic and taxonomic differences in species response, climatic conditions are universally key determinants in insect fitness, including the bleached sandhill skipper (see Chapter 2). Consequently, changes—even small, gradual changes—in temperature and moisture patterns can substantially affect a population's viability (Harvey et al. 2023, p. 5, 20).

The level of impact of climate change on population fitness is influenced by both the magnitude and patterns of climate change as well as the thermal sensitivity of the species of concern (Kingsolver et al. 2011, p. 7). Here, we focus on the underlying causal mechanisms (pathways) and probable climate change impacts on bleached sandhill skipper given the past and current drying and warming trends locally, and more broadly in southwestern U.S.

Underlying mechanisms

Bleached sandhill skipper fitness is tightly controlled by the microclimate (temperature and moisture) experienced by individuals and the quality and quantity of habitat resources (nectar resources and hostplants), as discussed in Section 2.4. Changes in the microclimate conditions and the quality of their habitat, therefore, directly and indirectly influence critical processes such as adult flight ability and timing, reproductive behavior, fecundity, oviposition, feeding, development, and diapause (Palumbo 2011, entire; Caldas 2012, entire).

The underlying mechanisms—how changes in temperature and moisture influence butterfly fitness—of climate change are: (1) interacting (operate singly and in combination), (2) cascading (injuries accumulate over the annual lifecycle), and (3) complex (impact individuals directly and indirectly; the species response varies across seasons, life stages, and localities) (York and Oberhauser 2002, p. 295; Kingsolver et al. 2011, p. 9; Klockmann et al. 2017, p. 6; Harvey et al. 2023, p. 5). Figure 4.3 provides a simplified diagram of a subset of mechanisms underlying how climate change directly and indirectly influences butterfly reproduction and survival and Textbox 4.1 provides a summary of key relationships relevant to climate change and butterfly fitness.

Direct effects – The effects of warming temperatures and decreasing moisture vary across the annual cycle, and although having some beneficial influence, the overall impact is negative. The mechanism in which insects respond to changing thermal and moisture patterns involves interacting, complex physiological processes. We provide a brief explanation but see Gonzalez-Tokman et al. (2020, entire) for a fuller description. During the active season, warming temperatures tend to stimulate growth, development, and reproduction (via increase in the number of generations), but they also incur metabolic costs that increase disproportionately, leading to developmental failure, reduced fecundity, impaired dispersal capacity, decreased reproductive success, and ultimately increased mortality (Gonzalez-Taokman 2020, p. 811; Harvey et al. 2020, p. 6687; Harvey et al. 2023, p. 5) Additionally, heat injury accumulates throughout the day, so night-time warming reduces respite time from daytime heat stress (Nail et al. 2015, p. 99; Halsch et al. 2021, p. 3; Harvey et al. 2023, pp. 14–15). Similarly, moisture levels play a critical role in development (Norhisham et al. 2013, p. 1), especially in desert environments (Palumbo 2011, entire; Chown et al. 2011, p. 1079). Although insects typically obtain water through their foodplants, a lack of moisture can interfere with an individual’s ability to regulate water loss thereby impairing its growth and development (Leather et al. 1995, p. 56; Palumbo 2011, entire; Norhisham et al. 2013, p. 1; Harvey et al. 2023, p. 15). The impacts may be exacerbated by the interaction of increasing temperatures and declining moisture (Crossley et al. 2021, p. 2707; Halsch et al. 2021, p. 3).

During the inactive season, diapausal individuals are especially sensitive to warming temperatures and decreasing moisture owing to both the normally high metabolic and moisture costs of this stage, as well as the delicate, intricate role of temperature and moisture in preparing, initiating, maintaining, and terminating diapause (Leather et al. 1995, pp. 2–3; McDermott et al. 2016, p. 111). Diapause initiation, maintenance, and termination is controlled by a complex, intricate interaction of photoperiod, temperature, and moisture (Leather et al. 1995, p. 27). Thus, warming temperatures and decreasing moisture can cause timing miscues and diapause disruptions, leading to increases in overwinter mortality. Additionally, the overwintering stage often incurs high mortality owing to complex physiological requirements and the immobilized state rendering them vulnerable to unfavorable conditions, drying, or waterlogging (Leather et al.

1995, p. 4). Diapausing individuals lose a significant amount of their body water content, and thus moisture is a limiting survival factor and a primary determinant of desiccation risk (Leather et al. 1995, p. 171; Palumbo 2011, entire). Beyond lethal effects, when pupae are dehydrated, adults emerge with deformed wings, and even slight crinkling interferes with flying and therefore feeding and survival. Diapausing individuals have elevated mortality rates under warming winter temperatures, owing to increased metabolic costs, respiration rates, and disease and fungal infections (Radchuk et al. 2013, p. 282; Oliver et al. 2015, pp. 2–4; Klockmann and Fischer 2019, p. 155).

In addition to detrimental impacts associated with gradual (chronic) warming and decreasing moisture, short-term (acute) extreme climatic events such as excessive cold or heat events (heat waves), drought conditions, and heavy precipitation events can cause substantial mortality directly by pushing individuals to and beyond their thermal tolerance (Harvey et al. 2020, p. 6687; Harvey et al. 2023, p. 12). When temperatures rise beyond their thermal tolerance, insects produce heat shock proteins in attempt to protect other heat sensitive proteins, but eventually, neural performance is impaired affecting the muscular function, triggering a temporary shutdown (coma) just before the insect dies (Harvey et al. 2020, p. 6687). Univoltine species are particularly sensitive to temperature extremes at both ends of the scale (heat or cold), with adult and overwintering phases being most vulnerable to these extremes (McDermott et al. 2016, p. 111). Given their short life spans, even short bouts (e.g., 30 minutes) of excessive heat can substantially impact reproductive success (Kingsolver and Watt 1983, p. 49, Harvey et al. 2020, p. 6689). Moreover, short heat exposure can have cumulative effects on later life stages (Klockmann et al. 2017, p. 6). Thermal limits vary among species; most published values for butterflies range from low to mid 30s C (86-95 F) for sublethal effects and low 40s C for lethal impacts (see Appendix, Table A1). The thermal limits are unknown for bleached sandhill skipper, but such effects are profound in temperature-sensitive univoltine insects with short life cycles or short reproductive periods (Harvey et al. 2020, p. 6689).

Indirect effects – Changes to temperature and precipitation levels can also indirectly affect butterfly fitness via impacts to their plant resources (nectar sources and hostplants) and changes to the plant community matrix. Thus, leading to further changes in microclimatic conditions and changes in the abundance of their natural enemies and diseases (Jaworski and Hilszczański 2013, pp. 345–346). Additionally, increases in carbon dioxide (CO_2), the key factor in climate change driven changes in temperatures and moisture levels, directly influences plant growth and chemistry (Stiling 2003, pp. 86–87).

In general, warmer and drier conditions can reduce nectar availability and induce early senescence of hostplants (Scaven and Rafferty 2013, pp. 421–422, Takkis et al. 2015, entire, McCombs et al. 2022, entire). Furthermore, extended exposure to high temperatures may affect plant growth and result in the production of toxic compounds (Harvey et al. 2020, p. 6690). Increased variability in precipitation affects the timing of plant senescence, potentially causing asynchrony between the hostplant and the butterfly (McLaughlin et al. 2002, p. 6073). Temporal mismatches with food resources are a major concern under climate change, and species will likely vary in their responses (Hill et al 2021, p. 2120). Species may be buffered against phenological mismatches if they are host generalists, while host specialists are likely to fare worse as they adjust for phenological mismatches by switching hosts (Hill et al. 2021, p. 2120).

Given that key stages in the bleach sandhill skipper's lifecycle occurs in late summer into fall, which corresponds to the waning productivity of plant species on which it depends, these affects may be amplified.

In summary, the effects of gradual, chronic warming and short-term exposures to climatic extremes can strongly influence individual fitness and population viability (Harvey et al. 2023, pp. 5, 20). Similarly, exposure to low moisture levels can impair development and increase desiccation risk, especially during the pupal stage. Moreover, these direct effects are exacerbated by negative impacts to bleached sandhill habitat conditions.

Adaptation – Although poikilothermy (body temperature controlled by temperature) leaves individuals susceptible to changing climactic conditions, there are numerous examples of insect populations adapting to changing conditions via shifting ranges, phenotypic plasticity, and genetic adaptation (Kingsolver et al. 2011, p. 6). However, adaptation to local conditions is not unexpected; without it, species extinction is inevitable. The critical question is whether populations can respond at the pace of current and future changing conditions. There is evidence of rapid evolution of morphological traits and shifts in distribution in butterfly populations, but data showing rapid evolution of physiological traits are lacking (Kingsolver et al. 2011, p. 7; Forister et al. 2018, p.6). On the contrary, data compiled thus far suggest that insects have limited capacity to change their thermal limits (Hoffman et al. 2013, pp. 938, 944; Weaving et al. 2022, p. 7). Having limited ability to adapt to the warming and drying conditions experienced in the southwestern U.S. is consistent with two recent studies of butterfly trends. Forister et al. (2021, p. 1044) implicated climate change—specifically, fall warming temperatures—as the primary cause leading to pervasive declines in butterfly abundance over the last 40 years in southwestern U.S. Similarly, Crossley et al. (2021, pp. 2707, 2709) found "overwhelmingly apparent" declines in butterfly abundance in both southwestern U.S. and the Intermountain West, driven largely by changes in temperatures and precipitation.

Bleached sandhill skipper possess a few life history traits that are adaptive (e.g., short generation time), but other important traits and environmental conditions likely constrain their adaptive capacity. Specifically, bleached sandhill skippers are dietary and habitat specialists and show little propensity for dispersal (see Chapter 2). Furthermore, a recent genetics study indicates that bleached sandhill skipper populations have low genetic diversity relative to its congeners (Jahner 2023, pp. 3–4), which reduces available genetic variation needed for evolutionary responses (Kardos et al. 2021, pp. 4–6). These traits coupled with the vulnerability of its food resources to warming and drying conditions, suggest that it is unlikely that bleached sandhill skipper is coping with climate change better than those species evaluated by Forister et al. 2021 and Crossely et al. 2021.

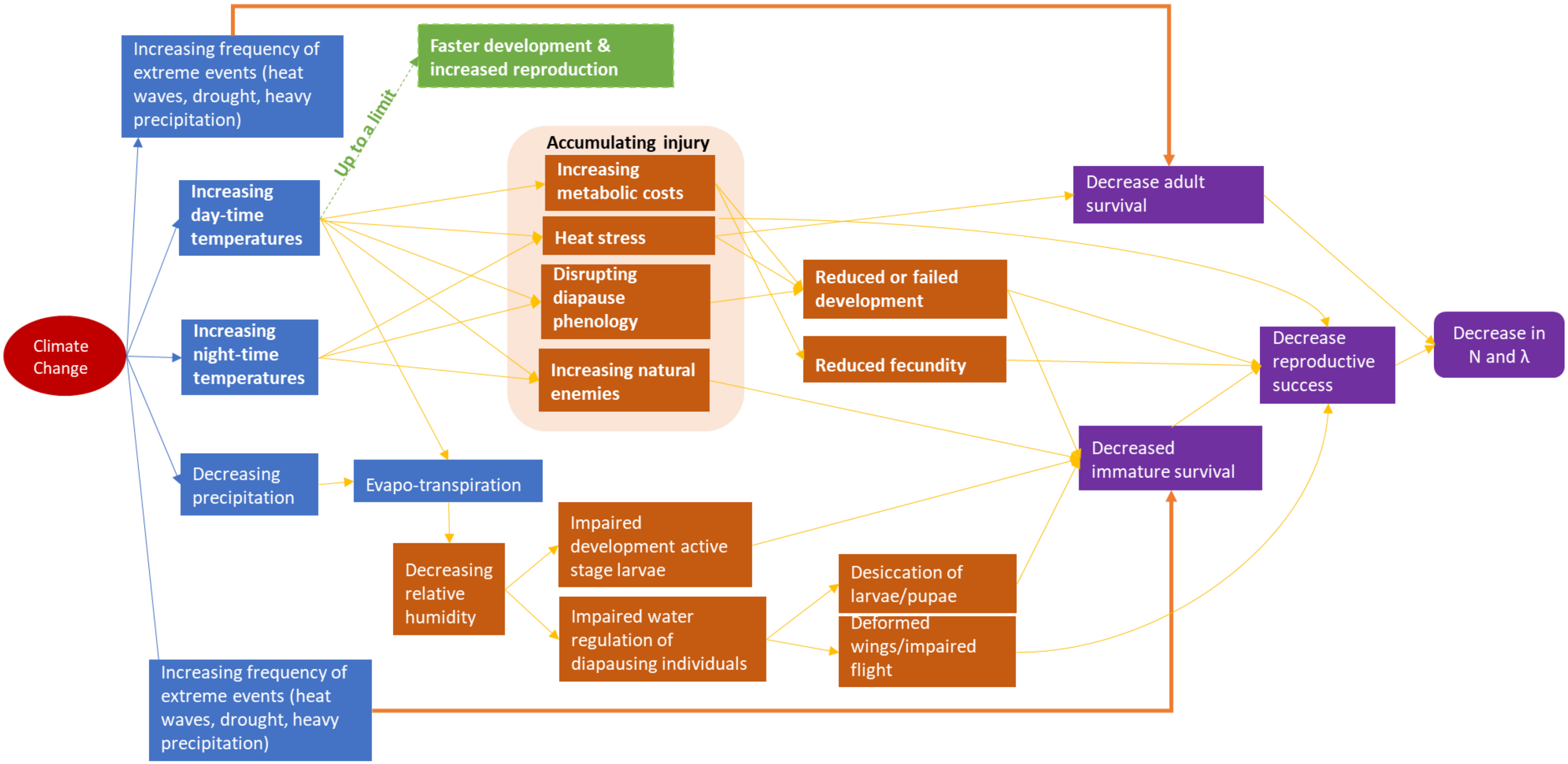

Figure 4.3 Mechanisms underlying the effects of increasing temperature and decreasing moisture on population abundance (N) and trend (λ). Note, this is a simplification; climate change processes operate singly and in combination resulting in complex interactions and cascading, additive, and synergistic impacts on butterfly fitness (reproduction and survival).

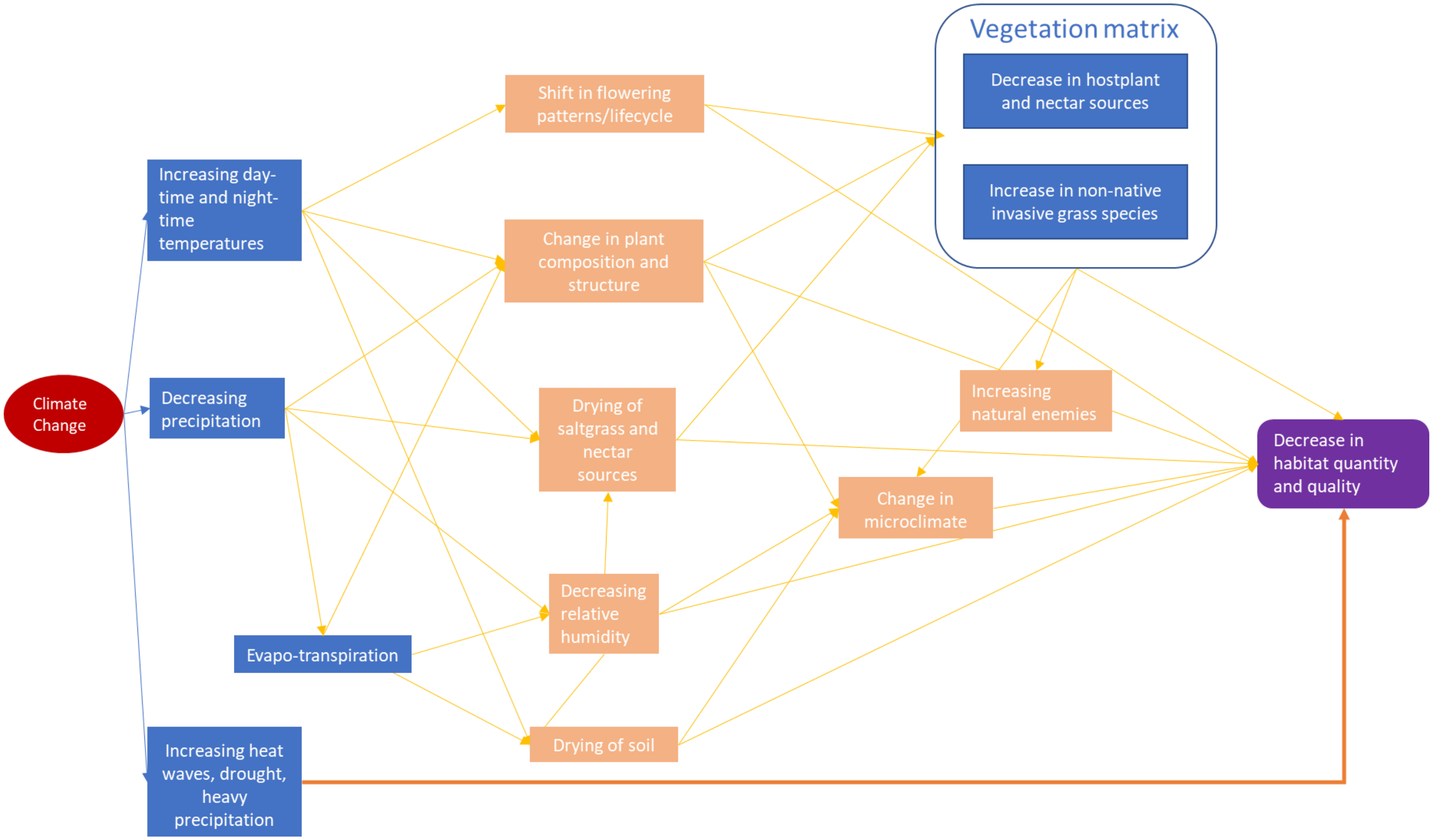

Figure 4.4. Mechanisms underlying the indirect effects of increasing temperature and decreasing moisture on population abundance (N) and trend (λ). This is a simplification; see caveat noted in Figure 4.3.

Magnitude and extent of impact arising from climate change to date

The Southwest region where the bleached sandhill skipper occurs is one of the hottest and driest areas of the United States, and climate change has exacerbated these conditions. Average annual temperatures have increased almost 1.1 C (2 F) over the last century (Garfin et al. 2014, p. 464). Every part of the Southwest experienced higher average temperatures between 2000 and 2020 than the long-term average (1895–2020) (EPA, 2023). Although not uniform, all areas were warmer than average; some areas were more than 1.1 C (2 F) warmer than average (see Figure 4.5; EPA, 2023).

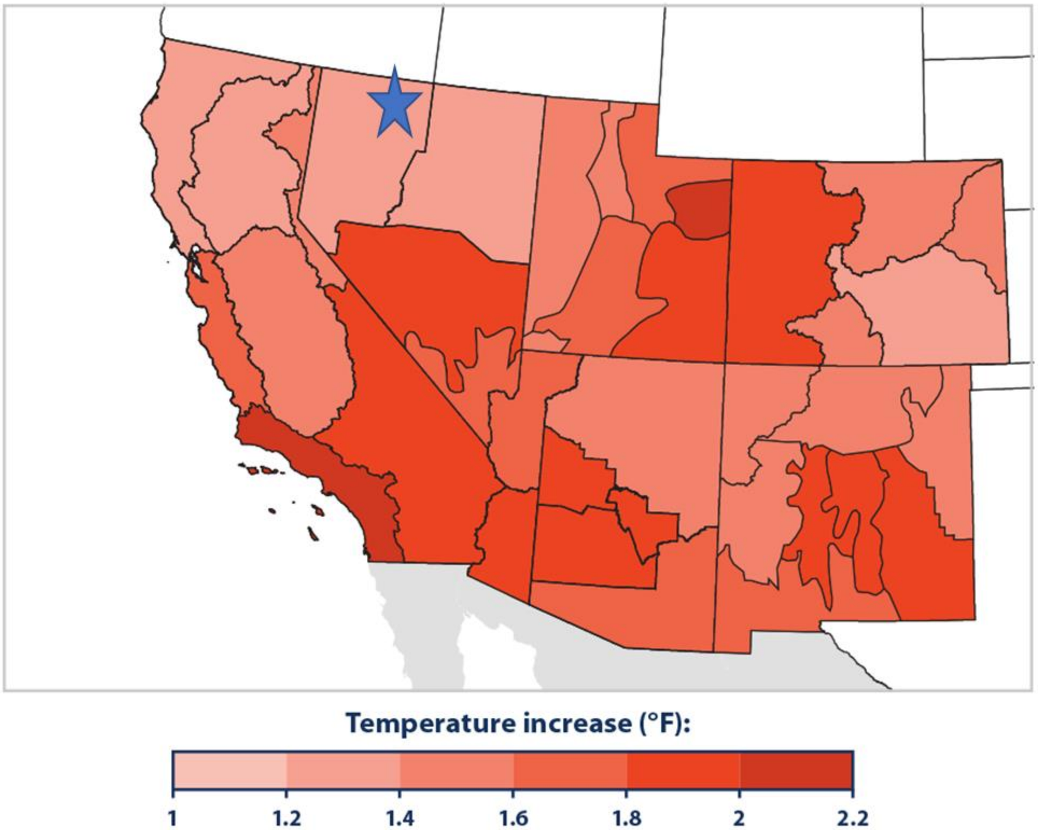

Figure 4.5. Map of the Southwest showing the increase in the average temperature over 2000 to 2020 from the long-term average (1895–2020) (EPA 2023). Blue star shows location of bleached sandhill skipper populations.

