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Case Study

Using landscape patterns, climate projections, and species distribution models to map future potential habitats for desert tortoise, Shivwits milk-vetch, and American pika in Zion National Park, Utah

By David Thoma and Henry Shovic

Abstract: Quantitative assessment of climate effects is needed to help understand the spatial distribution of change to species habitat and species distribution that may occur in the next 100 years. This can provide insight for developing mitigation and adaptation actions for species survival on a park-level basis. We modeled the potential impacts of projected temperature change on habitat suitability for desert tortoise, Shivwits milk-vetch, and American pika in and around Zion National Park, Utah. We used species distribution models with historical temperature data from weather stations and climate projections of temperature to determine the location and suitability of present-day potential habitat and potential habitat in the year 2100. Our analysis was not intended to predict habitat quality or how species might respond. Rather, it was intended to map the location of potential or suitable habitat in Zion. Results indicated suitable habitat may increase in area for Shivwits milk-vetch, increase in suitability for the desert tortoise, but decline in area for American pika. Based on these findings, we made interpretations that summarized species vulnerability and potential impacts on species habitat and on park management. This type of information can serve as a starting point for developing a practical adaptation framework that considers potential management options at different temporal and spatial scales.

Key Words: American pika, climate change, climate projections, desert tortoise, lapse rate , mapping habitat changes, Shivwits milk-vetch, species distribution model, vulnerability assessment

Introduction

Mean annual temperature (MAT) at Zion National Park, Utah, has steadily increased since 1928 and will likely continue to increase as more carbon dioxide is added to the atmosphere (IPCC 2007a; Gonzalez et al. 2010) (fig. 1a, below, and figs.1b and 1c). Climate projections for Zion suggest that mean annual temperature by 2100 may be higher on average than in any year in the last century, including the 1934 Dust Bowl. Natural variability ensures that the temperature trend will not be as linear as shown by projections in figure 1, but at broad scales the upward direction and magnitude are very likely (>90% probability), according to the most credible and widely accepted projections (IPCC 2007b). Projected changes in precipitation are less certain, with some scenarios indicating increase and others decrease. What effect these changes in climate might have on species distributions if the new “normal” exceeds anything we have seen in the last 100 years is of great interest to park managers. We examine this question by explicitly mapping potential habitat under climate change scenarios 100 years from now for three species of concern in Zion by following established guidelines for vulnerability assessments (Glick et al. 2011). These maps and the associated data are a first step toward developing the credible scientific underpinnings for park-level planning under the constraints and opportunities of climate change.

Figure 1. (A) Zion-centered study area with location of Zion National Park headquarters weather station (red star).

Climate is the most important driver of species distributions at broad scales, but other factors like species interactions, dispersal, and physical factors such as soil type influence species distributions at the local or park scale. As climate changes, species will adapt, migrate, or perish in response to both direct and indirect effects, but which are the most likely outcomes? That depends on species life history traits, availability of habitat in the future, and a host of other factors that we cannot predict with accuracy. However, mapping the intersection of important landscape parameters in and near parks and climate in relation to species distributions provides clues to help predict where suitable habitat may exist in the future.

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Habitat maps are integral to adaptation frameworks in order to plan courses of action that could include managing for resilience, resistance, and facilitated migration (Stephenson and Millar 2012). More immediate actions based on habitat maps could include negotiating land sales or conservation agreements to protect or link habitats. Collectively, these kinds of adaptation actions could provide time and space for species to adapt to new climates. Yet in spite of its importance for planning, predicting future habitat for specific organisms is an evolving science with considerable uncertainty.

The goal of this research was to use existing data, models, and information from subject-matter experts to map current and future potential habitat for selected species in Zion National Park as input to a vulnerability assessment. Our focus was on the potential future habitat of the threatened desert tortoise (Xerobates [Gopherus] agassizii), the endangered Shivwits milk-vetch (Astragalus ampullarioides), and the climate-sensitive American pika (Ochotona princeps) in and near Zion (fig. 1a, above).

Climate change and range shift

The net result of projected changes in temperature and precipitation over the next 100 years will most likely be upslope compensatory range shifts (retraction) for most species (Stephenson and Das 2011). The expectation of upslope range retraction in the next century is consistent with observed upslope retraction for small mammals in Yosemite National Park (California) since 1914 on the order of 500 m (1,641 ft) per century (Moritz et al. 2008) and observed vertical shifts of 145 m (476 ft) per decade for Great Basin region pika since 2000 (Beever et al. 2011).

We used mean annual temperature projections from the Intergovernmental Panel on Climate Change (IPCC 2007a) that were downscaled to our study area (Gonzalez et al. 2010). We selected 100-year climate scenarios B1, representing a low greenhouse gas emission scenario (using the lower value of the range, or a 3°C [5.4°F] increase), and A2, representing a high-emission scenario (using the upper value of the range, or a 4.6°C [8.3°F] increase). This gave us a wide range of possible MAT futures for modeling habitat shifts and changes in habitat suitability. For this study we used projected changes in MAT alone as the climate predictor because of the inherent variability of precipitation and the wide range in its projected changes, which include both increases and decreases for this region over the next 100 years (Gonzalez et al. 2010; IPCC 2007c).

Modeling habitat shifts with species distribution models and lapse rate

Our mapping of potential future habitat consisted of three steps. First, we identified the spatial habitat characteristics and extent (e.g., talus for pika) of present-day species occurrence. This was accomplished via literature review and application of species distribution and persistence models (SDMs) (Beever et al. 2011; Nussear et al. 2009; Miller et al. 2007). Then we used the lapse rate to predict the elevation range where temperatures favorable to the species may occur in 2100. In the third step we used the shift as input to each SDM, mapped the resultant habitat, and compared it with its present extent.

Temperature lapse rate is the change in mean annual temperature with elevation, which we estimated from quality-screened mean annual temperatures since 1993 collected from seven weather stations in and near Zion. The lapse rate of 7.3°C/km (4.0°F/1,000 ft) (90% confidence interval ± 0.9°C [1.62°F]) means the average annual temperature is 7.3°C (13.1°F) cooler for every 1,000 m (3,280 ft) increase in elevation. Although lapse rates vary by region and location, ours is within the range reported by others (Ray et al. 2010; Minder et al. 2010). We determined the vertical elevation shift where mean annual temperature today will be in 2100 by dividing the projected temperature increase by the MAT lapse rate. For example the lower range for scenario B1 projections suggests a +3°C (5.4°F) change in mean annual temperature by 2100, which results in a given MAT upslope shift of approximately 400 m (1,300 ft). Similarly, the higher range for the A2 projection indicates an upslope vertical range shift of approximately 650 m (2,100 ft) (fig. 1c).

Actual range shift will vary by individual species and location, as has been observed in both paleontological and contemporary studies (Lyons 2003; Moritz et al. 2008). However, our coarse estimates are similar to rates of upslope habitat retraction already observed for some small mammals in Yosemite National Park and are about half the rate of upslope retraction observed for pika across the Great Basin region (Moritz et al. 2008; Beever et al. 2011).

For this project, we mapped the extent of talus patches that consisted of talus fragments greater than 25 cm (9.8 inches) in diameter as potentially suitable pika habitat. We then compared the elevation of mapped talus patches with a model of pika persistence from the Great Basin that quantifies the likelihood of pika persistence as a function of latitude, elevation, and available nearby talus (Beever et al. 2011) to predict latitude and elevation ranges favorable for pika survival.

The suitability of desert tortoise habitat was based on a spatial, statistical species-presence model (Nussear et al. 2009). Nussear used tortoise locations with an array of environmental factors to predict determinants of habitat suitability in the species' range and to calculate a numerical index of that suitability. Elevation and vegetation productivity were the most important contributors to the model and were used in this analysis.

The milk-vetch habitat model is based on a spatial intersection of factors that are strongly correlated with its distribution (Miller et. al. 2007). These include an obligate relationship to the Chinle geologic formation, an elevation range between 600 m and 1,700 m (2,000 ft and 5,580 ft), and slopes of less than 30%. The intersection of these landscape factors indicates potential habitat.

This research was conducted as our understanding of species habitat relationships continues to evolve. Important efforts aimed at refining our understanding of species vulnerabilities are the Pikas in Peril project (Garret et al. 2011), ongoing research on the habitat and drivers of Shivwits milk-vetch in Zion, and ongoing research on the desert tortoise.

Results and management implications

Understanding the effect of climate change on plant and animal habitat requires models at various levels of sophistication (from quantitative to conceptual) to identify possible future effects and opportunities. We integrated our modeling results with the elements used in vulnerability analysis to estimate magnitude and direction of impacts on habitat and occurrence within the park, on the species in general, and on park management. We realize that these interpretations are subjective but feel they must be made to effectively communicate results and stimulate discussion.

We considered the three elements of vulnerability: sensitivity (species traits, both genetic and behavioral), exposure (IPCC climate projections), and adaptive capacity (future habitat availability). These elements are subjectively ranked high, moderate, or low based on our interpretation of life history traits (either behavioral or genetic) that enable resistance and resilience to climate change. Ratings of potential impacts on the species within the park boundary are based on the modeled magnitude of habitat change combined with species presence data. Ratings of potential impacts on the species in general are based on the proportion of the species' presence in the park to its entire range, and to the potential threats to that range. Park management impacts relate to the potential for significant management action based on all the other ratings, as well as outside pressures, available park resources, and priorities. These data are summarized in table 1 and each impact is discussed below by species.

American pika

Pikas have a high normal resting body temperature of approximately 40°C (104°F), which is only 3.0°C (5.4°F) below the acute lethal upper limit for the species. Hyperthermia or death can occur after brief exposure (as little as six hours) to temperatures greater than 25.5°C (77°F), and chronic exposure above 28°C 82.4°F beneath talus is a good predictor of local extirpations (Smith 1974; Beever et al. 2010). High body temperature and year-round activity result in high energy expenditures and thermoregulation challenges for the species.