Temperatures are increasing more at night than during the day and more in winter than in summer, leading to fewer cold snaps, more heatwaves, fewer frosty days and nights, less snow, and earlier snowmelt (Stewart et al. 2005, p. 1152; Mote et al. 2005, entire; Knowles et al. 2006, p. 4557; Abatzoglou and Kolden 2013, entire; Snyder et al. 2019, p. 3). Both daytime high temperatures and night-time low temperatures have exhibited widespread warming trends (Garfin et al. 2013, p. 79).

In recent decades, reductions in precipitation and winter snowpack—key sources of moisture—have been observed (Garfin et al. 2014, p. 465). Since 2001, large portions of the arid Southwest have experienced prolonged drought, with widespread drought occurring in 2002, 2003, 2007, and 2009 (MacDonald 2010, p. 21256). During these years, the region's precipitation averaged as much as 22–25% below the 20th-century mean, with local deficits being greater (MacDonald 2010, p. 21256). Based on the long-term Palmer Drought Severity Index, drought conditions in the Southwest have varied since 1895 (Figure 4.6). Since the early 1900s, the Southwest has experienced wetter conditions during three main periods: the 1900s, 1940s, and 1980s. Drier conditions occurred through the 1920s and 1930s, again in the 1950s, and since 1990, when the Southwest has seen some of the most persistent droughts on record (Garfin et al 2013, p. 84).

The period since 1950 was warmer than any comparable period in at least 600 years based on paleoclimatic reconstructions of past temperatures and the most severe and sustained droughts during 1901-2010 were exceeded in severity and duration by several drought events in the preceding 2000 years (MacDonald 2010, p. 21256). From 1901-2010, there was a trend towards increasing drought extent, in large part due to widespread drought during the 2001-2010 decade, which had the second largest area affected by drought (after 1951-1960) and the most severe average drought conditions of any decade (Garfin et al. 2013, p. 83). The severity of drought in 2001-2010 reflects both the decade's low precipitation and high temperatures (Garfin et al. 2013, p. 83).

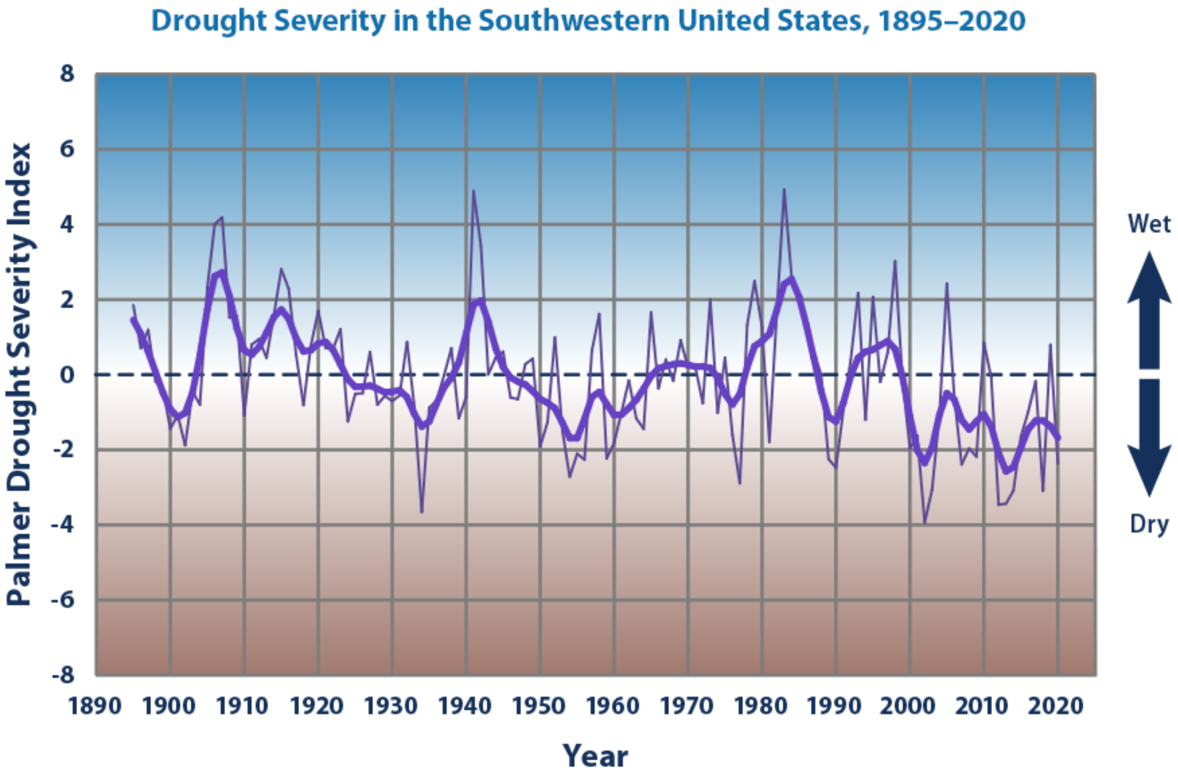

Figure 4.6 – Annual values of the Palmer Drought Severity Index, averaged over six states in the Southwest (Arizona, California, Colorado, Nevada, New Mexico, and Utah)[4]*.Graphic copied from USEPA 2023.*

Parts of the southwestern U.S. are also experiencing long-term reductions in mountain snowpack which accounts for a large portion of the region's water supply (Garfin et al. 2013, p. 83). From 1955 to 2022, April snowpack declined at 93% of sites measured, with an average of 23% decline. From 2001–2010, streamflow in the four major hydrologic basins in the Southwest (Colorado River, Sacramento-San Joaquin Rivers, Humboldt River, and Rio Grande) were 5–37% lower than their flows in the 20th century.

To assess how temperature and moisture has changed over time at a more local scale, we relied upon weather data housed at the Climate Toolbox (Hegewisch et al. 2023). The dataset consists of daily high-spatial resolution (~4 km (~2.5 mi)) weather data covering the contiguous U.S. We downloaded data for Humboldt County, Nevada. Specifically, we pulled data for five climate variables: [1] maximum (tmax) and [2] minimum (tmin) temperature, [3] precipitation (ppt), [4] potential evapotranspiration (PET), and [5] Palmer Drought Severity Index (PDSI). We used temperature data to discern changes in daytime (tmax) and nighttime (tmin) temperatures and changes in the frequency of extreme heat events (measured as the number of days where tmax exceeded three thermal limit thresholds. We used precipitation (ppt) and potential evaporation (PET) to discern changes in the moisture patterns and used PDSI to assess changes in the

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[4] Positive values represent wetter-than-average conditions, while negative values represent drier-than-average conditions. A value between -2 and -3 indicates moderate drought, -3 to -4 is severe drought, and -4 or below indicates extreme drought.-The thicker line is a nine-year weighted average.

extreme drought events. We report the results annually and seasonally (Winter: Dec-Feb, Spring: Mar-May; Summer: Jun-Aug; Fall: Sep-Nov). Historical average refers to 1958-2009; current decade refers to 2010-2019 but we also report out data for 2020-2022. We summarize the trend over time and the change from the historical period to current period. The absolute change in average values are provided in Appendix A, Table A2.

Key findings:
The results indicate increasingly warmer and drier conditions in Humboldt County. Temperatures are increasing, especially tmin (night-time) across all seasons. While precipitation (ppt) is mixed, PET is increasing and PDSI decreasing (both portending drier conditions) in all seasons. Below, we report the results by season. Historical average refers to 1958–2009; recent decade refers to 2010–2019.

Spring – increasing trend in temperatures, especially tmin (night-time); and while ppt is relatively stable over time, PDSI and PET show drying conditions (Figures 4.7, 4.11). Comparing recent decade average to the historical (decadal) average,

- tmax and tmin increased by +0.8 F and +1.8 F, respectively
- ppt increased by +0.42 inches, while PET increased by +0.35 inches and PDSI decreased by -0.81 (increasing PET and decreasing PDSI signify increasingly dry conditions)

Summer – increasing trend in temperatures and drying conditions (Figures 4.8, 4.11). Comparing recent decade average to historical (decadal) average,

- tmax and tmin increased by +1.7 F and +2.4 F, respectively
- ppt decreased by -0.58 inches, while PET increased by +0.86 inches and PDSI decreased by -0.84

Fall – increasing trend in temperatures, especially tmin (night-time); PET increased with concurrent decreases ppt and PDSI (Figures 4.9, 4.11). Comparing recent decade average to historical (decadal) average,

- tmax and tmin increased by +1.0 F and +2.0 F, respectively
- ppt decreased by -0.05 inches, while PET increased by +0.35 inches and PDSI decreased by -0.81.

Winter – relative to other seasons, less stark trends (Figures 4.10, 4.11). Comparing recent decade average to historical (decadal) average,

- tmax and tmin increased by +1.0 F and +0.9 F, respectively
- ppt increased by +0.35 inches but PDSI decreased by -0.66 (PET is not measured in winter months)

Additionally, there is an increasing trend in the average number of excessive heat events (when tmax exceeds thermal limits) (Figures 4.12, 4.13). Although the thermal limits are unknown and vary by life stage, it is reasonable to assume that sublethal effects (e.g., reduce reproductive success) are triggered around 35 to 38 C (95 to 100 F) and lethal effects towards 38 to 41 C (100 to 105 F) and (see Chapter 2 and above for discussion).

Comparing recent decade (2010) to the past (1958-2009), the average annual number of days (past vs recent) where tmax exceeded thermal limits increased by:

- 2 days (21 vs 23 days) for 35 C threshold
- 1.5 days (3 vs 4.5 days) for 38 C threshold
- 0.1 days (0.2 vs 0.3 days) for 41 F threshold

During the last three years (2020–2022), the average annual number of days where tmax exceeded thermal limits increased from the historical average by:

- 15 days for 35 C threshold, with 5 and 10 days in fall and summer, respectively
- 3 days for the 38 C threshold, with 2 and 1 days in fall and summer, respectively
- None for 41 F threshold

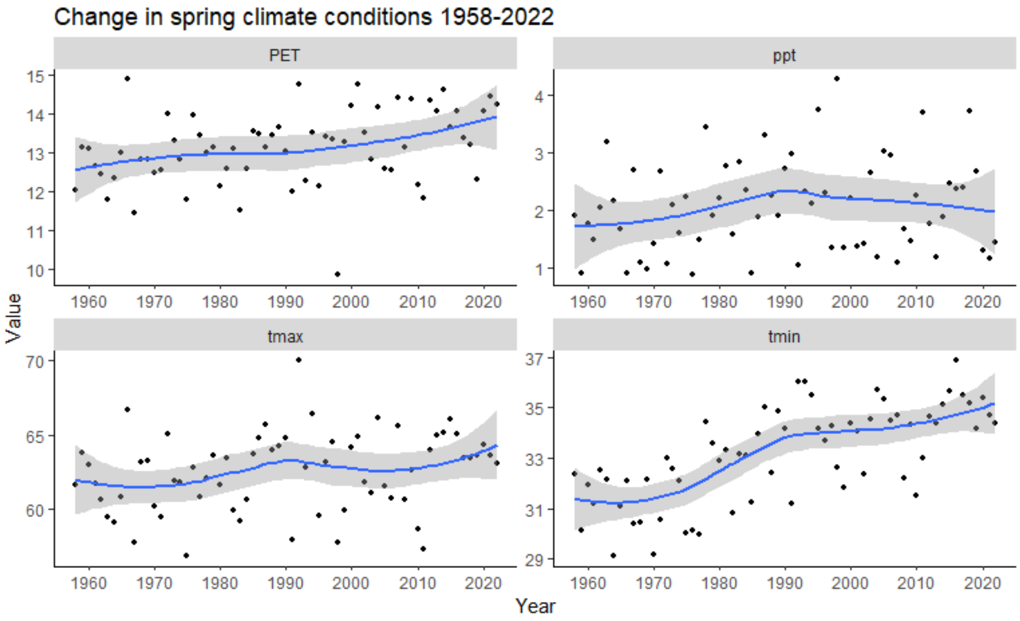

Figure 4.7. Spring tmax, tmin, PET, ppt from 1958 – 2022. Trend line: loess model in R, Tidyverse, ggplot2, and Viridis packages.

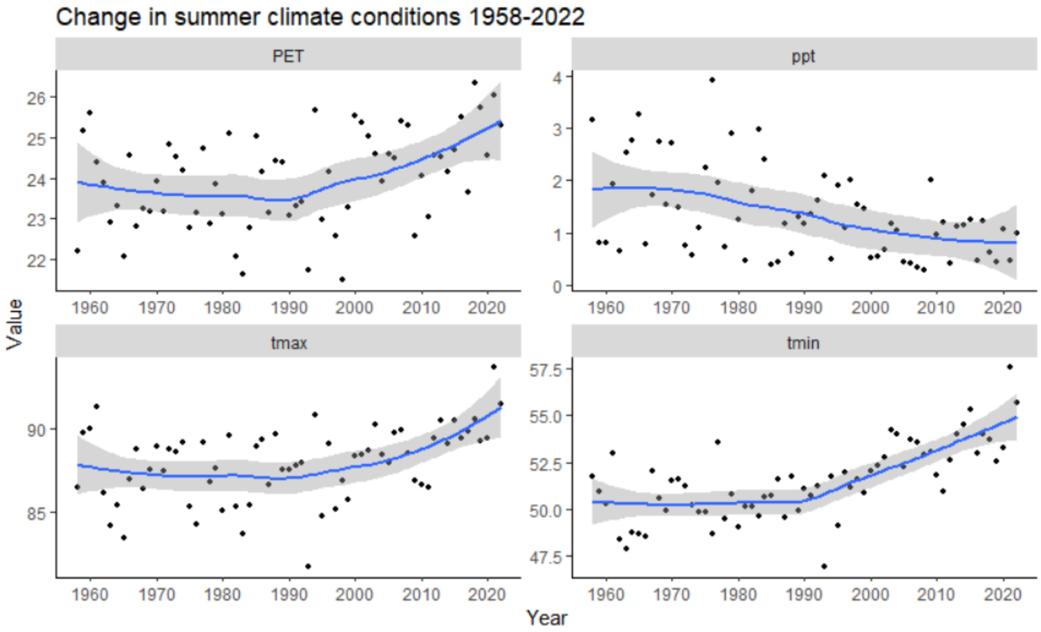

Figure 4.8. Summer tmax, tmin, PET, ppt from 1958 – 2022. Trend line: loess model in R, Tidyverse, ggplot2, and Viridis packages.

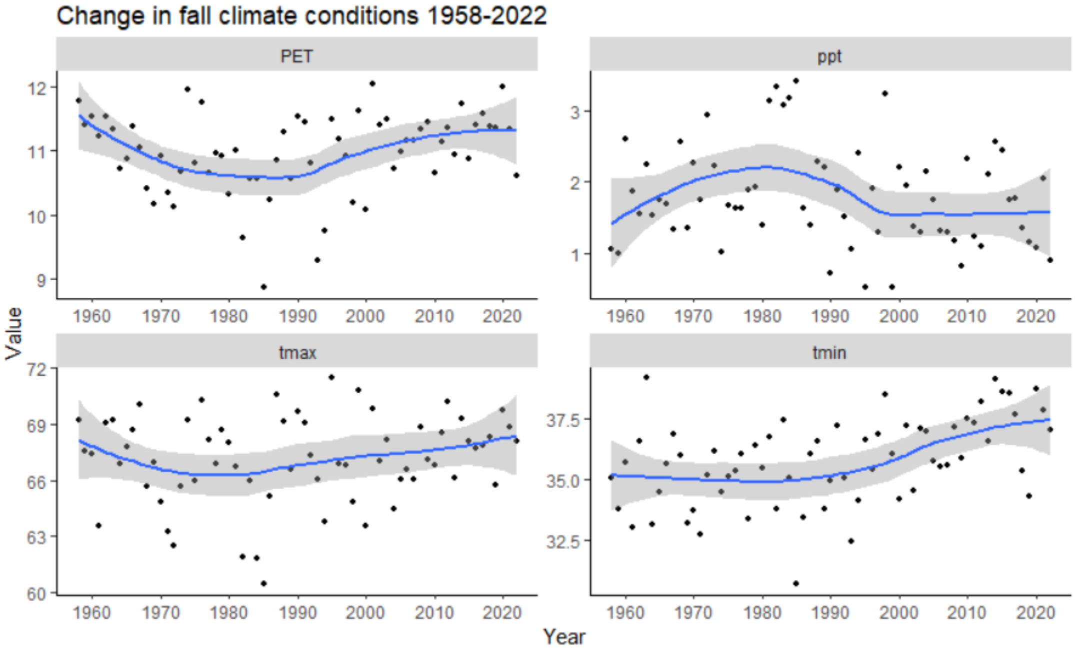

Figure 4.9. Fall tmax, tmin, PET, ppt from 1958 – 2022. Trend line: loess model in R, Tidyverse, ggplot2, and Viridis packages.

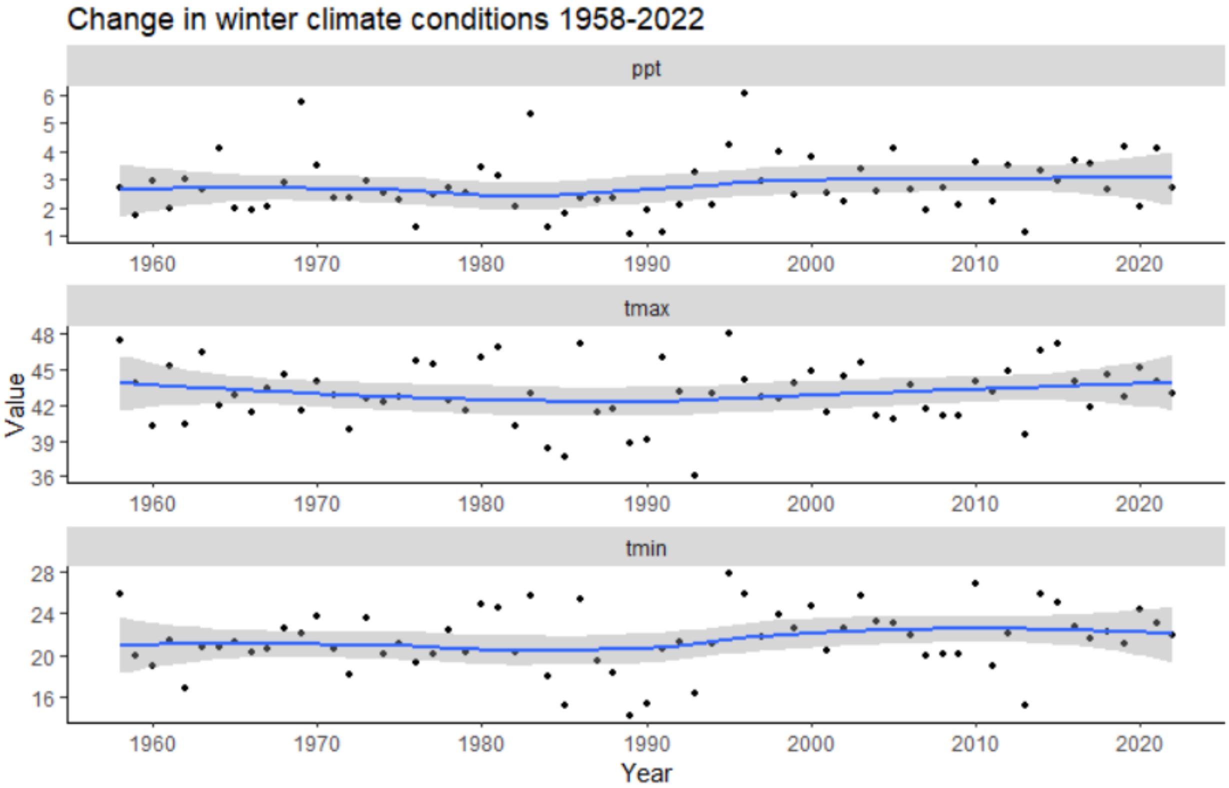

Figure 4.10. Winter tmax, tmin, ppt from 1958 – 2022. Trend line: loess model in R, Tidyverse, ggplot2, and Viridis packages.