In warmer environments pikas typically become inactive during midday hours and withdraw into cooler spaces below the talus surface. Pikas persist in low-elevation, thermally undesirable environments by selecting habitat that contains spaces for underground movement and provides physical protection and cool refugia during hot conditions (U.S. Fish and Wildlife Service 2010; Smith 1974). Although we did not consider it in our work, pikas are also susceptible to freezing temperatures in the absence of an insulating snowpack (Beever et al. 2010; Beever et al. 2011). Unfortunately, we did not have interstitial talus temperatures available for evaluation.

We mapped physical components of pika habitat (talus slopes) using air photography and on-site inspection (fig. 2). Surveys at Lava Point indicated that in 2011 and 2012, pika were present. However, based on the pika persistence model (Beever et al. 2011) that relates pika survival to latitude and elevation (our proxy for temperature), the two highest-elevation talus patches (Lava Point and Jobs Head) are more than 1,400 m (4,593 ft) below the elevation where other populations have persisted at similar latitudes in the Great Basin. This may indicate the Lava Point habitat has unique characteristics that have enabled survival up to this point. However, unless these populations have access to thermal microrefugia deep under the talus or possess higher adaptive capacity than the pikas in the Great Basin, pikas in Zion are probably on the brink of survival and are not likely to survive even minimal future warming. Although pikas are not likely to survive in Zion through 2100, some suitable habitat may remain at higher elevations north of the national park.

Because of its thermoregulation limits and specific talus habitat requirements, pika is rated “high” in sensitivity (table 1). Its adaptive capacity is rated “low” because of its generally low ability to move between potential habitats (Beever et al. 2010). Potential impacts on pika in the park are “high” (negative) in spite of available talus. Those areas are too low in elevation to support viable populations under warming scenarios. Potential impacts on the species in general are rated “low” because of the species’ wide geographic distribution. Its loss from Zion would not highly affect the species distribution as a whole, unless the local populations have some unique genetic characteristics (Rodhouse et al. 2010). However, potential impacts on park management are “moderate.” All native species are important to the preservation of park ecosystems, and this species is at great risk of local extirpation because of expected increases in temperature.

Desert tortoise

The desert tortoise occurs in the Mojave Desert, where it occupies a variety of habitats, from flats and slopes dominated by creosote bush (Larrea tridentata) scrub at lower elevations to rocky slopes in blackbrush (Coleogyne ramosissima) and juniper (Juniperus spp.) woodland ecotones (transition zones) at higher elevations (U.S. Fish and Wildlife Service 2008; Meyer 2008). Two areas in Zion (northern and southern habitats) that have suitable soil substrate and vegetation were coarsely delineated as focus areas in this project via consultation with park staff and literature review fig. 3. There are no known tortoise observations for the northern area. Monitoring by park staff shows desert tortoise are present in the southern area and are a reproducing population, as evidenced by the presence of eggshell fragments and young tortoises with only one annular ring on their scutes.

The northern habitat suitability (vegetation productivity within favorable elevations) stays very low under both of the modeled climate scenarios for the next 100 years. In the southern area, climate warming is expected to substantially enhance the suitability of tortoise habitat. The modeled habitat suitability index, ranging from 0 to 1 at present, averages 0.2 in the southern area and increases to 0.3 under both climate scenarios, an increase of 66%. Within the southern area, the southwestern corner of Zion National Park is closer to the current Mojave Desert range of the species and shows the largest increase in habitat suitability.

The species is dependent on certain vegetation types, but because of its physiology and behavioral adaptations to high temperatures we rate it “moderate” in sensitivity. Though slow moving and slow growing, the species is capable of migrating to connected habitats (U.S. Fish and Wildlife Service 2008; Meyer 2008) and is therefore rated “moderate” in its ability to adapt to warming temperatures.

Potential impacts on the species in the park are rated “high” and positive because the model indicates an increase in area of suitable habitat by 2100 in Zion. The quality of that potential habitat depends on many factors, but presently there is evidence of population stability. Impacts on the species in general are “moderate,” because though the park is only a small part of its existing range its environment in the park is protected from habitat destruction and human activities common on other private and public lands. Potential impacts on park management are “high” because of the species federal listing as threatened, its high public profile, and the proximity of its habitat to the busy community of Springdale, Utah, which is becoming increasingly “tortoise aware” through education.

Shivwits milk-vetch

Shivwits milk-vetch was first identified as a new plant species in 1997 and was listed as federally endangered in 2001. Depending on temperatures and precipitation, emergence and flowering occur from April to late May, and plants senesce (die back aboveground) by mid-June. The perennial rootstock allows Shivwits milk-vetch to survive dry years, and in a drought year plants may not emerge or fruit production may be diminished (Miller et al. 2007). This adaptation allows the plant to conserve energy for reproductive effort when resources are available (U.S. Fish and Wildlife Service 2001). It is unknown whether milk-vetch is truly a Chinle "specialist" (primarily obligated to that geologic type) or whether the Chinle geologic formation is inhospitable to competitors like native blackbrush (Coleogyne ramosissima Torr.) and nonnative red brome (Bromus rubens). If the Chinle formation is a "refuge" from competitors, then milk-vetch response to climate change will be highly contingent on competitor response to climate change. Herbivory and dispersal are also important but poorly understood determinants of survival and will undoubtedly influence realized habitat. In our work the species is modeled as a Chinle specialist where present and potential habitat is defined as the spatial intersection of geologic type, elevation, and slope based on known populations.