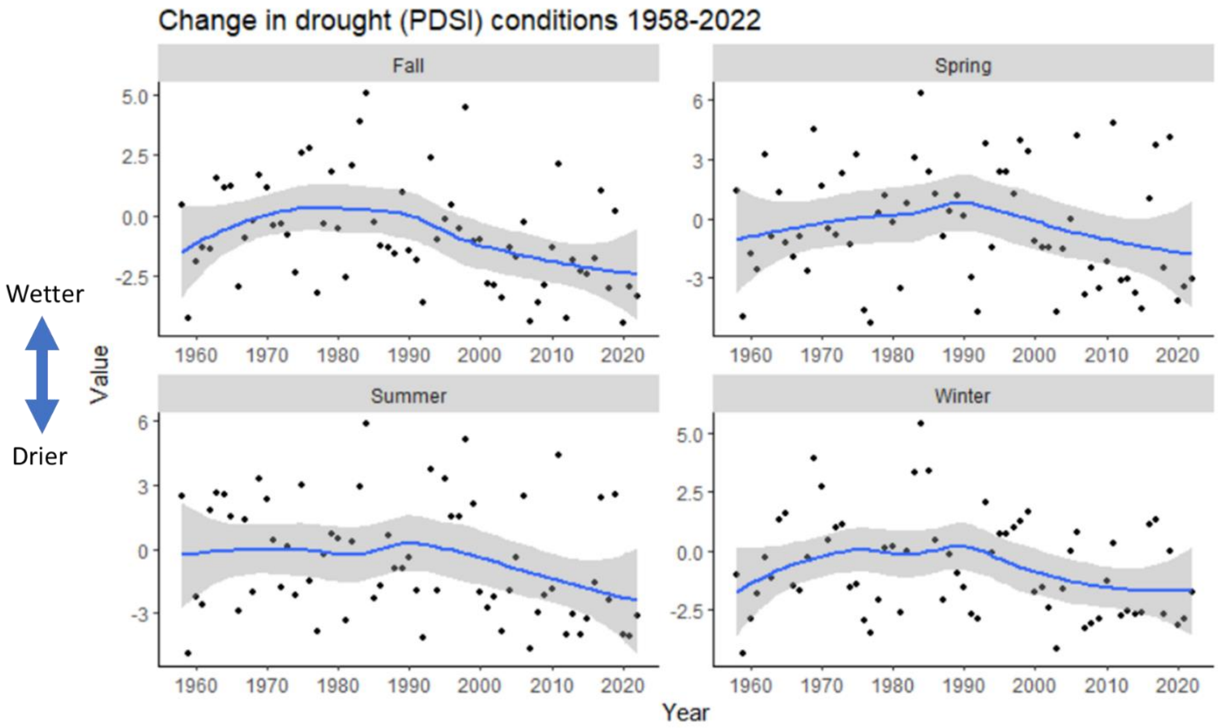

Figure 4.11. PDSI from 1958 through 2022. PDSI is a unitless index for measuring drought severity: 0 is normal, positive numbers represent wetter than normal conditions and negative numbers drier than normal conditions. For example, -2 is moderate, -3 is severe, and -4 is extreme drought conditions. The index has proven most effective in determining long-term drought over several months, but it is not as good with conditions over a matter of weeks. Trend line: loess model in R, Tidyverse, ggplot2, and Viridis packages.

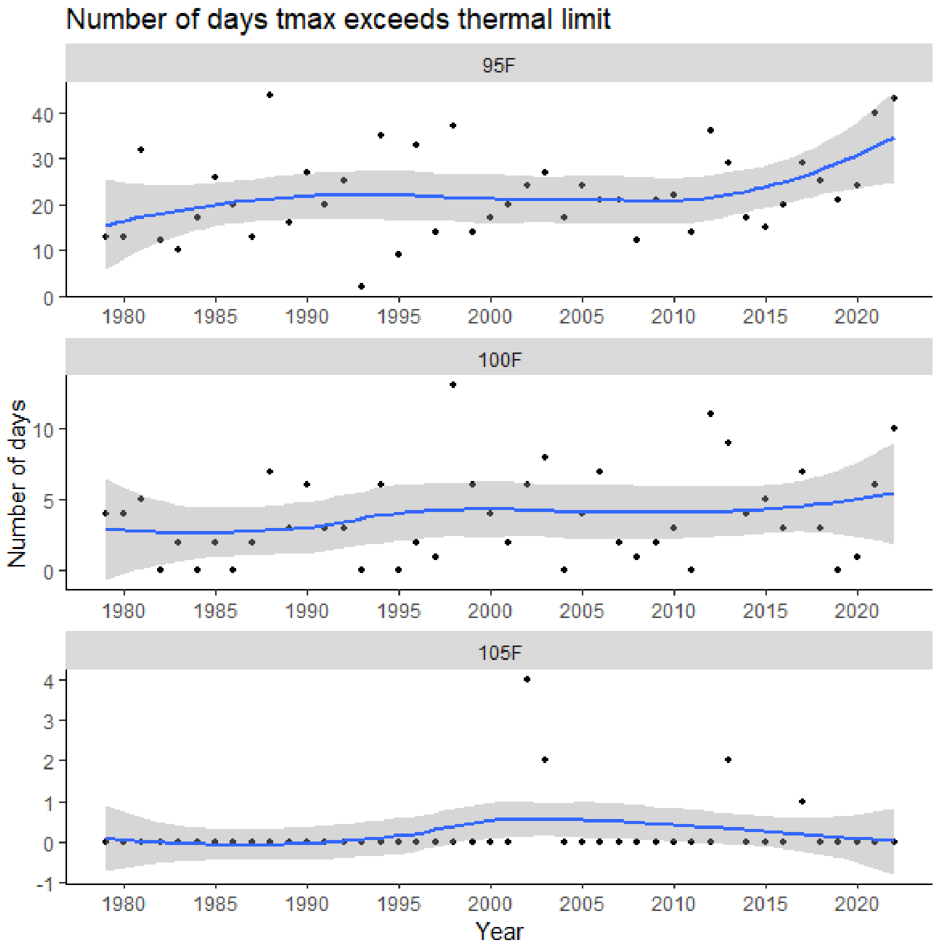

Figure 4.12. The number of days annually where daily tmax exceeded sublethal and lethal thermal limits from 1958 through 2022. The threshold for the sublethal thermal limit is likely to lie between 35 – 38 C (95 –100 F) to 38 C (100 F) and lethal threshold between 38–41 C (100 to 105 F). Trend line: loess model in R, Tidyverse, ggplot2, and Viridis packages.

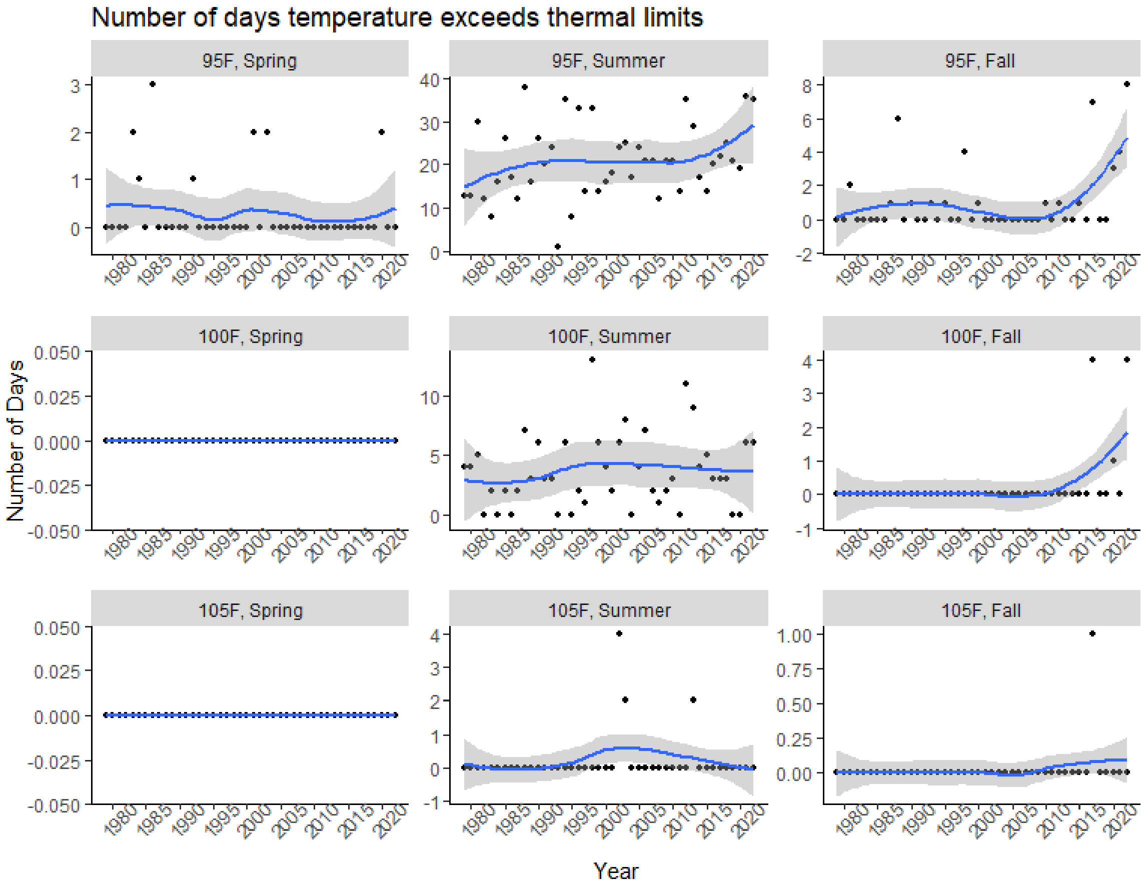

Figure 4.13. The number of days seasonally where daily tmax exceeded sublethal and lethal thermal limits from 1958 through 2022. The threshold for the sublethal thermal limit is likely to lie between 35 – 38 C (95 –100 F) to 38 C (100 F) and lethal threshold between 38– 41 C (100 to 105 F). Trend line: loess model in R, Tidyverse, ggplot2, and Viridis packages.

In summary, the climate in the Southwest is warming and drying, with implications for butterfly populations. Climate change impacts on butterflies and its habitat vary among species and among sites, with some populations showing neutral or favorable response, while other showing negative responses. These seemingly conflicting results are neither surprising nor unexpected given that (1) the magnitude of climate change is not uniform across space; (2) species response is a function of a complex interplay among life history sensitivities, dispersal abilities, and (macro and micro) habitat heterogeneity; and (3) climate variables and species response metrics used vary across studies. Even with idiosyncratic and heterogenous results reported in the literature, recent syntheses completed by Halsch et al. (2021, entire) and Harvey et al. (2023, entire) coupled with the findings from Crossley et al. (2021, entire) and Forister et al. (2021, entire) strongly implicate climate change as the primary driver in declining butterfly abundance throughout the southwestern U.S. Given bleached sandhill skipper physiology (poikilothermy) and that they occupy areas that are likely at or close to their upper thermal limits, the best available data suggest that the regional warming and drying conditions are negatively driving bleached sandhill skipper population trends.

4.4 Inadequacy of Existing Regulatory Mechanisms

The Nevada Department of Wildlife (NDOW) and the Nevada Department of Conservation and Natural Resources do not have authority to manage or conserve terrestrial invertebrates such as the bleached sandhill skipper. Nevada Revised Statute (NRS) § 501.110 outlines the "Classification of Wildlife" in Nevada, and lists NDOW as having authority over wild mammals, wild birds, fish, reptiles, amphibians, mollusks, and crustaceans but does not mention insects. The Nevada Department of Agriculture has statutory authority over insects that are "normally considered to be a pest of cultivated plants, uncultivated plants, agricultural commodities, or nursery stock, or that the Director [of the Department of Agriculture] declares to be a pest," (NRS § 555.005(5)). Because the bleached sandhill skipper is not an agriculture pest, it is functionally unmanaged by any state agency.

The bleached sandhill skipper has been placed on Nevada's list of "at-risk species" by the Nevada Division of Natural Heritage (Nevada Division of Natural Heritage 2022, p. 16). However, species included on the At-Risk Plant and Animal Tracking List are not provided any protections by the state (Nevada Division of Natural Heritage 2022, p. 1).

The bleached sandhill skipper is considered a BLM Sensitive Species in Nevada (BLM 2017, p. 24). BLM Sensitive Species are "species requiring special management consideration to promote their conservation and reduce the likelihood and need for future listing under the ESA" (BLM 2008, p. 3). Beyond the Sensitive Species designation, other BLM regulations do not provide protections for the bleached sandhill skipper. The BLM Winnemucca District Resources Management Plan requires that proposed actions on BLM land do not affect a species in such a way that it may lead to further listing under the ESA (BLM 2013b, p. 34). This is the only regulatory mechanism providing any level of protection for the bleached sandhill skipper.

4.5 Summary of Past and Current Influences Driving Population Conditions

We identified three influences as the primary drivers of the current population and habitat conditions described in Chapter 3. These primary influences are grazing, groundwater pumping, and climate change, with the latter being the strongest driver. To facilitate comparison among the influences, we classified the magnitude of impact as:

- No effect = no resulting effects to population abundance, stable
- Minor = likely to cause only temporary reductions in population numbers
- Moderate = likely to cause reduction in population numbers and stabilizes at a lower level
- Major = likely to cause a continued reductions over time, leading to extirpation
- Unknown = insufficient information to reliably estimate population response

The magnitudes are provided in Table 4.1 and key summary points underlying our analysis follows.

Grazing – The grazing system at Pueblo Slough is likely affecting habitat conditions, via stress on saltgrass and rabbitbrushes by allowing grazing during the same time each year with no years of intervening rest, and directly affecting bleached sandhill skippers via trampling and direct consumption of larvae. Given the level of grazing, however, it is likely having only minor impacts on the population. At Gridley Lake, grazing occurs only during the pupal overwintering stage and thus is unlikely to be affecting the population. At Rincon Creek, there is no authorized grazing occurring.

Groundwater pumping – depth-to-groundwater data coupled with NDVI data suggest a drying of the phreatophytic communities across the two water basins, and groundwater pumping data suggest that pumping contributing to increasing the depth-to-groundwater levels at Pueblo Slough and Gridley Lake. Based on these data, groundwater pumping is likely causing minor to moderate impacts to the Pueblo Slough and Gridley Lake populations. Groundwater pumping is likely have having no effect to potentially minor effects on habitat conditions at Rincon Creek population.

Climate change – The climate within bleached sandhill skipper range has been drying and warming over the last several decades. These warming and drying conditions are likely impacting the quality of bleached sandhill skipper habitat, specifically causing early senescence of saltgrass and rabbitbrushes, although the extent to which this is occurring is unknown. That being said, the bleached sandhill skipper is a desert occupant, likely living close to its upper thermal limits under normal conditions, leaving little buffer for accommodating warming and drying conditions. Given its limit dispersal ability, low standing genetic diversity, inflexible thermal limits, and narrow diet, bleached sandhill skippers likely lack the capacity to timely and sufficiently adapt to warming temperatures.

The steep decline in bleached sandhill skipper population counts coupled with recent studies implicating climate change as the cause of butterfly declines in the southwestern U.S. (Crossley et al. 2021, p. 2707; Forister et al. 2021, p. 1044), suggest that climate change is a key driver in bleached sandhill population dynamics at Pueblo Slough. Given the regional extent of climate change, it is likely that it is a key driver of the population dynamics at Gridley Lake and Rincon Creek populations as well. Taken together with the magnitude of warming and drying that has occurred in the last couple of decades, it is likely that climate change is having a moderate to major impact on all three bleached sandhill skipper populations.

Table 4.1 Current magnitude (and confidence) of impact on bleached sandhill skipper populations. Good confidence means our assumptions are strongly supported by the best available data and represent plausible outcomes. Fair confidence means our assumptions are reasonably by patterns in the available data and represent plausible outcomes. Low confidence signals scant data to inform our assessment, but minimally sufficient confidence that assumptions produce plausible outcomes.

Population	Grazing	Groundwater pumping	Climate Change
Pueblo Slough	Minor (Fair)	Minor-moderate (Good)	Moderate-major (Good)
Gridley Lake	No effect (Fair)	Minor-moderate (Good)	Moderate-major (Good)
Rincon Creek	No effect (Good)	No effect-minor (Fair)	Moderate-major (Good)

Textbox 4.1 : Climate change impacts & butterflies

- Butterflies are vulnerable to climate change impacts (Radchuk et al. 2013, p. 275)
- Their high relative sensitivity is due to poikilothermy, where environmental conditions (temperature and moisture levels) determine an animal's body temperature, which in turn regulates critical functions such as respiration, immunity, metabolism, growth and reproduction, flight ability, dispersal, fecundity, oviposition, feeding, development, and diapause (Gonzalez-Tokman 2020, p. 811; Jaworski and Hilszczanski, 2013, p. 346; Palumbo 2011, entire).
- Sensitivity varies by life stage, with immature stages being more sensitive and heat stress can carry-over to latter life stages triggering cumulative fitness consequences (Klockmann et al. 2017, p. 6).
- Changes in temperatures can disrupt the tight phenology with their hostplants and nectar plants, as well, timing of their development and metamorphosis events (transition from one life stage to another). For example, successful overwintering requires larval development to the requisite diapausing stage at precisely the time of year when individuals are sensitive to initiation cues (Leather et al. 1995, pp. 25–26).
- Moisture conditions are especially important in desert areas (Palumbo 2011, p. 1; Chown et al. 2011, p. 1071; Norhisham et al. 2013, p.1), as low humidity levels influence an insect's ability to regulate water loss, affecting growth and behavior and increasing desiccation risk (Norhisham et al. 2013, pp. 2-5; Woods and Singer 2000, pp. 594, 602).
- Consequently, changes—even small, gradual changes—in temperature and moisture levels can substantially affect a population's fitness (Harvey et al. 2023, p. 5, 20).
- Bleached sandhill skippers as desert occupant likely live close to their thermal limits under normal conditions, leaving little buffer for warming and drying conditions.
- Moreover, insects have fertility and survival thermal limits, making them vulnerable to acute heat events. For most species, significant fitness and survival consequences are triggered between 35 - 44 C, with immature stages more sensitive at the lower end of the range. Importantly, this thermal range may shift downward when high daytime temperatures are coupled with high night-time temperatures (Zhao et al 2013, p. 774).
- Exposure to these extreme temperatures for even short bouts (e.g., 30 minutes) can lead to a breakdown of metabolic functions and death (Harvey et al. 2020, p. 6689; Kingsolver and Watt 1983, p. 49).
- Bleached sandhill skippers are univoltine and thus short periods of reproduction loss or reductions in survival can have profound population-level impacts (Harvey et al. 2020, p. 6689).
- Bleached sandhill skipper's ability to adapt to the warming and drying conditions is constrained by their life history (diet specialist, low dispersal tendencies, tight phenology), low standing genetic diversity, and inflexible upper thermal limits.

CHAPTER 5 FUTURE PROJECTIONS OF THE PRIMARY FACTORS INFLUENCING VIABILITY

Here, we describe plausible range for the projected change in each of the key influences, plus a new potential threat for Pueblo Slough, geothermal development. A summary description of the lower and upper bound projections for each threat is presented in Tables 5.1–5.3; the accompanying rationale and methods used to derive these lower and upper bounds, as well as our assessment of impacts to the three populations under each bound, are described below. We do not reiterate the mechanisms and supporting literature underlying our assessments for influences already presented in Chapter 4.

Table 5.1. The future projections for the influences at Pueblo Slough. Timeframe is the period over which the change in the influence will occur. PY = perennial yield; RCP = representative concentration pathways

Influence	Lower Bound	Upper Bound	Timeframe
Grazing	Current grazing system	Current grazing system	22 years
Groundwater pumping	Current pumpage – 22% of PY	Full use of appropriated water rights, 97% of PY	77 years
Climate change	RCP 4.5	RCP 8.5	77 years
Geothermal development	0% reduction in discharge rate	25% reduction in discharge rate	5 to 10 years

Table 5.2. The future projections for the influences at Gridley Lake. Timeframe is the period over which the change in the influence will occur. PY = perennial yield; RCP = representative concentration pathways

Influence	Lower Bound	Upper Bound	Timeframe
Grazing	Current grazing system	Current grazing system	22 years
Groundwater pumping	Current pumpage – 152% of PY	Full use of appropriated water rights, 206% of PY	77 years
Climate change	RCP 4.5	RCP 8.5	77 years
Geothermal development	Not applicable	Not applicable	Not applicable

Table 5.3. The future projections for the influences at Rincon Creek. Timeframe is the period over which the change in the stressor will occur. PY = perennial yield; , RCP = representative concentration pathways.

Influence	Lower Bound	Upper Bound	Timeframe
Grazing	None	None	Not applicable
Groundwater pumping	Current pumpage – 22% of PY	Full use of appropriated water rights, 97% of PY	77 years
Climate change	RCP 4.5	RCP 8.5	77 years
Geothermal development	Not applicable	Not applicable	Not applicable

5.1 Grazing

We did not include grazing for the Rincon Creek population in future projections as we do not anticipate authorized nor unauthorized grazing to occur into the future.

Future projection and rationale

At Pueblo Slough, the grazing permits for Pueblo Mountain Allotment and Alder Creek Allotment are set to expire in 2025. We have no information suggesting the grazing system will change into the future. Therefore, we assume the plausible projections for grazing systems will remain unchanged for the next 22 years for both the lower and upper bound projections (remainder of the current permits plus an additional permit renewal under current decisions). At Pueblo Slough, despite the potential for the ongoing impacts to amplify over time, we expect only minor effects to the population over the next 22 years.

At Gridley Lake, we anticipate no impacts to the population as the grazing management strategy includes rest periods. This will allow for adequate rest and recovery of the vegetation system and will have minimal impacts on immature butterfly stages.

5.2 Groundwater Pumping

Future projection and rationale

The two groundwater basins we analyzed are either over appropriated or almost fully appropriated, and it is unlikely there will be significant change in water rights allocation in the future. Once basins are fully appropriated, further water rights are generally not issued except for temporary uses, such as a mine (Kryder 2023, pers. comm.). Water right applications may also be protested which is a consideration in whether to granted the request. The Nevada Water plan is currently being revised, with the final plan anticipated in 2025. It will not change state law or reallocate water rights among current users but will develop options for management strategies, actions, and policies that can be implemented by various stakeholders. It will also develop recommendations aimed at increasing the sustainability and improving the management of water resources (NDWR 2023c, pp. 2–3). This may result in reduction of water use by highlighting challenges and need for efficiency and providing tools to stakeholders; however, there is no regulatory certainty behind this. For these reasons, we assume there will be no change in water right allocations for these basins. We do not have information in future trends for agriculture in these basins to know if pumpage may decrease into the future.

Based on the above, we set the lower plausible scenario at the current pumpage rates for the next 77 years and upper plausible projections at the fully appropriated values, as water law is not under revision. For the lower plausible scenario, current pumpage rates (described in section 4.2) are calculated as the annual average pumpage of the last three years of available data. The absolute value of these pumpage rates is not as important as the values relative to perennial yield, or as the relative increase between current pumpage and upper bound projections, so that is what is presented.

<u>Lower bound projections</u>
Pueblo Slough – current pumpage, 22% of perennial yield
Gridley Lake – current pumpage, 150% of perennial yield
Rincon Creek – current pumpage, 22% of perennial yield

Upper bound projections
Pueblo Slough – fully appropriated, 97% of perennial yield
Gridley Lake – fully appropriated, 206% of perennial yield
Rincon Creek – fully appropriated, 97% of perennial yield

Anticipated population impacts response to the lower and upper projections

At Pueblo Slough, under the lower bound projection of continued pumping at 22% of perennial yield, we anticipate ongoing effects to amplify over time, as groundwater will continue to be extracted from the system, resulting in moderate impacts in the near and far term (2030 and 2090). Under the upper bound projection of an increased pumpage to 97% of perennial yield, which is a fourfold increase from current rates, we anticipate moderate effects in the near-term and major effects in the far-term due to increasing groundwater extraction.

At Gridley Lake, we anticipate similar impacts to that of Pueblo Slough. Under the lower bound projection of continued pumping at 150% of perennial yield, we anticipate ongoing effects to amplify over time, as groundwater will continue to be extracted from the system, resulting in moderate impacts in the near and far term (2030 and 2090). Under the upper bound projection of an increased pumpage to 206% of perennial yield, a 35% increase from current rates, we anticipate moderate effects through the near-term, but major effects in the far-term due to increasing groundwater extraction.

At Rincon Creek, under the lower bound projection of continued pumpage at 22% of perennial yield, we anticipate effects to amplify over time, as groundwater will continue to be extracted from the system, resulting in minor effects through the near-term (2030) and increasing to moderate impacts in the far-term (2090). Under the upper bound projection of an increased pumpage to 97% of perennial yield, a four-fold increase from current rates, we anticipate similar effects anticipated for the lower bound scenario. However, as we note in Section 4.2, pumping affecting Rincon Creek is likely occurring in Oregon, on which we have little data. However, we anticipate near-term future conditions mirroring those at Pueblo Slough and Gridley Lake given the upgradient agricultural pumping, and for far-term future conditions, we anticipate the same patterns to continue but to a lesser degree (compared to Pueblo Slough and Gridley Lake) remaining at moderate impacts.

5.3 Climate Change

Future projections and rationale

To assess how temperature and moisture will change into the future, we relied on climate projections from the Climate Toolbox (Hegewisch et al. 2023). The projections are derived from 20 climate models from phase 5 of the Coupled Model Intercomparison Project (CMIP5) of the IPCC. Consistent with the past weather data, these data are downscaled to a ~4 km (~2.8 mi) resolution. We chose two representative concentration pathways (RCPs) as our plausible bounds:

- Lower bound: RCP 4.5
- Upper bound: RCP 8.5

The higher emission scenario, RCP 8.5, represents a future pathway similar to a business-as-usual continuation of the 2010 emissions, while the RCP 4.5 scenario assumes a curtailment in greenhouse gas emissions. These models represent the best science for climate modeling, and thus, provide reasonable lowest (RCP 4.5) and highest (RCP 8.5) plausible projections of temperatures and moisture trends. For both scenarios, we downloaded data for the same climate variables as done for assessing past trends, except PDSI because future projections are not available.

The results indicate continued increasingly warmer and drier conditions in Humboldt County, Nevada, with temperatures increasing under both scenarios. While precipitation (ppt) trends are stable (but note the large uncertainty bounds), increasing PET trends signal increasingly drier conditions. Below, we report seasonal changes for decades 2020s, 2040s, 2090s; the projected changes for all decades are provided in the Appendix A, Tables A2–A3. The historical timeframe is 1958 to 2009, current timeframe is 2010–2022, and future 2023–2099. The ranges provided are given for RCP 4.5 to RCP 8.5. The data are summarized by season and trends over time are shown in (Figures 5.1 – 5.4)[5].

Spring – the increasing trend in temperatures continues under both RCP scenarios. The 10-year average tmax in the 2020s is projected to be 3.2 – 3.4 F (1.81 – 191 C) higher than the historical average and 7.2 – 10.7 F (4.01 – 5.95 C) higher by 2090s. Similarly, the average 10-year night-time temperatures (tmin) are projected to rise, increasing by 2.9 – 3.0 F (1.6 – 1.69 C) in 2020s and 5.9 – 8.8 F (3.21 – 4.90 C) by 2090s. The 10-year average ppt is projected to be 0.22 to 0.19 inches below historical average in the 2020s but increasing from that point on, reaching 0.05 – 0.10 inches above historical average by 2090s. These increases, however, do not keep pace with the amount of moisture loss due to evapotranspiration. Compared to the historical average, the average 10-year PET increases by 1.98 – 2.03 inches in the 2020s and by 3.21 – 4.09 inches by 2090s.

Summer – both temperatures and moisture are projected to markedly change. Average summer temperatures increases over time; the 10-year average tmax increases by 3.8 – 4.1 F (2.14 – 2.30 C) in the 2020s, reaching 7.6 – 13.2 F (4.2 – 7.33 C) above the historical average by 2090s. Similarly, the 10-year average for tmin increases by 2.9 – 3.2 F (1.63 – 1.76) in the 2020s, reaching 5.5 – 10.8 F (3.07 – 6.02 C) above historical average by the 2090s. The largest changes in moisture are during the summer, with both ppt and PET trends portending increasingly drier conditions. The 10-year average in ppt declines by 0.55 – 0.54 inches in the 2020s, and although less severe by the end of the century, the 10-year average is 0.43 – 0.34 inches lower than the historical average. The trend in PET increases across the decades with the average 10-year PET increasing by 1.60 – 1.69 inches in the 2020s and reaching 2.57 – 3.85 inches above the historical average by 2090s.

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[5] Note, disconnects between time steps 2022 and 2023 signify differences between conditions experienced in recent years and the predictions from climate models. Climate modelers use past observations to inform their choice of model parameters, but do not fit the models to historical observations (Schmidt et al. 2017, p. 16). Because of this, “jumps” from 2022 and 2023 can occur.

Fall – the 10-year average tmax rises markedly over time, increasing by 1.9 – 2.1 F (1.08-1.18 C) in the 2020s and reaching 5.5 – 10.2 F (3.04 – 5.69 C) above historical average by the 2090s. The 10-year average tmin increases by 0.4 – 0.6 F (0.23 – 0.32 C) above the historical average in the 2020s and continues increasing over time, reaching 2.4 – 7.2 F (1.35 -3.98 C) above historical average by the 2090s. Projected trends in PET and ppt point to increasing drier conditions during the fall. Changes in ppt are variable but decreases from the historical average ppt are expected, with the 10-year average ppt declining from the historical average by 0.21 – 0.17 inches in the 2020s and by 0.02 – 0.07 inches by the 2090s. Changes to PET, conversely, are unidirectionally increasing; the 10-year average increases by 1.0 – 1.03 inches in the 2020s and reaches 2.01 – 2.86 inches above the historical average by the 2090s.

Winter – average temperatures continue to rise over time. The 10-year average tmax increases by 1.9 – 2.2 F (1.08 – 1.23 C) in the 2020s, reaching 5.4 – 9.2 F (2.98 – 5.11 C) above historical conditions by the 2090s. Similarly, the 10-year average tmin increases by 1.3 – 1.7 F (0.74 – 0.94 C) during the 2020s, reaching 4.4 – 8.3 F (2.46 – 4.60 C) above the historical average by the 2090s. The average ppt is projected to be below the historical average through mid-century with 10-year average 0.09 – 0.06 inches below the historical average in the 2020s. By end of the century the winter ppt increases, with the 10-year average 0.02 – 0.33 inches above the historical average by the 2090s.

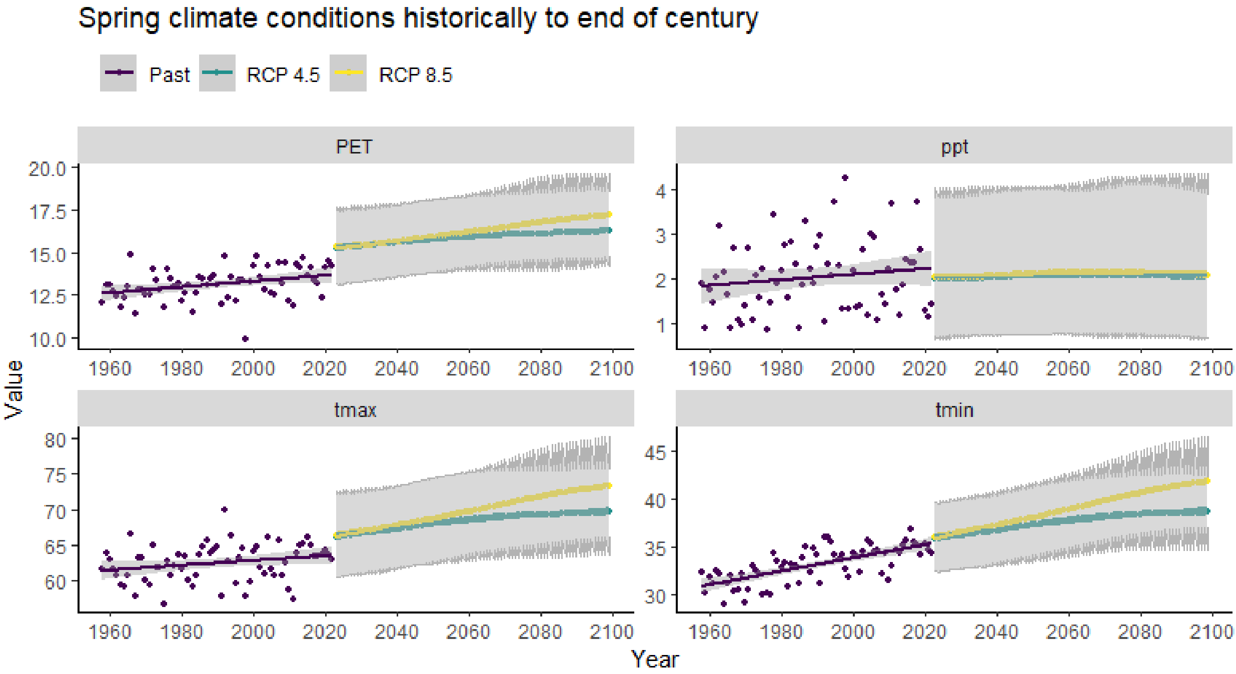

Figure 5.1. Climate conditions for spring from 1958 through 2099. Axes units are: inches for PET and ppt; F for tmax and tmin. Trend line: linear model in R, Tidyverse, ggplot2, and Viridis packages.

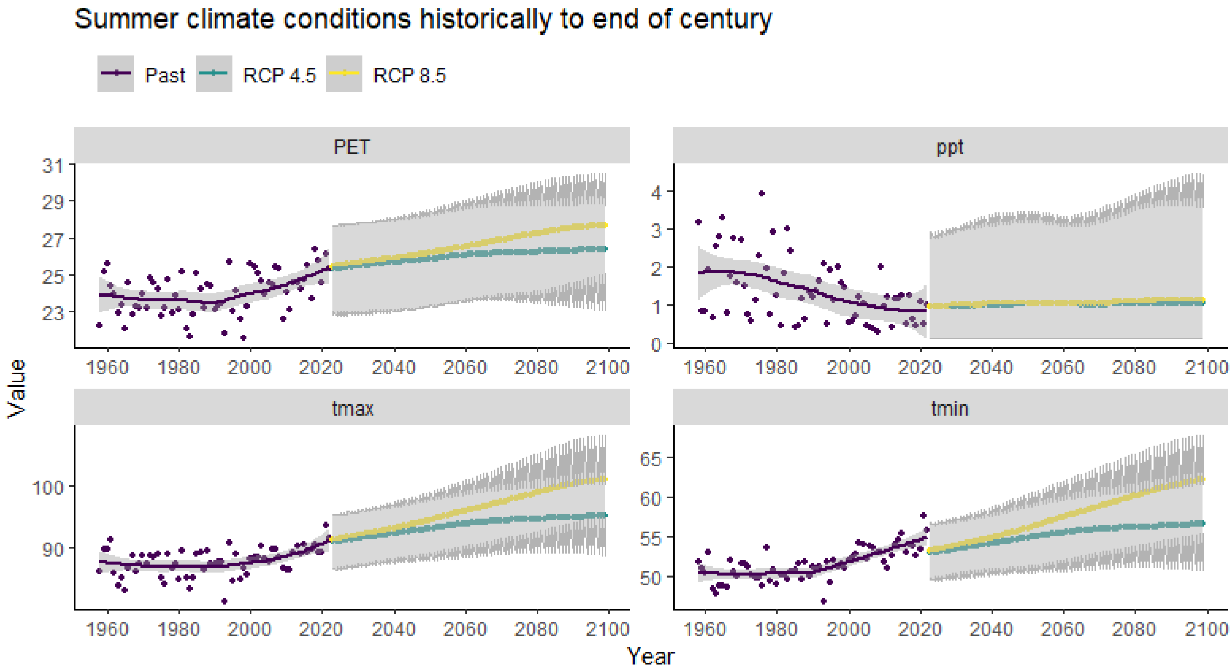

Figure 5.2. Climate conditions for summer from 1958 through 2099. Axes units: inches for PET and ppt; F for tmax and tmin. Trend line: linear model in R, Tidyverse, ggplot2, and Viridis packages.

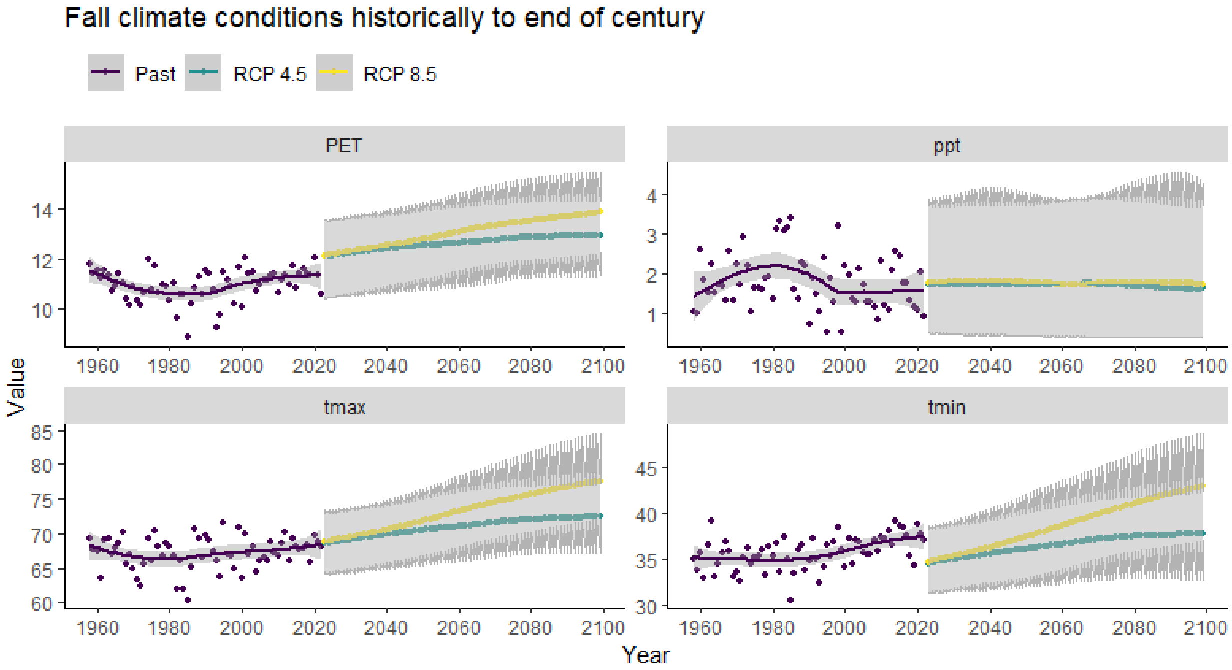

Figure 5.3. Climate conditions for fall from 1958 through 2099. Axes units: inches for PET and ppt; F for tmax and tmin. Trend line: linear model in R, Tidyverse, ggplot2, and Viridis packages.