Climate warming is expected to raise the elevation range of potential milk-vetch habitat and its extent in Zion (fig. 4). Presently there are 1,669 ha (4,124 ac) of potential habitat in Zion, with 1,914 ha (4,730 ac) of potential habitat in 2100 under climate B1 (an increase of 15%) and 1,840 ha (4,547 ac) of potential habitat in 2100 under climate A2 (an increase of 10% over present). The primary change in potential habitat comes in its distribution, with most of the increase in the northern part of the park and a slight decrease in the southern part of the park near Springdale. Occupied habitat outside the park is at lower elevations on a mixture of private and public lands having lower protection potential, and may become too warm for a viable population, raising the importance of the Zion habitat.

Sensitivity is rated "high" in table 1 because of the species' strong relationship to elevation and small spatial extent. Adaptive capacity is rated "low" because of its strong tie to a specific geologic type, limiting its potential range. Also, though its potential habitat is relatively widespread in Zion, its presence has been verified in only a few areas.

Potential impacts on the species in the park are rated "low" and positive. The modeled future habitat exhibits only a moderate increase in extent over present conditions. Impacts on the species in general are "high" and positive. This is because most of the present and projected habitat is within the park, a protected area. Impacts on park management are probably also "high" because of the species' federally endangered status, since it is possible that most of its remaining range outside the park will degrade significantly, raising the importance and visibility of the remaining habitat.

Uncertainty

Our modeling provides a starting point for understanding direction and magnitude of shifts in potential suitable habitat. We speculate on climate change impacts to species but do not make predictions because we did not consider additional complexity, such as interspecies competition, microclimates, extreme weather events, genetic diversity, behavioral plasticity, or whole ecosystem effects. It was beyond the scope of this research to test the sensitivity of species to environmental variables. Species-environment relationships today are assumed to hold in the future, and no adaptation or evolution is assumed to occur that would affect species-environment relationships. But all of these factors may affect realized habitat occupancy.

In this research we focused on mean annual temperature effects, but seasonal temperature and precipitation effects, as well as temperature minima, variability, or cumulative effects, could also be modeled. For instance, seasonal lapse rates can be used with seasonal climate projections to give a clearer picture of seasonal effects on species with different seasonal sensitivities to climate (e.g., summer and winter extremes for pika).

For example, continuing with temperature as a driver, our locally derived June, July, and August summer lapse rate of 2.2°C/km (1.2°F/1,000 ft) with a projected western U.S. summer warming of about 2.8°C (5.0°F) (Ray et al. 2010) by 2100 would shift today's thermal habitat boundaries upward approximately 1,250 m (4,100 ft), considerably more than the 400–650 m (1,300–2,130 ft) per century upslope shift determined using the MAT lapse rate of 7.3°C/km (4.0°F/1,000 ft). The alarming aspect of this example is that upslope range retraction of pika in the Great Basin (145 m [475 ft] per decade or 1,450 m [4,750 ft] per century) observed during 1999–2008 has already outpaced our predicted future rates of retraction (Beever et al. 2011) that we modeled using an MAT lapse rate. While we cannot predict with certainty how conditions will evolve at any given location, it may be wise for managers to consider in their planning the likely upslope range shift of suitable habitats in the future and the potential magnitude of these retractions.

Our intent was to use readily available information to model a range of possible changes in habitat suitability and distribution affected by temperature that bracket much of the range in projected temperatures expected for different carbon dioxide emission scenarios. The scope of this research is a relatively rapid screening in which we mapped potential future habitat, while not suggesting those habitats can or will be occupied. This level of effort results in predictions with a high degree of uncertainty, but provides a baseline for discussion, focused monitoring, and planning.

Conclusions

Literature review, consultation with academic and agency science experts, and use of existing models were brought together for mapping future potential species-specific range shifts under IPCC climate scenarios in and near Zion National Park. The maps of future potential habitat suggest there will be opportunities for some species and limitations for others in Zion. For instance, potential area of suitable tortoise and milk-vetch habitat may increase in and near Zion while pika habitat may disappear entirely from within park boundaries. The realized species response to climate change may depend on many interacting factors that we did not model, including management actions.

We acknowledge that our approach to modeling vulnerability is narrowly focused primarily on temperature and habitat characteristics, but suggest the possibility—even necessity—of learning as we go by iterating modeling efforts as new and better information becomes available. For instance an explicit accounting of coupled changes in projected precipitation and temperature will be an improvement on this work. This is a process in which scientists and park staff will benefit by working together through the complexities of modeling and planning so that collectively we increase our understanding of interactions, vulnerability, and uncertainty.