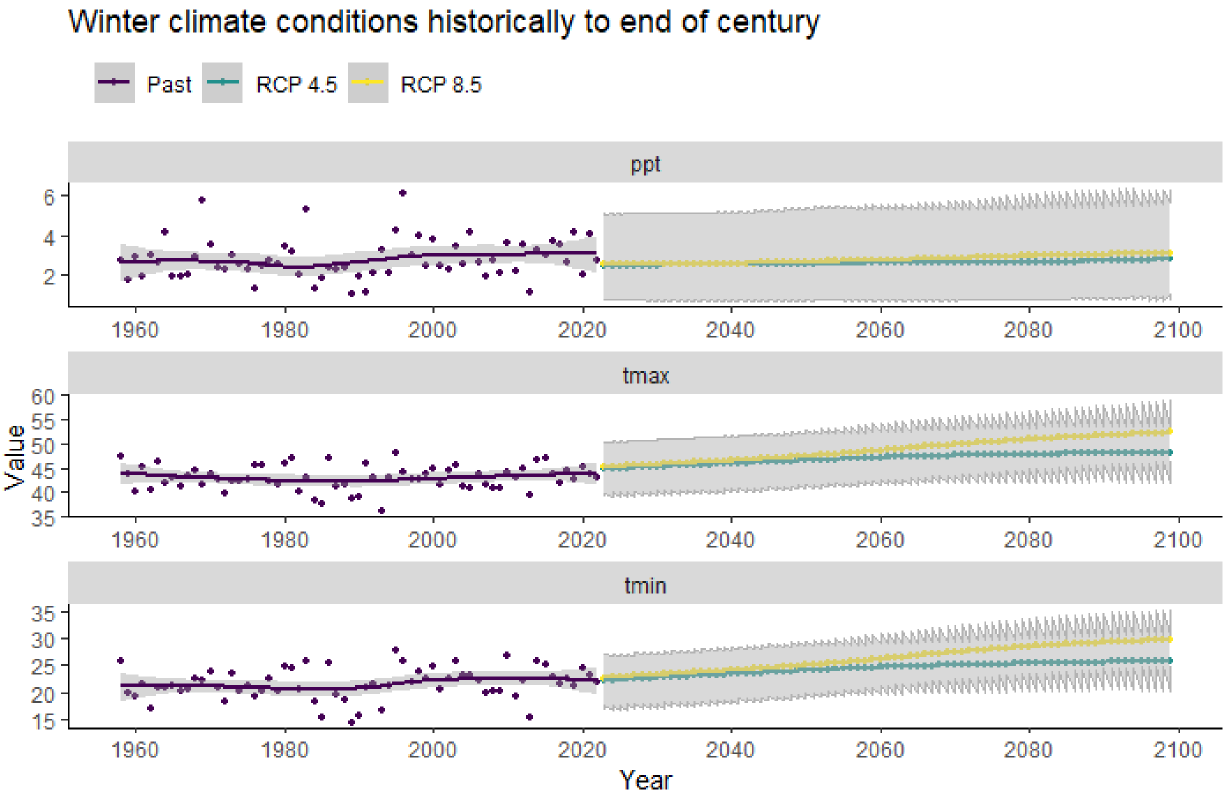

Figure 5.4 . Climate conditions for winter from 1958 through 2099. Axes units: inches for PET and ppt; F for tmax and tmin. Trend line: linear model in R, Tidyverse, ggplot2, and Viridis packages.

Number of heat events — the trend in the number of extreme heat days continues increasing under both scenarios (Figures 5.5 and 5.6). The average annual number of days exceeding the 35 C (95 F) threshold increases by 16 – 24 days in the 2020s and by 36 – 66 days in the 2090s. The average annual number of days exceeding the 38 C (100 F) threshold increases by 8 – 12 days in the 2020s and by 22 – 61 days in the 2090s. The average annual number of days exceeding the 41 C (105 F) threshold increases by 1 – 2 days during the 2020s and by 8 – 37 days during the 2090s. The projected average number of heat events (RCP 4.5, RCP8.5) are provided below for decades 2020s, 2040s, and 2090s; see Appendix A, Tables A3 -A4 for all decades.

The average annual number of days where tmax exceeds the 35 C (95 F) thermal threshold:

- 2020s: 37 – 45 days; of these, 35 – 42 days are in summer
- 2040s: 49 – 58 days; of these, 45 – 51 days are in summer
- 2090s: 57 – 87 days; of these, 51 – 70 days are in summer

The average annual number of days where tmax exceeds the 38 C (100 F) thermal threshold:

- 2020s: 11 – 15 days; of these, 11 – 14 days are in summer
- 2040s: 23 – 23 days; of these, 21 – 23 days are in summer
- 2090s: 25 – 65 days; of these, 25 –57 days are in summer

The average annual number of days where tmax exceeds the 41 C (105 F) thermal threshold:

- 2020s: 1– 2 days, all of which occur in summer
- 2040s: 3 – 5 days, all of which occur in summer
- 2090s: 8 – 38 days, 8 – 36 days are in summer

Anticipated population response

Given the projected increases in temperatures and projected decreases in moisture, population abundance is expected to decline over time. Data from studies of insects and butterflies indicate that sensitivity to changes in environmental conditions vary by life stages, with immature stages generally more sensitive than adults (see Chapters 2 and 4 for further discussion of the underlying mechanisms and references).

During the active life stages (adult, egg, and larvae), in the summer and fall, temperatures and moisture levels are projected to markedly deviate from historical averages under both scenarios. In the near-term (over the next 7–10 years, 2020s) under the lower bound projection, for example, summer maximum and minimum temperatures will exceed the historical average by 4 F and 3 F (2 and 1.6 C), respectively, and fall maximum and minimum temperatures will rise by 2 F and 0.4 F (1 and 0.2 C), respectively. These projected near-term increases in temperature are likely to reduce immature and adult fitness and likely intensify over time with increasingly warmer temperatures. Under the upper bound projection, the fitness consequences will mirror the lower bound in the near-term but by mid-century the impacts increase in severity as temperatures rise faster. For example, the increase in tmax from the historical average for the lower and upper bounds in 2050s is 6 F and 8 F (3 and 4 C), respectively, and by 2090s, 8 F and 13 F (4 and 7 C), respectively. The fitness consequences associated with rising temperatures will likely be exacerbated by declining moisture levels (increasing PET and stabilizing yet below historical ppt averages).

The pupal stage is the longest, spanning winter through summer. Pupae are immobile making them especially vulnerable to unfavorable conditions (York and Oberhauser 2002, p. 295). During the winter diapause stage, when individuals are especially sensitive to warming temperatures and decreasing moisture, temperatures are projected to increase and do so similarly under both the lower and upper projections until 2070s, where temperatures rise more steeply under the upper bound projection. Although the average projections for precipitation suggest little change from historical levels, the uncertainty bounds for precipitation are inordinately large and do not appear to be a reliable indicator of moisture level (e.g., past winter moisture levels are declining despite stable ppt levels), so we do not have good confidence in the average projections for moisture. From late spring through summer, both maximum and minimum temperatures are projected to increase under the lower and upper bound projections. Although projections for precipitation suggest stasis, marked increases PET indicate drier conditions under both scenarios. Increases in temperature can lead to premature development and adult emergence, and the concomitant decreases moisture can increase risks of desiccation and death. Overall, the projected increases in temperatures in winter through summer, coupled with the already drying conditions, are likely to substantially impact the fitness of pupae.

Additionally, the annual number of extreme heat events increase rapidly over time. In the near-term, under both projections, the number of 35 C (95 F) days continues to increase during the summer months, and while there are far fewer events in the fall, the increasing trend observed in the recent decade continues. Looking further out, the number of days steadily increases both in summer and fall under the lower and upper bound projections. Although the temperature experienced by the individuals may be buffered by micro habitat heterogeneity, temperatures exceeding 35 C (95 F) are likely to impose at least sublethal fitness consequences. The severity of these consequences will increase with increasing frequency of exposure. Also, the sensitivity of individuals to heat events may be heightened over time as increasing night-time temperatures limit recovery time from daytime heat stress. Furthermore, heat stress experienced in an earlier life stage can accumulate over time, leading to adult fertility and survival consequences despite not being directly exposed to summer heat events (York and Oberhauser 2002, p. 295; Klockmann et al. 2017, p. 6). As the entire next year's cohort depends upon the previous year's reproductive success, even a few extreme heat events in a single year can substantially reduce abundance.

Exposure to the heat events exceeding 38 C (100 F) could cause mortality. The number of days where temperature exceeds 38 C (100 F) is confined largely to summer period until later century, where notable increases in the number of extreme temperature events in the fall occur under both scenarios. Exposure to extreme temperatures for even a limited time can lead to substantial mortality and possibly extirpation; the latter is true especially for univoltine species, whose subsequent year's population rests solely on the performance and survival of a single cohort.

Lastly, there are habitat implications associated with projected changes in climate conditions. Increasing temperatures and drying conditions projected under both scenarios during the larval stage may affect the nutritional value and availability of saltgrass and rabbitbrushes, further exacerbating the direct impacts.

Given these results and the poor current condition of the Pueblo Slough population, it is likely that the negative impacts from warming and drying conditions continue in the near-term and intensify over time. We lack population trend data for both Gridley Lake and Rincon Creek populations, but given the magnitude of warming projected, it is likely both populations will respond similarly to the projected climate conditions. If these populations currently have robust population growth rates (which is highly unlikely for Rincon Creek given its low survey count), the populations will have more buffer (less likely that all individuals perform poorly) than the Pueblo Slough population, exposing them to a lower risk of extirpation in the near-term. Nonetheless, as they are exposed to increasing higher temperatures and drying conditions over the next 7–10 years and beyond, population declines are likely. Notably, the risk of catastrophic declines and extirpation due to extreme heat events is increasing. The risk of exposure to the 38 C (100 F) thermal limit continues increasing in the near-term and accelerates by mid-century; the risk of exposure to the 41 C (105 F) threshold increases more slowly but under the upper bound, the trend markedly increases in 2060. Thus, climate change impacts, both direct and indirect, are likely to have major impacts on all three populations in the near-term and intensifying over time under both the lower and upper bound projections.

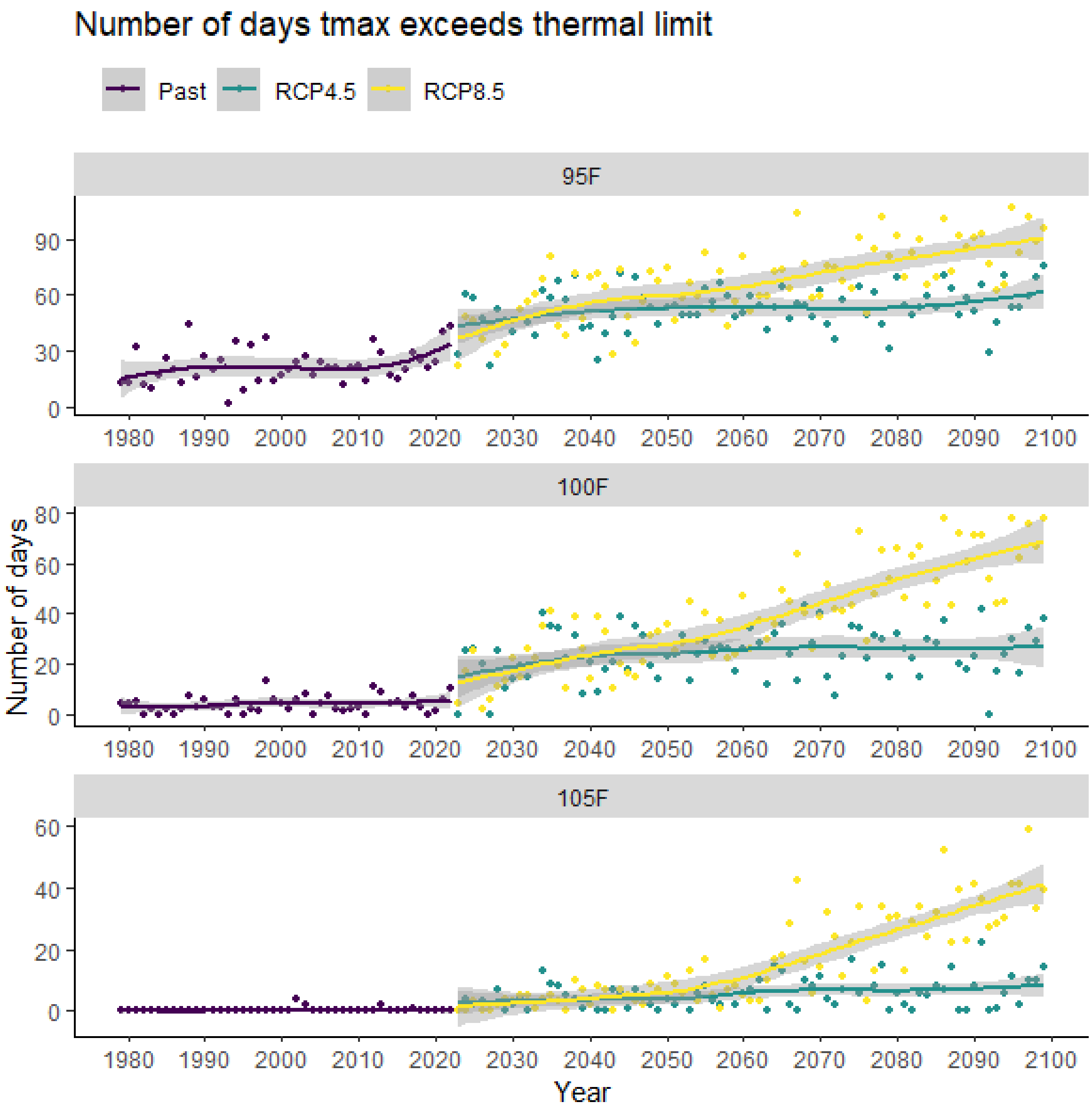

Figure 5.5. Number of days by year where tmax exceeds 3 thermal limits under RCP 4.5 and RCP 8.5.

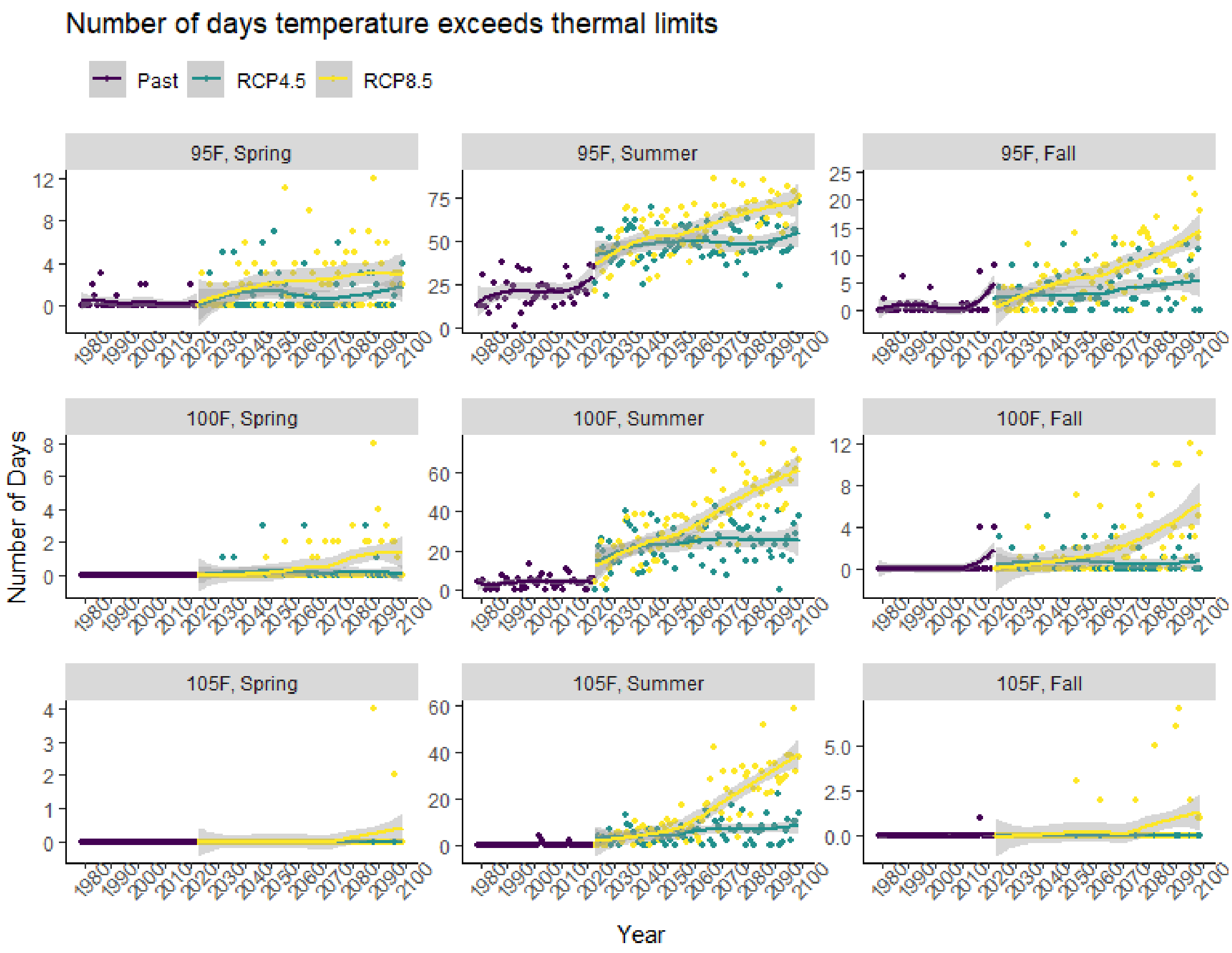

Figure 5.6. Number of days by season where tmax exceeds 3 thermal limits under RCP 4.5 and RCP 8.5.

5.4 Geothermal Energy Production

In 2021, the BLM approved a geothermal development project (the Baltazor Geothermal Development Project, "Geothermal Project", proposed by Ormat Nevada, Inc.) adjacent to bleached sandhill skipper's habitat at Pueblo Slough (Figure 5.7). The proposed development is a binary closed-loop geothermal facility; meaning it will pump groundwater from the geothermal reservoir, extract heat from the water by using a heat exchanger and secondary fluid that remains isolated, and then reinject the cooled groundwater into the geothermal reservoir (BLM 2021a, p. 10). During testing and development, geothermal flow at the spring may be affected (i.e., higher or lower) until the new flow pattern associated with extraction and reinjection re-equilibrates, as long as they effectively reinject into the same reservoir. While the physical footprint of the Geothermal Project is outside of bleached sandhill skipper habitat (BLM 2021c, Appendix A-1), the 11 proposed well pads, which would be built for both production (extraction) and injection wells are located between 200 m (656 ft) to 1000 m (3280 ft) from habitat, and the proposed power plant is 200 m (656 ft) from habitat. The closest well pads and power plant would be approximately 500 m (1640 ft) and hydrologically upgradient from the surface expression of Baltazor Hot Spring. The Geothermal Project is targeting a geothermal resource 1000 m (3280 ft) to 4000 m (13123 ft) below ground surface.

Because it is a closed loop system, essentially the same amount of water will be reinjected as extracted. Similarly, the water chemistry is expected to be minimally affected (allowing for slight differences that may occur due to cooling temperatures). Ormat intends to extract water at 137 C (280 F), with planned reinjection temperature of 76 C (170F). Reinjected water will eventually cool the reservoir over geothermal power plant operational timelines, and these waters will blend with natural hydrothermal circulation, ultimately reaching Baltazor Hot Spring or other discharge locations.

Generally, the development or operation of the geothermal power plant may lead to a reduction or alteration in hot spring flow, groundwater flow patterns, and changes in spring water temperature and chemistry (Hunt 2001, p. 14; Bayer et al. 2016, pp. 366–367). The geothermal resource being targeted by Geothermal Project is almost certainly the same source that provides flow to Baltazor Hot Spring (Szymanski et al. 2023, entire). Complete understanding of the hydrogeology is unknown at this time. The two mostly likely effects are changes in pressure to the system that could affect discharge to the hot springs for short or sustained periods, or changes that could alter underlying hydrology and permanently affect discharge from the springs. Temperature of the geothermal resource will decline over time, however given the system is significantly above boiling temperature for atmospheric pressures (100 C, 212 F), temperatures of the geothermal reservoir would have to decrease from 137 C (280 F) to below 100 C (212 F) or less before those temperature changes would be realized at the surface discharge of Baltazor Hot Springs.

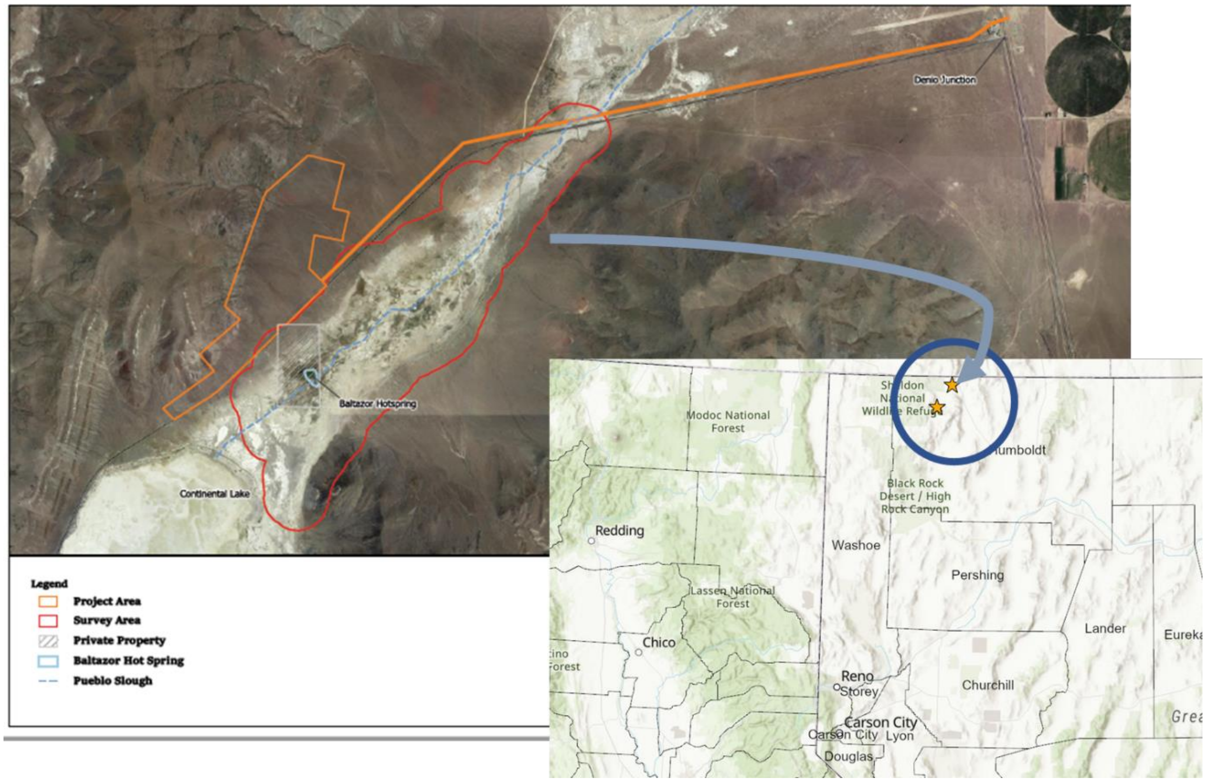

Figure 5.7. Map of the proposed geothermal energy project adjacent to Pueblo Slough bleached sandhill skipper population (BLM 2021a, Figure 2-1.1).

Baltazor Hot Spring provides perennial water to Pueblo Slough, and thus, loss or decline of this flow would result in increasing depth-to-groundwater for this system. We are unable to assess impacts from associated actions (e.g., noise or night-time lights from drilling or plant operation) due to insufficient information in both the scientific literature and project information.

Future projections and rationale

Limited information is available for future projections of geothermal development at Baltazor Hot Spring. Thus, we conducted a structured expert elicitation to better discern likely impacts from the proposed Geothermal Project (Szymanski et al. 2023). The results from the elicitation were used to derive lower and upper bound projections. Both experts on our panel expressed a strong belief (both 100%) that due to proximity between hydrothermal upflow measured in wells near the proposed powerplant and Baltazor Hot Springs, there is a connection between the geothermal reservoir and Baltazor Hot Springs. However, the experts differed in their estimate of whether a decrease in discharge would occur at Baltazor Hot Springs with best estimate of 0–66% (experts' uncertainty ranged from 0–100%). However, if a decrease in discharge were to occur, the experts' best estimate was overall 10–25% decrease in discharge (experts' uncertainty ranged from 0–75%). This potential decrease in discharge was considered most likely to occur during the initial 5 to 10 years (resource confirmation phase) of the project; with decreases during the production phase considered less likely (10–20% chance) but still possible due to reconfiguration of hydrothermal flowpaths in response to pumping (Szymanski et al. 2023). Any reduction in discharge would likely return to pre-project conditions, or close to, following operational adjustments to maintain pressure in the geothermal resource. We used the experts' best estimates to develop our lower and upper bound projections (we discuss the implications of the experts' uncertainty in Chapter 7).

- Lower bound projection: A reduction in discharge of 0% over the first 5 to 10 years Expert 1's best estimate of the "likelihood of a decrease in discharge" was zero, so we chose 0% as the lower bound.

- Upper bound projection: A reduction in discharge of 25% over the first 5 to 10 years Expert 2's best estimate of the "likelihood of a decrease in discharge" was 66%, so we chose this experts estimate of the "% reduction that would occur," which was 25%, as the upper bound.

Under both scenarios, we assume it is in the best business interest of Ormat Nevada, Inc.to maintain stable pressure in the geothermal reservoir, and thus, if the reservoir would become unstable, we assume they would quickly identify and remedy the situation. At this time, however, the water monitoring plan is still under development, so uncertainty exists on whether they will be able detect declines and what mitigation may be implemented should a decline be detected.

Anticipated population and habitat response to the lower and upper projections

Similar to anticipated population and habitat responses outlined for groundwater pumping, with decreased flow of Baltazor Hot Springs under the lower and upper bound projections, we anticipate increases in depth-to-groundwater. See Section 4.2 for a discussion on impacts to bleached sandhill skipper species and its habitat. While we have projected estimates for discharge reduction, we cannot quantitatively derive what that would mean in terms of absolute increase in depth-to-groundwater, due to lack of understanding how that subsurface flow moves across the slough, and we do not know the current depth-to-groundwater. Although the phreatophyte community is sensitive to drying conditions, Baltazor Hot Springs is not the only source of water for Pueblo Slough, thus we anticipate only minor effects under the upper bound, at a 25% decline in discharge rate.

For the Gridley Lake population, there is a geothermal exploration project 3–5 km (2–3 mi) northwest of Gridley Lake that is in the planning stages. The potential impacts to the bleached sandhill skipper population, if any, from this project are unknown at this time. There are no known geothermal development projects near the Rincon Creek population.

5.5 Summary of Impacts Associated with the Lower and Upper Bound Projections

Following methods in Chapter 4, we summarized the magnitude of impact at three distinct periods for the lower and upper bounds (Tables 5.4, 5.5 and Figures 5.8 – 5.10). A summary of the underlying rationale for each scenario is below.

Grazing Synopsis – At Pueblo Slough, under both the upper and lower bound projections, the current grazing system continues, with minor impacts to the population. The grazing system permits grazing during sensitive periods (nectar and hostplant development, and chrysalis emergence, or caterpillar activity and hostplant use) resulting in trampling or consumption of larvae and pupae and repeated stress on hostplant and nectar resources during critical periods. Two different grazing windows are permitted, potentially allowing for multiple years with no rest and therefore repeated direct impact on the immature stages and no recovery periods for the rabbitbrushes and saltgrass and the larger vegetation matrix. Given this potential, we anticipate minor effects on the population over time. Similarly, at Gridley Lake and Rincon Creek, the current grazing system (or lack there of) continues, and thus, under both the lower and upper bounds, we anticipate grazing will have no effect on the bleached sandhill skippers or their habitat,

Groundwater Pumping Synopsis – For all three populations, the lower bound projection is groundwater pumping at current rates; the upper bound projection is pumping at rates equal to water right appropriation, which are at or above perennial yields.

Available data suggest ongoing drying in the phreatophytic communities at Pueblo Slough and Gridley Lake, which we assess may be attributed to groundwater pumping for irrigation purposes. Because these effects likely take time to play out across the system (both in terms of time for water movement and then vegetation response time), under both upper and lower bound projections in the near-term, and lower bound projections far-term, we expect a continued reduction in the extent of suitable habitat. This is due to an increase in the depth-to-groundwater, but not a complete elimination of habitat due to a disconnect of the water table with saltgrass roots. Thus, we anticipate moderate impacts to the population under both the upper and lower bound projections in the near-term, and lower bound projections in the far-term at both Pueblo Slough and Gridley Lake. Under the upper bound projections in the far-term, we expect the impacts from groundwater pumping to worsen as more water is removed from the system (greater than four-fold increase for Pueblo Slough and 35% increase for Gridley Lake), with drying of the phreatophytic communities such that they will no longer support a vegetation matrix needed to support the bleached sandhill skipper populations. Thus, we anticipate major impacts to the population under the upper bound scenario in the far-term.

At Rincon Creek, we do not yet see a similar drying pattern in the southern extent of the population, but the population is down gradient to irrigated lands and we anticipate a similar pattern playing out here as at the other sites. Thus, under the lower and upper bound projections, we expect minor impacts in the near-term but increasing to moderate impacts in the far-term due to drying and subsequent deterioration of phreatophyte community over time.

Climate change synopsis- Under both climate change projections, temperatures and moisture levels are projected to markedly deviate from historical averages. Under the lower bound scenario, projected near-term increases in temperature during the summer and fall are likely to reduce immature and adult fitness and intensify over time as warming increases. Under the upper bound projection, the fitness consequences will mirror lower bound until mid-century when the rise in temperatures accelerates, likely leading to commensurate increases in the severity of fitness consequences. These fitness consequences may be exacerbated by declining moisture levels. Moreover, the number of extreme heat events (>35 C (95 F)) steadily increase in the fall and rapidly during summer in the near-term and far-term under both scenarios. Similarly, the number of lethally extreme heat events increase in the summer, with increases projected in fall beginning mid-century under the upper bound scenario. With these increases in extreme heat events, repeated exposure is likely potentially resulting in substantial mortality. As a univoltine species, bleached sandhill skipper's population persistence rests solely on the performance and survival of individuals from the previous year. Thus, increasing exposure to extreme heat events can substantially reduce population numbers and increase extirpation risk. Additionally, the increasing warming and drying conditions projected under both scenarios may affect the nutritional value and availability of saltgrass and rabbitbrushes, exacerbating the impacts on bleached sandhill skippers.

Given their proximity, all three populations will likely experience similar climate conditions and severity of impact, although the timing may differ. Given the current poor condition of the Pueblo Slough population, the negative impacts from warming and drying conditions will continue in the near-term and intensify over time. The population trend is unknown for both Gridley Lake and Rincon Creek, but given the magnitude of the change projected, it is likely both populations will respond similarly to changing climate conditions. If they have robust population growth rates (which is highly unlikely for Rincon Creek given its low survey count), the risk of extirpation will be lower in the near-term. However, as they are exposed to higher temperatures and drier conditions, population declines are likely, regardless of their current population health. Moreover, all three populations face increasing risk of severe declines due to extreme heat events in the near-term under both lower and upper bounds, with markedly increased risk of potentially catastrophic lethal temperatures in 2060 and beyond, under the upper bound scenario. Exposure to lethal extreme temperatures for even a limited time can lead to substantial mortality or extirpation, especially for univoltine species, whose subsequent year's population rests solely on the performance and survival of previous year's cohort. Thus, climate change impacts are likely to have major impacts on all three populations in the near-term and beyond under both the lower and upper bound projections.

Geothermal Synopsis – For effects to Pueblo Slough population, under both lower projects, no impacts are anticipated. Under upper bound projections, impacts are considered most likely only during the resource confirmation phase or initial years of commercial production until conditions equilibrate, estimated at 5–10 years from present. The geothermal development may affect discharge flow at Baltazor Hot Springs, resulting in increased depth-to-groundwater at Pueblo Slough under the upper bound projection. As Baltazor Hot Springs is not the only source of water for Pueblo Slough, we expect a 25% reduction in discharge rate may cause minor impacts to the habitat.

Table 5.4 Lower bound magnitude (confidence level) of impact in the near-term/mid-term/far-term associated with each influence for each population. Good confidence means our assumptions are strongly supported by the best available data and represent plausible outcomes. Fair confidence means our assumptions are reasonably by patterns in the available data and represent plausible outcomes. Low confidence signals scant data to inform our assessment, but minimally sufficient confidence that assumptions produce plausible outcomes.

	Grazing	Groundwater pumping	Climate change	Geothermal development
Pueblo Slough	Min/Min/Min (Fair)	Mod/Mod/Mod (Fair)	Maj/Maj/Maj (Good)	No effect/No effect/No effect (Good)
Gridley Lake	No effect (Fair)	Mod/Mod/Mod (Fair)	Maj/Maj/Maj (Good)	Not applicable
Rincon Creek	No effect (Good)	Min/Min-mod/ Mod (Fair)	Maj/Maj/Maj (Good)	Not applicable

Table 5.5 Upper bound magnitude (confidence level) of impact in the near-term/mid-term/far-term associated with each influence for each population. Good confidence means our assumptions are strongly supported by the best available data and represent plausible outcomes. Fair confidence means our assumptions are reasonably by patterns in the available data and represent plausible outcomes. Low confidence signals scant data to inform our assessment, but minimally sufficient confidence that assumptions produce plausible outcomes.

	Grazing	Groundwater pumping	Climate change	Geothermal development
Pueblo Slough	Min/Min/Min (Fair)	Mod/Mod-Maj/ Maj (Fair)	Maj/Maj/ Maj (Good)	Min/No effect/ No effect (Good)
Gridley Lake	No effect (Fair)	Mod/Mod-Maj/ Maj (Fair)	Maj/Maj/Maj (Good)	Not applicable

Rincon Creek	No effect (Good)	Min/Min-Mod/ Mod (Low)	Maj/Maj/ Maj (Good)	Not applicable

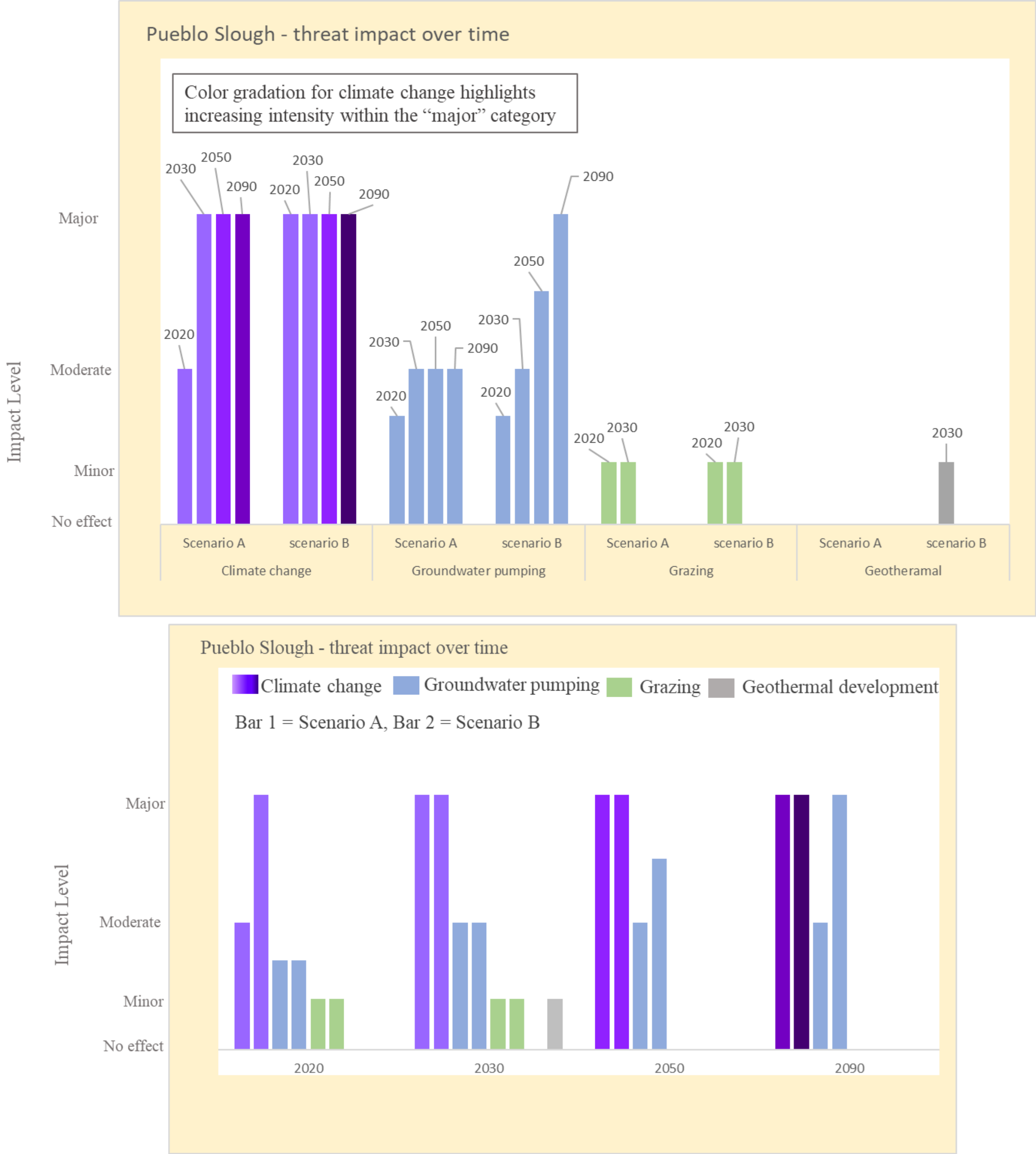

Figure 5.8. Projected impact category at the near-term (2030), mid-term (2050), and long-term (2090) for each threat for Pueblo Slough: categorized by threat (top) and by time (bottom).

Figure 5.9. Projected impact category at the near-term (2030), mid-term (2050), and long-term (2090) for each threat for Gridley Lake: categorized by threat (top) and by time (bottom).

Figure 5.10. Projected impact category at the near-term (2030), mid-term (2050), and long-term (2090) for each threat for Rincon Creek: categorized by threat (top) and by time (bottom).

CHAPTER 6. FUTURE CONDITIONS

In this chapter, we describe the subspecies and habitat conditions in response to two future scenarios. We combined the lower and upper plausible bound projections for each threat to create lower impact (Scenario A) and higher impact (Scenario B) composite future scenarios, which assess threats holistically. We used these composite scenarios to forecast bleached sandhill skipper habitat conditions and population abundance and trend over time.

Our analysis is predicated on the sensitivity of bleached sandhill skippers to warming and drying conditions. Although we have imperfect information, there is strong evidence and support underlying our assumptions about bleached sandhill skipper sensitivity to changing climate conditions and habitat sensitivity to increasing depth-to-groundwater levels. The underlying rationale for our assumptions are provided in Chapters 4 and 5, and we discuss the implications of key assumptions in Chapter 7.

6.1 Future Near-term and Long-term Habitat Conditions

Below we describe the impact to bleached sandhill skipper habitat conditions at the three populations in light of the interaction of the four primary threats: climate change, groundwater pumping, grazing, and geothermal development. These threats have overlapping, intensifying effects on the subspecies' habitat. Groundwater pumping and climate change are likely to contribute to drying habitat conditions through increases in depth-to-groundwater (pumping of groundwater, loss of recharge due to decreased spring flow, increasing evapotranspiration and decreasing precipitation). These factors will operate concurrently, accelerating the rate of drying. As drying conditions stress the habitat, impacts from livestock grazing and geothermal development become more influential.

Scenario A (composite of all lower bound projections)

At Pueblo Slough, we anticipate major impacts to the depth-to-groundwater, affecting habitat, due to synergistic effects of climate change and groundwater pumping. While existing shallow groundwater will be affected by groundwater pumping (loss of water) and climate change (loss of recharge), the decrease in flow of perennial water to the slough will be intensified through synergistic effects of these two factors. In addition, minor impacts from livestock grazing will become exacerbated under drying conditions as individual plants will not be able to recover from grazing under drying conditions, and area will be more prone to invasion by non-native species. Thus, the extent and suitability of the habitat will decline extensively in the near-term and substantially more so in the far-term, as these three factors affect the habitat. This may include shifts in relative cover of saltgrass and rabbitbrushes, or complete loss of these species, invasion by non-native plants, and decreased palatability of saltgrass for caterpillars. Rabbitbrushes may persist, but the production of nectar will decline. As extent and quality of habitat declines, so too does opportunity for habitat heterogeneity, thereby reducing availability of microclimate diversity. Thus, we anticipate major impacts to habitat at Pueblo Slough in near-term (2030) and intensifying from mid-century (2050) through in the far-term (2090).

At Gridley Lake, we anticipate similar impacts as described for Pueblo Slough. We do not anticipate the impacts from grazing, but the impacts from groundwater pumping and climate change will be similar to Pueblo Slough. Thus, we anticipate major impacts to habitat at Gridley Lake in the near-term through the far-term under the lower impact scenario.

At Rincon Creek, we anticipate moderate impacts for both the near-term and far-term. Grazing will not be acting on this population in the future and we anticipate that groundwater pumping will not play as strong of a role, but we expect similar impacts from climate change. Thus, we anticipate moderate impacts to habitat at Rincon Creek in the near-term through the far-term under the lower impact scenario.

Scenario B (composite of all upper bound projections)

The habitat consequences for all three populations under the higher impact Scenario B in the near-term will be similar to Scenario A, but more severe. At Pueblo Slough, loss of discharge from Baltazor Hot Spring and grazing would exacerbate the synergistic drying effect of climate change and groundwater pumping. In the near-term, major impacts are likely at Pueblo Slough and Gridley Lake and moderate impacts at Rincon Creek. By the end of the century, major impacts to habitat at all three populations are expected.

6.2. Future Near-term and Long-term Abundance and Trends

Below we describe bleached sandhill skipper abundance and trends given the combined direct impacts of climate change and the indirect impacts of projected habitat conditions as described above. We followed the methods in Chapter 4 to assign the magnitude of impact at three distinct periods: near-term (2030), mid-term (2050), and far-term (2090) for the lower and upper bounds (Figures 6.1, 6.2).