This process helps develop options supported by science. Mitigating impacts and giving species time to adapt will improve the likelihood of species survival, yet inaction will result in lost opportunities if ecological thresholds are surpassed. Interactively working through analyses like these helps to put bounds on uncertainty so that it does not hinder planning or management action, if necessary. Science-based options are an integral part of adaptation frameworks that enable conservation through management. Considering the complexity and magnitude of climate change effects on park resources in the next 100 years, there will be many opportunities for learning and collaboration in conservation.

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Acknowledgments and references

Acknowledgments

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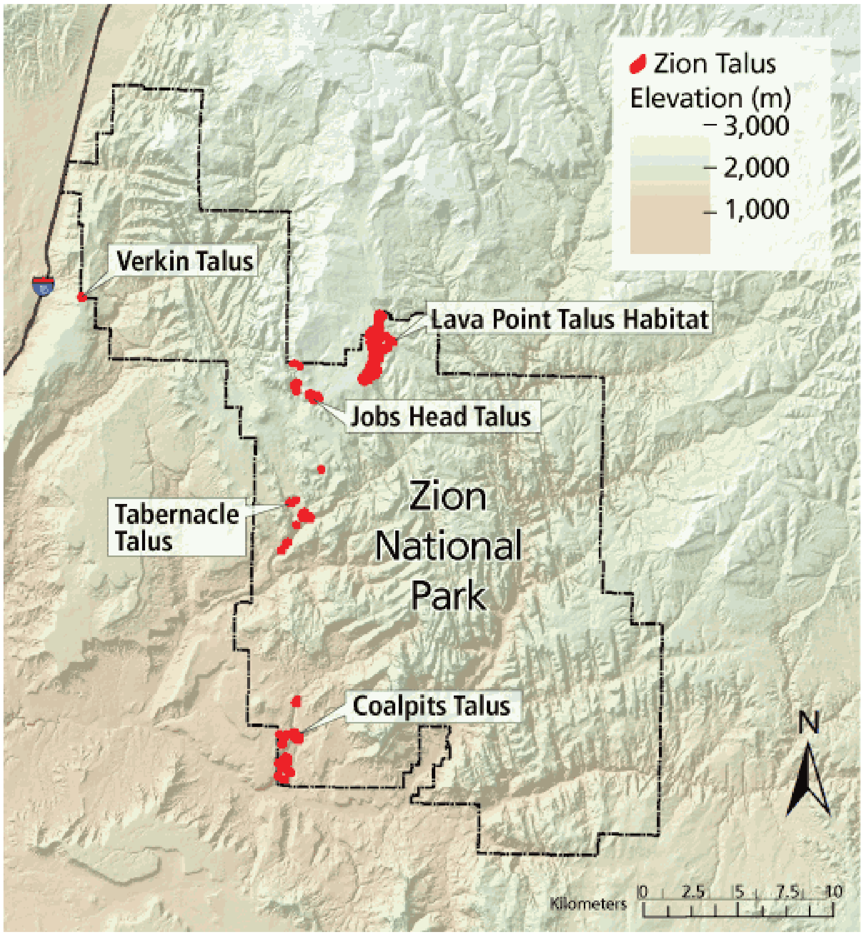

Figure 2. Talus patches in Zion with rock fragment sizes suitable for potential pika habitat. The pika persistence model, coupled with mean annual temperature projections, indicates that suitable pika habitat may not exist in Zion by 2100.

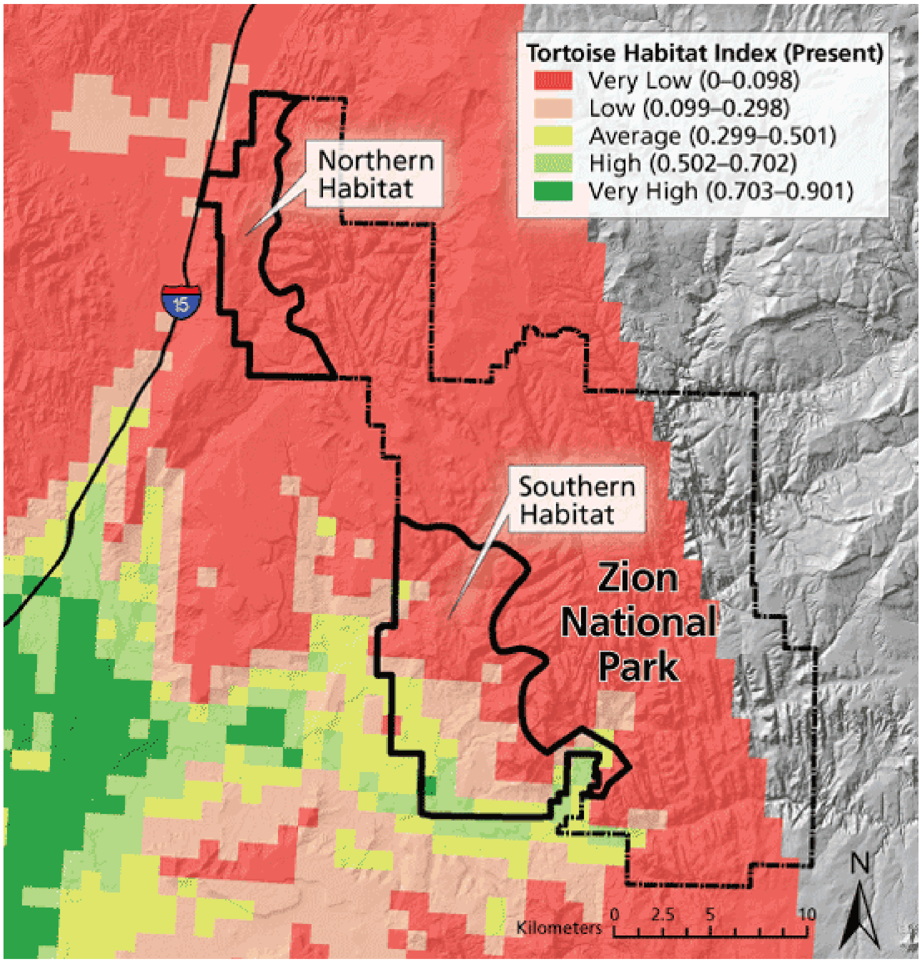

Figure 3. Suitability of potential desert tortoise habitat today (this map) and in 2100 under emission scenarios B1 and A2. Potential is rated "low" (red) to "high" (green). Northern and southern habitat zones are based on vegetation and slopes appropriate for potential habitat.

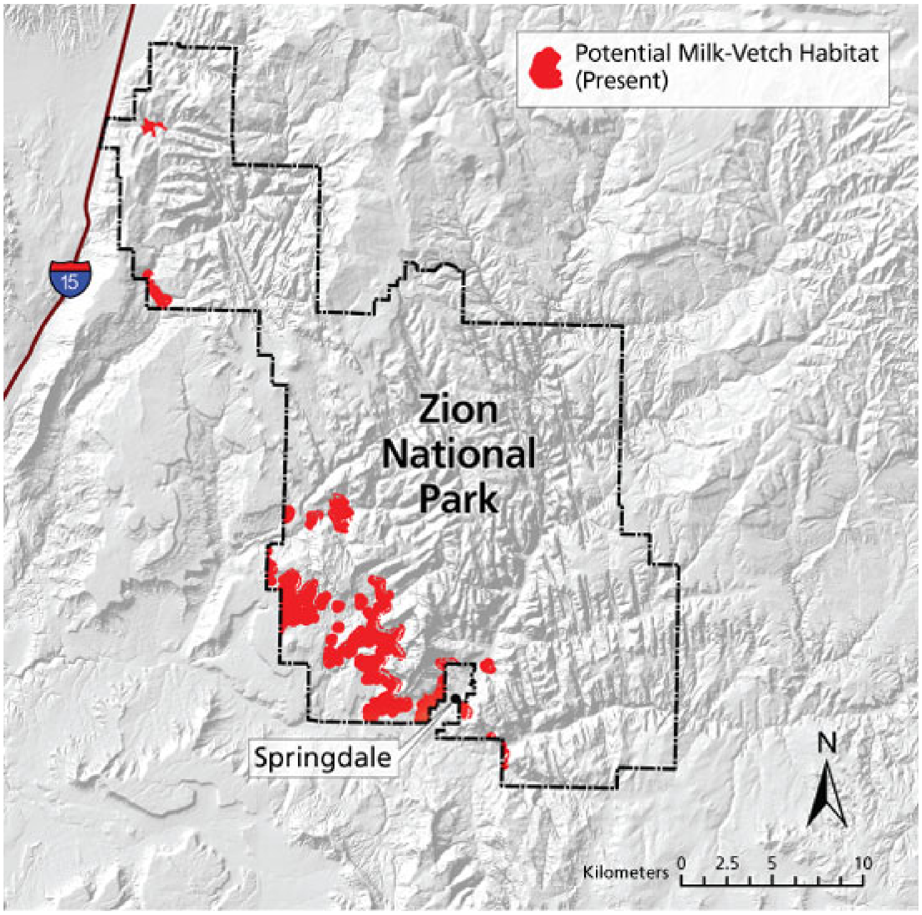

Figure 4. Potential milk-vetch habitat at present (shown here) and in 2100 under emission scenarios B1 and A2 in Zion.