Scenario A (composite of all lower bound projections)

Under Scenario A, population abundance at Pueblo Slough is likely to continue in a downward trajectory, despite possible increases in abundance in years with favorable weather conditions (as observed in 2023). These favorable years are unlikely to compensate for the increasing and overriding deteriorating climate conditions. During the summer and fall, warming and drying trends continue, reducing immature and adult fitness, with increasing severity over time. Additionally, in the near-term, the number of days where temperature reaches or exceeds 35 C (95 F) (temperatures that likely cause negative population-level fitness consequences, and possibly mortality for immature stages) rapidly increase during the summer months affecting pupae; and while there are far fewer events in the fall, the increasing trend in the number of 35 C (95 F) heat events observed in the recent past continues. Exposure to these temperatures will likely cause fitness consequences in the pupal and adult life stages, with increasing severity as the frequency of exposure increases over time and increasing night-time temperatures limit recovery potential from daytime heat stress. Concurrently, the risk of extreme heat events, >38 C (100 F), are increasing as well, although more slowly and confined largely to the summer period. Exposure to 38 C (100 F) or higher temperatures is likely lethal for pupae, and severe sublethal fitness, and possibly lethal, consequences are likely for adults. Exposure to extreme temperatures for even a limited time can lead to substantial mortality and possibly extirpation if severe enough given its subsequent year's population rests solely on the performance and survival of a single cohort. The impacts from warming and drying conditions will be exacerbated by concurrent deteriorating habitat conditions described in Section 6.1.

The current health of the Gridley Lake and Rincon Creek populations are unknown. Assuming they have robust population growth rates, they may withstand the deteriorating climate conditions for a longer time, but population declines are likely given the projected increases in temperatures and drying conditions, exacerbated by concurrently deteriorating habitat conditions. Similar to Pueblo Slough, these populations face increasing risk of potentially catastrophic declines and extirpation due to extreme heat events.

Scenario B (composite of upper bound projections)

The population consequences for all three populations will be similar to Scenario A in the near-term, but likely more severe by mid-century as temperatures rise faster and more severe drying conditions are realized under RCP 8.5. Similarly, the number of extreme heat events mirrors Scenario A until mid-century, at which there is marked increase in the number of heat events, including potentially catastrophic (>38 C (100 F)) events.

In summary, for both Scenario A and B, we expect major impacts to abundance and trend in near term and far term for all three populations. That being said, the impacts under Scenario B are expected to be greater.

6.3. Summary of overall impact under the two future scenarios

Under both scenarios, the ongoing warming and drying conditions lead to deteriorating habitat conditions and population declines over the next 10 years with accelerated deterioration and declines by mid-century. The magnitude of declines will be similar under both the lower and higher impact scenarios until mid-century, when impacts to bleached sandhill skippers will likely be more acute under the higher impact scenario. As population abundances decline, they will reach a point where demographic and genetic stochasticity interact synergistically with environmental stochasticity, further reducing population size and genetic diversity, triggering a self-reinforcing extirpation vortex (Figure 6.2). It is unknown whether any of the three populations are presently near or in an extirpation vortex, but it appears to be inevitable in the future without population adaptation. Bleached sandhill skipper population adaptive capacity, however, is likely constrained by its relatively low genetic diversity (Jahner 2023, pp. 3–4) and its inflexible thermal limits. Both conditions suggest little potential for successful population adaptation given the magnitude and rapid change in climate conditions projected into the future.

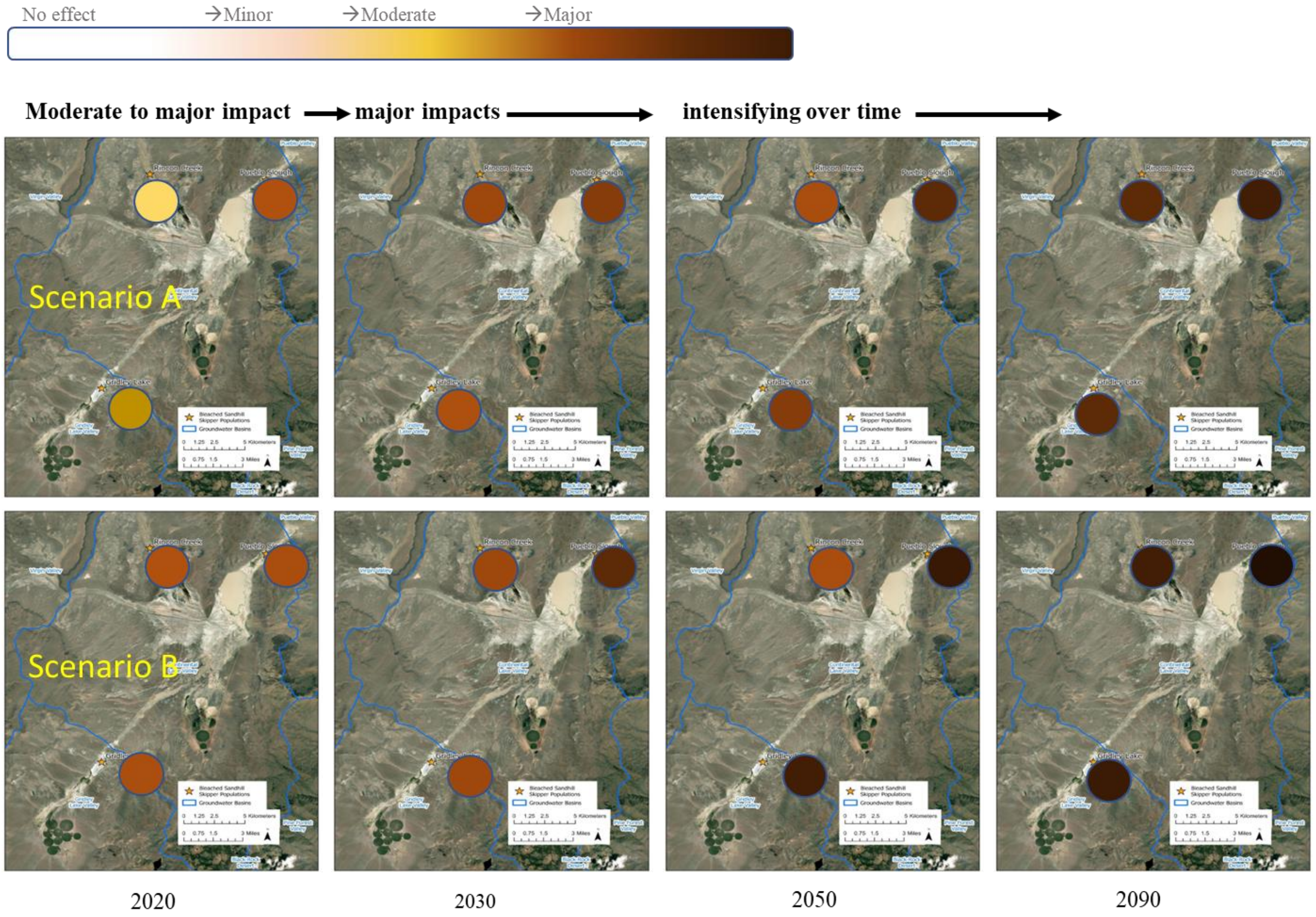

Figure 6.1 Magnitude of overall impact over time (2020 to 2090) given the combined effect of the influences under Scenario A (top row) and Scenario B (bottom row) for: Rincon Creek (top left circle), Pueblo Slough (top right circle), and Gridley Lake (bottom left circle). We have good confidence in our combined effect analyses. Shading depicts severity of impact.

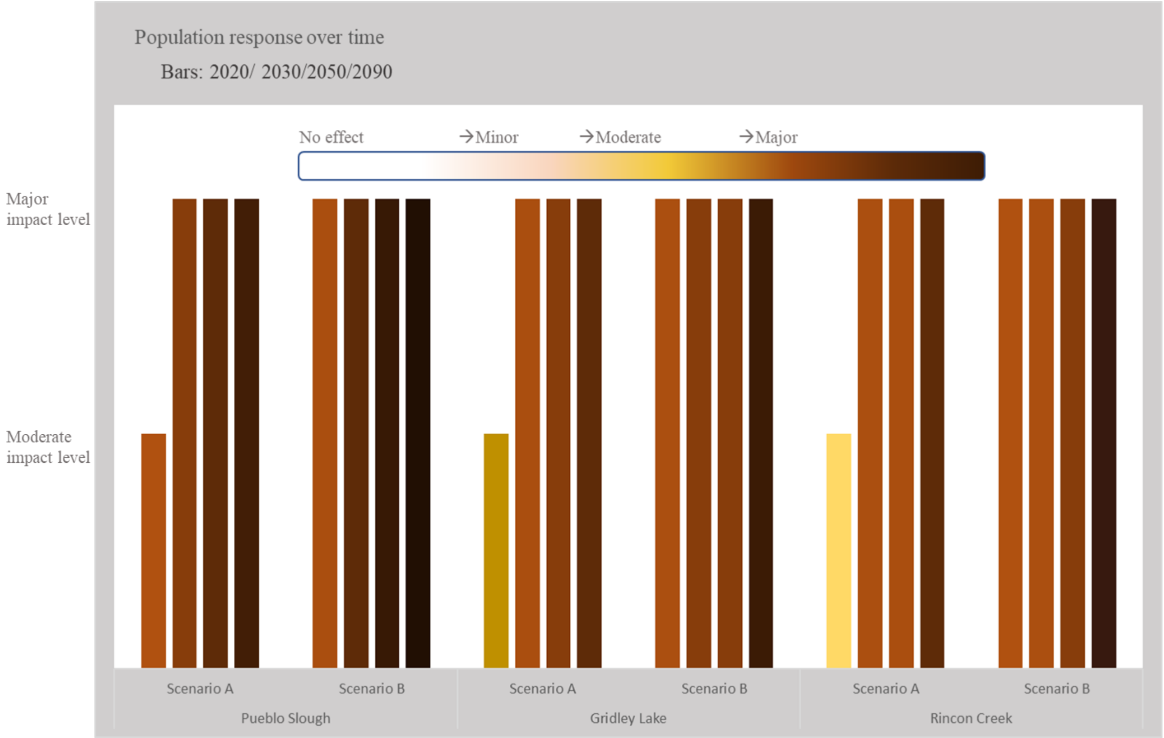

Figure 6.2 Magnitude of overall impact over time (2020 to 2090) given the combined effect of the influences for Scenarios A and B (data in Figure 6.1 grouped by population). Height of bars indicates moderate or major impact shading depicts severity of impact.

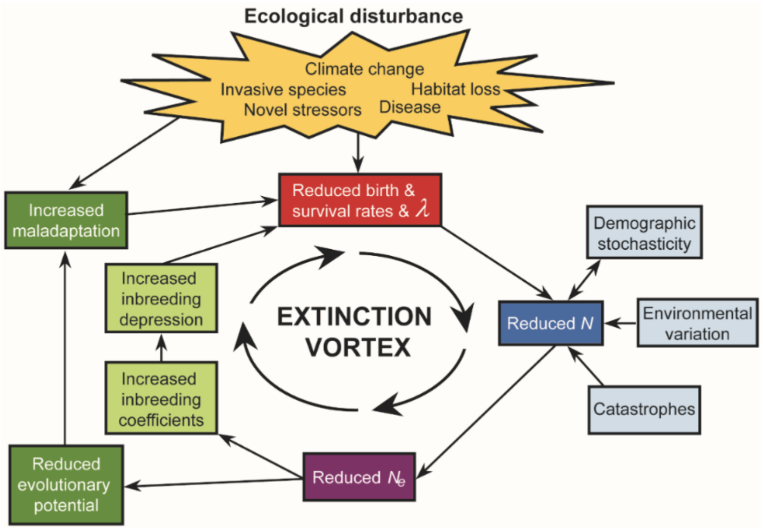

Figure 6.2. Extirpation process: threats (yellow) and stochastic processes (lt blue) interact, creating a vortex where threats reduce fitness (red), leading to declines in abundance (N, dk blue), increasing susceptibility to stochastic processes causing further declines in N, decreasing effective population size (N_e, purple), further reducing fitness via inbreeding depression (lt green) and maladaptation (Forester et al. 2022, p. 509).

CHAPTER 7. VIABILITY SYNTHESIS

This chapter synthesizes the results from our historical, current, and future analyses to assess the consequences for bleached sandhill skipper viability and extinction risk over time. As with any future-looking assessment, we have imperfect information and irreducible uncertainty. Our description of viability consequences applies the best available science and supportable, valid assumptions about bleached sandhill skipper response to stressors. These assumptions were derived from a comprehensive, although not exhaustive, review of a vast body of literature. We describe the implications of key uncertainties and our assumptions in the Uncertainties section below.

7.1 Ecological Needs for Viability

Bleached sandhill skipper viability is dependent on its ability to withstand environmental, demographic, and genetic stochasticity as well as perturbations (resiliency), catastrophic events (redundancy), and novel biological and physical changes in its environment (representation). Bleached sandhill skipper is a narrow endemic with seemingly little among-site habitat heterogeneity and [inferred] limited between-site dispersal potential. Thus its resiliency depends upon maintaining high population abundances and large effective (Ne) population sizes to withstand environmental, demographic, and genetic stochasticity, and on having sufficient quantity and quality of suitable habitat with diverse microclimates to support a healthy demography. Similarly, the subspecies' ability to withstand catastrophic events (redundancy) is completely dependent on maintaining high abundance in each of the three populations. Maintaining multiple populations is critical to the subspecies' survival as extirpation of a population would significantly lower redundancy, greatly increasing its risk of extinction to both catastrophic and non-catastrophic events. Bleached sandhill skipper ability to adapt to changing conditions (representation) is constrained by many of its life history traits (e.g., univoltine, diet and habitat specialist, inflexible thermal limits, inferred poor dispersal habits) and relies primarily on its within and among population genetic diversity. Thus, bleached sandhill skipper viability is strongly influenced by the demographic and genetic health of its three known populations.

Owing to its physiology, bleached sandhill skipper fitness (reproduction and survival) is tightly controlled by the temperature and moisture levels experienced by individuals, with significant reproduction and survival consequences triggered when environmental conditions fall outside the optimal range. Climate conditions also affect the quality of its hostplants, saltgrass, and its primary nectar plants, rabbitbrushes, with warmer and dry conditions reducing plant growth, inducing early senescence, and producing toxic compounds. Reductions in the quality and abundance of the subspecies' resources in turn influence individual fitness. Thus, the amount of good quality habitat (i.e., abundance of high-quality hostplants and nectar resources embedded within a well-connected, heterogeneous phreatophyte community with a diversity of microclimates) influences population abundance and growth rates. Additionally, maintaining (restoring) the natural levels of gene flow between populations is needed to support genetic health and thereby evolutionary potential.

7.2 Viability Synthesis

Bleached sandhill skipper viability requires multiple, healthy populations (abundant and strong growth rates). Until recently, bleached sandhill skipper populations had sufficient abundances and growth rates to withstand unfavorable environmental conditions despite its narrow geographic extent and low among-site heterogeneity. Over the last 10 years, however, bleach sandhill skipper abundance has been declining at Pueblo Slough, most likely due to climate change and groundwater pumping. Gridley Lake and Rincon Creek populations, because of their proximity and low among-site heterogeneity, are likely experiencing and responding similarly to rising temperatures and drying conditions.

With declining population health (low abundances) coupled with small geographic extent and low among-site heterogeneity, the subspecies now possesses limited ability to withstand inherent stochasticity (environmental, demographic, and genetic), catastrophic events (e.g., heat waves and droughts), and changing environmental conditions (e.g., chronic increases in temperatures, drying conditions, changing abundances of natural enemies, novel pathogens). The plausible future includes increasing temperatures and drying conditions over the near-term and markedly intensifying at mid-century and beyond under the higher impact scenario. In response, population declines will be exacerbated, further reducing the bleached sandhill skipper's ability to sustain itself, while concurrently, impairing the subspecies' ability to withstand stochasticity and catastrophic events. Moreover, declining population health constrains bleached sandhill skipper's seemingly low evolutionary potential (owing to the inferred limited ability to shift its range and its low within and among population genetic diversity), thereby exacerbating declines in the subspecies' resiliency and redundancy over time. Accordingly, our results suggest increasing, though unquantifiable, extirpation risks at all three populations in the near-term under both scenarios and accelerating by mid-century under the higher impact scenario owing to the rapidly increasing number of extreme heat events and concomitant habitat deterioration.

7.3 Uncertainties and Assumptions

We have imperfect information and irreducible uncertainty pertaining to future events. We are required, however, to make reasonable, plausible projections and assumptions. Below, we highlight key uncertainties and our confidence in the data underlying supporting assumptions and our best assessments of the implications of these assumptions. Good confidence means our assumptions are strongly supported by the best available data and represent plausible outcomes. Fair confidence means our assumptions are reasonably by patterns in the available data and represent plausible outcomes. Low confidence signals scant data to inform our assessment, but minimally sufficient confidence that assumptions produce plausible outcomes.

Population abundance and trends (low data, good confidence)

We have limited population data from Pueblo Slough and even fewer data for Gridley Lake and Rincon Creek populations. We have butterfly counts but insufficient data to derive population abundance estimates. Given the survey effort relative to the size of these sites, the count data provide a general idea of the population abundance. However, generally, at least 10 years of data are needed for determining population trend with great certainty (Didham et al. 2020, p. 109). At Pueblo Slough, the data suggest declining abundance, although increases are likely during good years (like observed in 2023). At Gridley Lake and Rincon Creek populations the data are too sparse to draw insights about population trend, but given the low counts and proximity to Pueblo Slough, we expect similar trends for these populations. Moreover, the sensitivity of bleached sandhill skipper to warming and drying conditions (see Species response) nullify many of these uncertainties as the populations are unlikely to withstand the magnitude of warming and drying regardless of their current health. That being said, if the population growth rates are robust and the abundance rebounds to healthy levels, declines may occur more slowly than we projected.

Groundwater pumping (fair data, fair confidence)
The State of Nevada Water plan is currently being revised, with the final plan anticipated in 2025. It will not change state law or reallocate water rights among current users but will develop options for management strategies, actions, and policies that can be implemented by various stakeholders. It will also develop recommendations aimed at increasing the sustainability and improving the management of water resources (NDWR 2023c, pp. 2–3). This may result in reduction of water use by highlighting challenges and needs for efficiency and providing tools to stakeholders; however, there is no regulatory certainty behind this. For these reasons, we assume there will be no further changes in water right allocations for these basins. Should these planning efforts, other steps by Nevada Division of water resource, or other factors such as a reduction in irrigated agriculture, affect water use in these groundwater basins below current pumpage rates, then we may find that effects from this threat are reduced. However, that reduction would need to be sufficiently at or below perennial yield, to allow depth-to-groundwater to maintain/reach the phreatophytic communities.

For Pueblo Slough, we have uncertainty that groundwater pumping as far away as Alder Creek (approximately 14 km (9 mi), may be affecting Pueblo Slough. However, the pattern in decreasing vegetation health is demonstrated by the NDVI data and consistent across the landscape between Alder Creek and Pueblo Slough. Beyond groundwater pumping, we are lacking reasonable other explanations, as this analysis controlled for climatic variability. In addition, Sinclair (1963 p.6) described that when there is sufficient groundwater in upgradient areas, that this would recharge areas downgradient. Thus, reduction in groundwater in upgradient areas (Gridley Lake and Alder Creek), would reduce this recharge to Pueblo Slough. Through this mechanism, we assume the more distant effects of groundwater pumping are percolating to Pueblo Slough. If we are incorrect in this assumption, then impacts to habitat at Pueblo Slough may be less than we predict.

Rincon Creek is located in Nevada, however, the northern extent of that valley where irrigated agriculture is occurring, is located in Oregon and is in the Harney Basin Groundwater Administrative Area. This demarcation is due to the state boundary and is not hydrologically driven. There are no data on current pumpage, aquifer recharge, depth to groundwater trends, or water rights for the northern extent of that valley. The extent also does not have a water budget determined (Oregon's equivalent to Nevada's perennial yield). However, current pumpage is exceeding recharge in other areas within that Administrative Area in Oregon (Gingerich et al. 2022, p.103). Therefore, we assumed impacts to Rincon Creek on the information for the groundwater basin within which it occurs (Continental Lake Valley) as we presume patterns are similar. If patterns of water rights, such as pumpage relative to aquifer recharge, are less for the extent in Oregon than in the rest of Continental Lake Valley, then the impacts to habitat may be less than we predict.