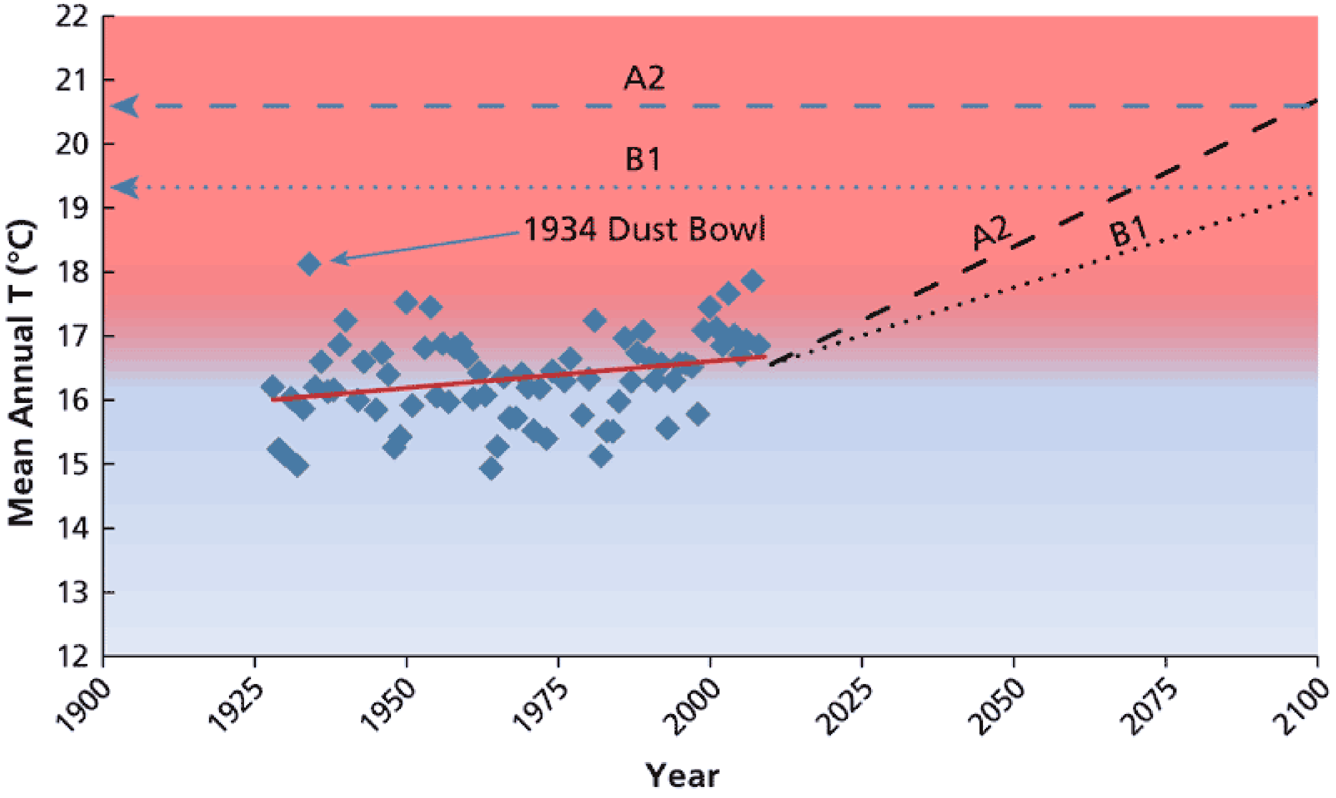

Figure 1. (B) Historical and projected trends in mean annual temperature (MAT) for the 1928–2008 period. The red line is the linear trend in the historical MAT. The dashed and dotted lines are the most recent 30-year averages, 16.6°C (61.9°F) linearly modeled into the future under IPCC emission scenarios with MAT in 2100 projected to be 19.3°C (66.7°F) under B1 and 20.7°C (69.3°F) under A2 scenarios (projections made using IPCC 2007) (Gonzalez et al. 2010).