Climate change projections (good data, good confidence)
The lower and upper bound projections (RCP 4.5 and RCP 8.5) were derived from models developed by climate scientists around the world and represent best science for climate

modeling. These climate projections are based on assumptions about plausible future changes for four factors that are the dominant drivers of GHG emissions: population growth, economic growth or per capita gross domestic product (GDP), energy intensity, and the carbon intensity of energy production (Van Vuuren et al, 2011, pp. 16-18). A combination of projections can produce a reasonable range of plausible outcomes (Terando et al. 2020, p. 8).

Species response to increasing temperatures and drying conditions (fair data, good confidence)

Our assessment was based on a comprehensive although not exhaustive review of a vast body of literature. We made a concerted effort to understand the patterns of butterfly response to climate change, and thus, despite imperfect information, we believe our analysis is valid and represents plausible responses to the warming and drying conditions. Our reasons are many. First, findings from a rapidly amassing number of studies over the last decade indicate high vulnerability of insects to the direct and indirect effects of changing temperature and moisture patterns (Harvey et al. 2023, p. 3; Halsch et al. 2021, p. 1), with butterflies considered especially vulnerable (Radchuk et al. 2013, p. 275). Owing to their small size and poikilothermic physiology, temperature and moisture control their flight ability, reproductive behavior, fecundity, ovipositing, feeding, development, and diapause (Gonzalez-Tokman 2020, p. 811; Palumbo 2011, entire). Thus, temperature and moisture are universal key determinants of insect fitness, including bleached sandhill skipper (Chapter 2), and even gradual, small changes in temperature and moisture can substantially affect insect viability (Harvey et al. 2023, p. 5, 20).

Second, for most species, response to warming and drying conditions has been negative (Crossley et al. 2021, p. 2709). This is particularly true in the southwest U.S. and Intermountain West as they are considered “hotspots for declining butterfly abundances” in response to dry or hot conditions (Crossley et al. 2021, p. 2707). Similarly, data from multiple sources show butterfly abundances have been declining in the southwest U.S. for the past several decades, and although the magnitude of decline varies with species and by location within species, there is a clear overall declining trend for the majority of the species studied (Forister et al. 2021, p. 1044). Notably, the nominate species, *P. sabuleti*, is among those with a declining trend and is considered among the top 10 at-risk species (Forister et al. 2021, p. 1043, Figure 2A; Forister et al. 2023, pp. 12-13, Figure 2). Moreover, bleached sandhill skipper-specific population data at Pueblo Slough, although limited, show a unidirectional decline (98 percent over 8 years) in bleached sandhill skippers.

Third, in addition to gradual increases in temperatures, insects are vulnerable to extreme, acute heat events. Data show that insects have sublethal and lethal thermal limits, temperatures beyond which severe reproduction, fecundity (fertility limits), and survival (critical limits) consequences occur (Harvey et al., 2020, p. 6687), with limited ability to acclimate (Weaving et al. 2022, p. 7). Coupled with the short lifespan and its annual lifecycle, a few hot day events in a single year can substantially impact reproductive success and reduce abundance and increase extirpation risk.

As a desert climate occupant, bleached sandhill skipper likely experiences conditions close to its upper thermal and moisture limits under normal conditions, leaving little buffer to cope with increasingly warming and drying conditions. The exact thermal limits for bleached sandhill skippers are unknown, but the range of temperatures triggering significant fitness consequences is fairly consistent among insects (Addo-Bediako et al. 2000, p. 742; Chown 2001, pp. 1070–1071; Sunday et al. 2011, p. 1823; Hoffman et al. 2013, p. 937). The thresholds selected are within the range reported by many studies. Bleached sandhill skipper thermal limits could be higher or lower, but based on available data, we have good confidence that at a minimum reproductive consequences will be triggered. Moreover, we did not shift the thermal limits downward in light of increasing nighttime temperatures (Harvey et al. 2023, pp. 12–14; Zhao et al 2014, p. 774) lending further support that our assumed thermal limits are plausible, if not low estimates for bleached sandhill skippers. Taken together, these data suggest that bleached sandhill skippers are sensitive to warming and drying conditions and corroborate our assessment of populations' response to the projected trends in environmental conditions.

If bleached sandhill skipper are less sensitive than we have assumed, the risk of catastrophic declines will be lower than we have projected in the near-term but unlikely to change for mid-century and beyond. Conversely, if the thermal limits are lower than we assumed, bleached sandhill skipper could be in an extinction vortex already and face high risk of catastrophic declines due extreme temperature events.

We did not analyze the potential change of precipitation type (e.g. snow versus rain) that may occur with warming conditions. However, with increasing temperatures, should more precipitation fall as rain instead of snow within habitat, this may affect pupal diapause fitness Changes in precipitation type across the region may also affect hydrology patterns, including recharge, that may affect habitat.

Climate change adaptation (fair data, good confidence)

Bleached sandhill skippers could be anomalous but vast majority of research suggest that insects can only weakly alter their temperature limits (Hoffman et al. 2013, p. 938, 944; Weaving 2022, p. 7). Based on the best available data, bleached sandhill skippers possess limited capacity to adapt to projected increases in temperatures, and thus, we have good confidence that our assumptions are valid and plausible. If incorrect, our assessment of impacts would likely be lower in the near-term, but unaffected in the far-term.

Local adaptation (low data, low confidence)

We do not have data on whether bleached sandhill skipper is uniquely adapted to its current locations and assumed none exist. Given the unique habitat (low lying alkaline meadows, with geothermal activity), coupled with its genetic distinctiveness from other subspecies' of *P. sabulet*i, the bleached sandhill skipper may be locally adapted to specific habitat conditions. If this is true, the subspecies' ability to adapt to changes in its local environmental will be more limited than we assumed.

Geothermal development (fair data, good confidence)

Under both scenarios, we assume it is in the best business interest of Ormat Nevada, Inc. to maintain stable pressure in the geothermal reservoir, and thus, if the reservoir would become unstable, we assume they would quickly identify and remedy the situation. At this time, however, a water monitoring plan for the project is still under development, so uncertainty exists on whether they will be able to detect declines and what management responses may be implemented to respond to such, such as adjusting pressure within the system or supplementation of flow, should discharge from the spring decrease.

During the expert elicitation, at least one expert assumed a monitoring plan would include development of a water monitoring plan, with baseline data collected for at least a year, include direct monitoring of discharge rates of Baltazor Hot Spring in addition to shallow and deep groundwater, and consideration for supplementing flows by diverting water from geothermal development if discharge is not otherwise recovered. If not able to monitor under those conditions, then outcomes could be more impactful to discharge rates, and thus habitat, than analyzed above.

For the upper bound scenario, we used experts' highest best estimate for decreases in discharge at Baltazor Hot Spring, which was 25%, and we estimated this would have minor impacts to habitat conditions at Pueblo Slough. However, the experts estimated uncertainty bounds, based on what could realistically occur, ranged from 0 to 75%. If decrease in discharge is greater than 25%, impacts up to 75% could result in moderate impacts to the habitat conditions at Pueblo Slough. Regardless, climate change will remain the most dominant threat.

The experts also noted that if the geothermal development affects the permeability of the geologic structure that feeds the spring and discharge, then discharge could be lost entirely and the loss of discharge would be unlikely to recover. They indicated very low likelihood of impacts to permeability the geologic structure, but noted it is a possibility.

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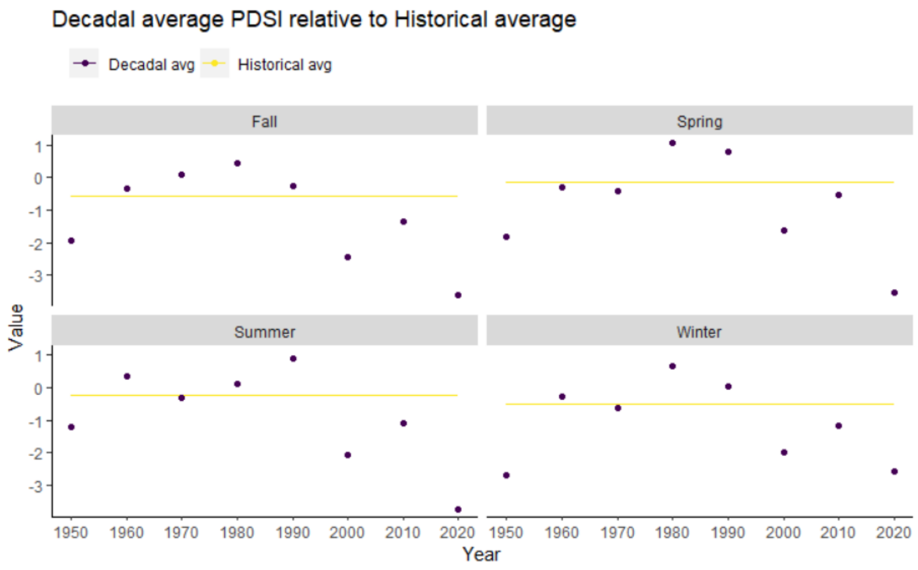
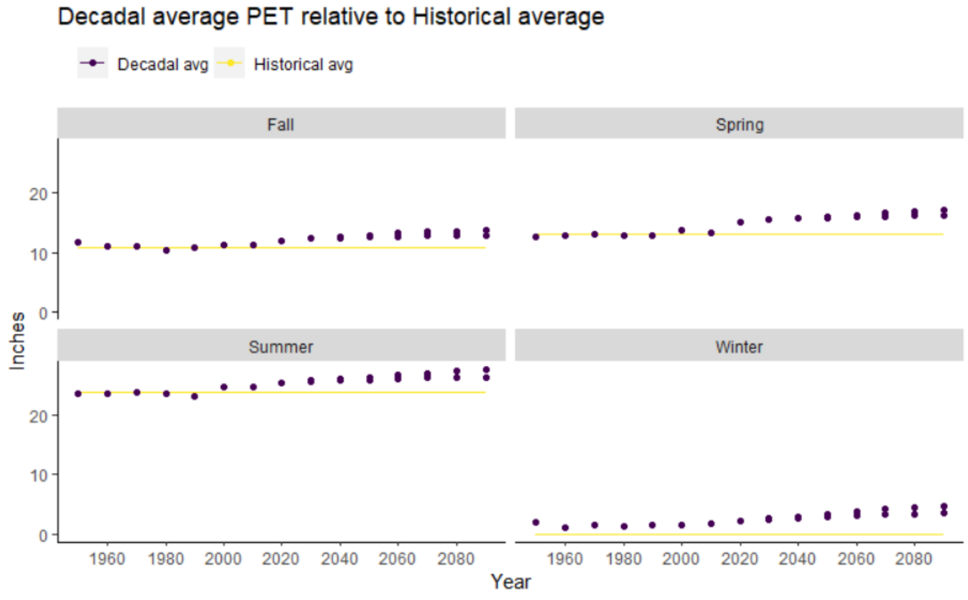
APPENDIX A – SUPPLEMENTAL RESULTS

Table A1. Example of butterfly upper thermal limits/sensitivities.

- *Danaus plexippus* (monarch) larval survival substantially declined when exposed to 40 C and 42 C and no larvae survived when exposed to 44 C (Nail et al., 2015, p. 106); larval development slowed with increasing temperatures 30 to 38 C (Zalucki 1982, p. 242; York and Oberhauser 2002, p.295; Nail et al. 2015, p. 107)
- *Colias eurytheme* (orange sulphur) larvae did not survive heat shocks at 35 C (Sherman and Watt 1973, p. 37); *Colias eurytheme and C. eriphyle* (yellow sulphur) larvae did not survive to pupate at 35 C (Sherman and Watt 1973, p. 37)
- *Colias eurytheme* adults experienced deleteriously high body temperatures at >40 C (Kingsolver et al. 2011, p. 5); adult males mean life span declined from 9.5 to 5.9 days at 45 C for 2 hours (Kingsolver and Watt 1983, p. 40); above 40 to 42 C, activity was substantially restricted (Kingsolver and Watt 1983, p. 48)
- *Colias eurytheme and C. meadii* egg and adult survival declined at temperatures greater than 38 C and significant declines at 40 C, although relatively high egg hatching rates was observed at some populations at 48 C (MacLean et al. 2016, p. 110)
- *Lycaeides melissa samuelis (*Karner blue butterfly) adult thermal limit is 35.5 to 36.5 C (96 to 98 F) (Lane 1999, p. 16)
- *Lycaeides melissa samuelis (*Karner blue butterfly) had reduced fecundity when exposed throughout the year to temperatures 2 C degrees above historical averages and the generally declined (mean egg count) with increasing temperatures (Bristow et al. 2023, p 8).
- *Bicyclus anynana*, a tropical butterfly, egg survival declined from 50% at 27 degree C to ~30 percent at 37 C; hatchling survival was 50% less when egg stage experienced 37 C compared to egg stage exposed to 27 C; declines in pupal survival declined from ~90 to ~50% when egg stage exposed to 27 C and 37 C, respectively (Klockmann et al. 2017, Figures 2, 3); egg numbers strongly reduced in both groups exposed to 39 C (Franke et al. 2014, p. 93)


Decadal average PDSI relative to Historical average
Decadal avg
Historical avg
Fall
Spring
Summer
Winter
Value
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000
2010
2020
Year


Decadal average PET relative to Historical average
Decadal avg
Historical avg
Fall
Spring
Summer
Winter
Inches
20
10
0
1960
1980
2000
2020
2040
2060
2080
Year

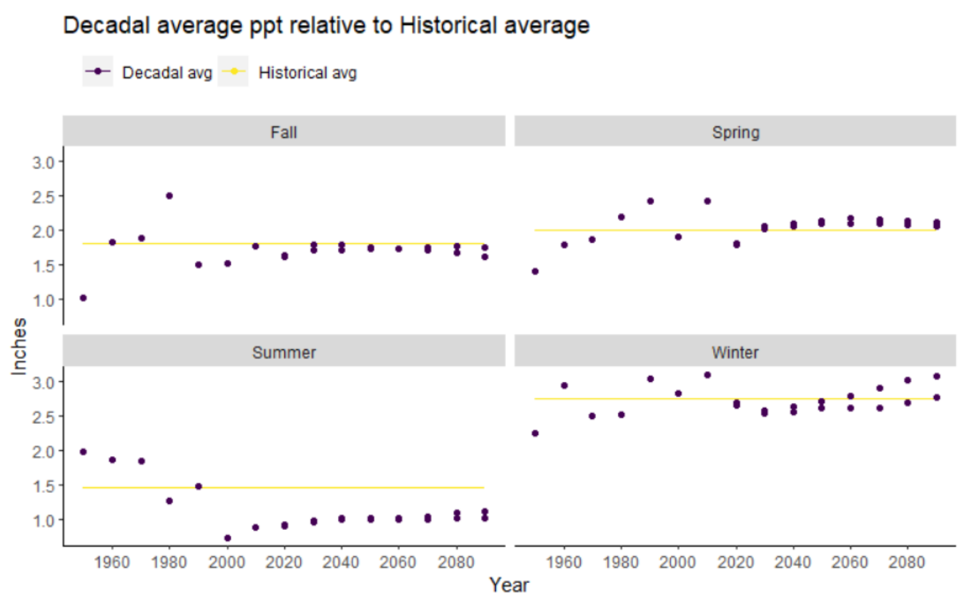


Figure A1. Showing the observed (up to 2022) and projected (>2022) decadal averages (dots) relative to the historical (<2010) average (horizontal line) for the three moisture variables: Palmer Drought Severity Index (PDSI), potential evaporation (PET), and precipitation (ppt). The decadal average is mean of values for the decade.

Table A2. Historical & observed decadal average for daily maximum (tmax) and minimum (tmin) temperatures (C), precipitation (ppt, in), and potential evapotranspiration (PET, in). Historical average is the average <2010. The observed 2010 average is for years 2010-2019; observed 2020 average is for years 2020-2022.

Variable	Season	Historical Average	2010 Observed	2020 Observed
tmax	fall	66.9	67.87	68.84
tmax	spring	62.3	63.14	65.55
tmax	summer	87.5	89.17	91.34
tmax	winter	42.8	43.83	44.75
tmin	fall	35.3	37.31	35.71
tmin	spring	32.8	34.61	35.68
tmin	summer	50.9	53.26	53.84
tmin	winter	21.3	22.19	22.63

Variable	Season	Historical Average	2010 Observed	2020 Observed
ppt	fall	1.82	1.77	1.61
ppt	spring	2.01	2.43	1.79
ppt	summer	1.46	0.88	0.91
ppt	winter	2.74	3.09	2.65
PET	fall	10.9	11.25	11.9
PET	spring	13.01	13.37	14.99
PET	summer	23.77	24.63	25.37
PDSI	fall	-0.56	-1.37	-3.62
PDSI	spring	-0.16	-1.18	-2.58
PDSI	summer	-0.24	-1.08	-3.73
PDSI	winter	-0.52	-0.55	-3.56

Table A3. The projected 10-year (decadal) averages under the lower bound (RCP 4.5) climate scenario. Daily maximum (tmax) and minimum (tmin) temperatures (C), precipitation (ppt, in), and potential evapotranspiration (PET, in).

Variable	Season	2020	2030	2040	2050	2060	2070	2080	2090
		RCP 4.5	RCP 4.5	RCP 4.5	RCP 4.5	RCP 4.5	RCP 4.5	RCP 4.5	RCP 4.5
tmax	Fall	68.84	69.46	70.13	70.73	71.28	71.79	72.14	72.36
tmax	Spring	65.55	66.91	67.58	68.28	68.82	69.15	69.35	69.52
tmax	Summer	91.34	91.95	92.73	93.51	94.17	94.58	94.83	95.05
tmax	Winter	44.75	45.59	46.25	46.89	47.4	47.72	47.96	48.17
tmin	Fall	35.71	35.3	35.85	36.38	36.9	37.35	37.61	37.73
tmin	Spring	35.68	36.44	36.98	37.55	38.01	38.34	38.5	38.58
tmin	Summer	53.84	53.71	54.42	55.11	55.67	56.03	56.23	56.43
tmin	Winter	22.63	22.99	23.68	24.36	24.86	25.22	25.51	25.72
ppt	Fall	1.61	1.72	1.72	1.73	1.74	1.72	1.67	1.62
ppt	Spring	1.79	2.03	2.07	2.09	2.09	2.09	2.08	2.06
ppt	Summer	0.91	0.96	0.99	1.01	1	1.01	1.03	1.03
ppt	Winter	2.65	2.53	2.55	2.61	2.62	2.62	2.68	2.76
PET	Fall	11.9	12.31	12.46	12.57	12.68	12.8	12.88	12.91
PET	Spring	14.99	15.48	15.67	15.86	16	16.08	16.15	16.22
PET	Summer	25.37	25.57	25.75	25.94	26.11	26.2	26.27	26.34

Table A4. The projected 10-year (decadal) averages under the upper bound (RCP 8.5) climate scenario. Daily maximum (tmax) and minimum (tmin) temperatures (C), precipitation (ppt, in), and potential evapotranspiration (PET, in).

Variable	Season	2020	2030	2040	2050	2060	2070	2080	2090
		RCP 8.5	RCP 8.5	RCP 8.5	RCP 8.5	RCP 8.5	RCP 8.5	RCP 8.5	RCP 8.5
tmax	Fall	69.02	69.91	71.07	72.43	73.83	75.04	76.15	77.14
tmax	Spring	65.75	67.25	68.16	69.16	70.17	71.25	72.24	73.01
tmax	Summer	91.64	92.56	93.77	95.17	96.59	98.04	99.52	100.69
tmax	Winter	45.02	46.13	46.94	47.99	49.22	50.33	51.26	52
tmin	Fall	35.87	35.77	36.8	37.97	39.21	40.4	41.54	42.47
tmin	Spring	35.85	36.85	37.6	38.42	39.31	40.22	41.02	41.61
tmin	Summer	54.07	54.25	55.35	56.65	58.01	59.35	60.67	61.73
tmin	Winter	22.98	23.62	24.49	25.55	26.79	27.97	28.93	29.59
ppt	Fall	1.65	1.8	1.8	1.76	1.74	1.76	1.78	1.75
ppt	Spring	1.82	2.06	2.1	2.14	2.17	2.16	2.13	2.11
ppt	Summer	0.92	0.99	1.02	1.02	1.01	1.05	1.1	1.12
ppt	Winter	2.68	2.56	2.62	2.7	2.78	2.91	3.01	3.07
PET	Fall	11.93	12.39	12.62	12.9	13.19	13.41	13.59	13.76
PET	Spring	15.04	15.52	15.76	16.04	16.31	16.61	16.89	17.1
PET	Summer	25.46	25.74	26.01	26.33	26.68	27.04	27.38	27.62