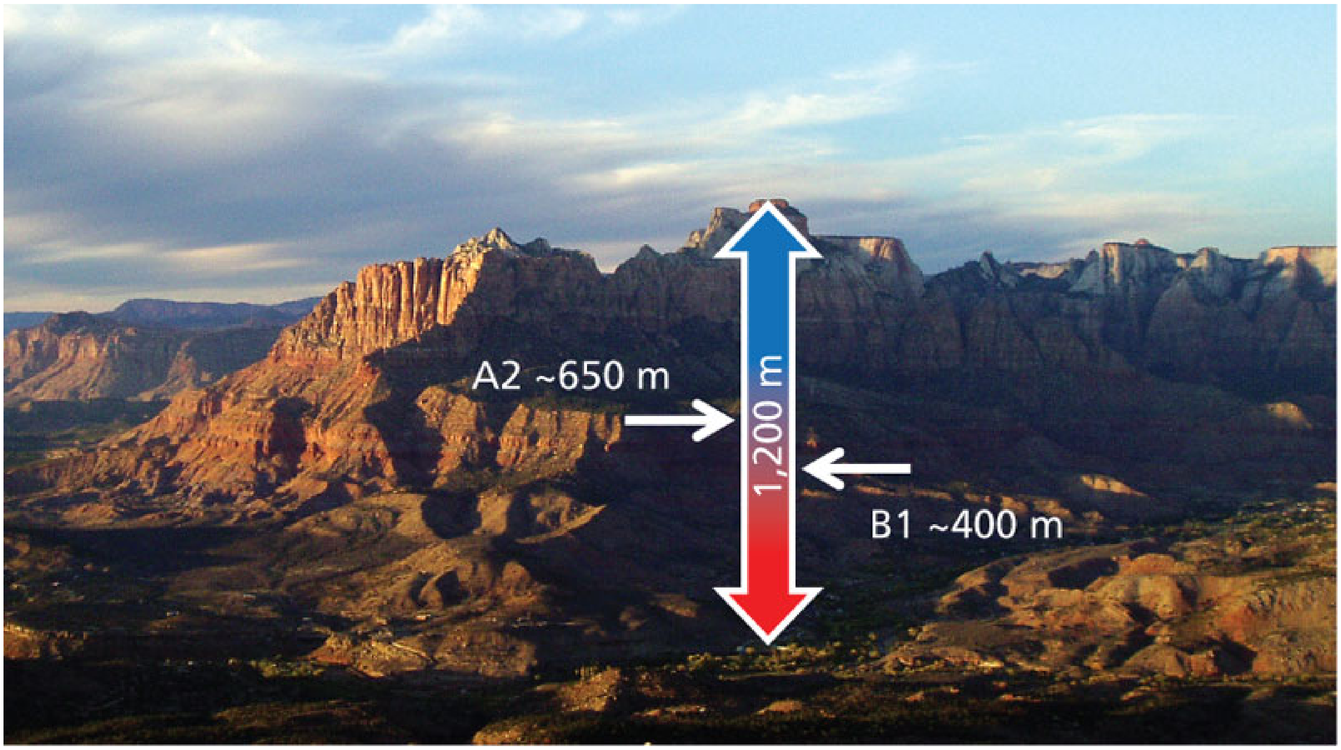

Figure 1. (C) Zion Canyon and the town of Springdale, Utah, looking north across desert tortoise and Shivwits milk-vetch habitat. Potential pika habitat occurs in isolated areas on the highest plateaus. Large vertical arrow indicates relief between Zion Canyon and the summit of West Temple. Horizontal arrows indicate vertical shift in MAT that may affect habitat suitability and location under A2 and B1 emission scenarios by 2100.

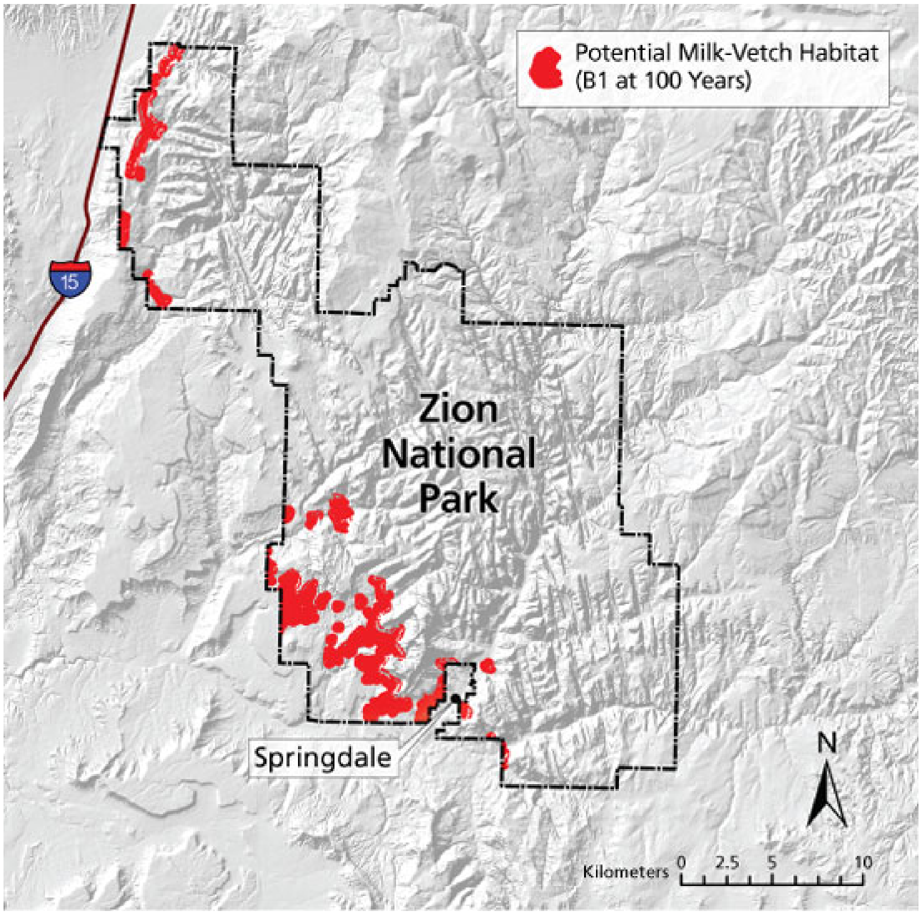

Figure 4. Potential milk-vetch habitat at present and in 2100 under emission scenarios B1 (shown here) and A2 in Zion.

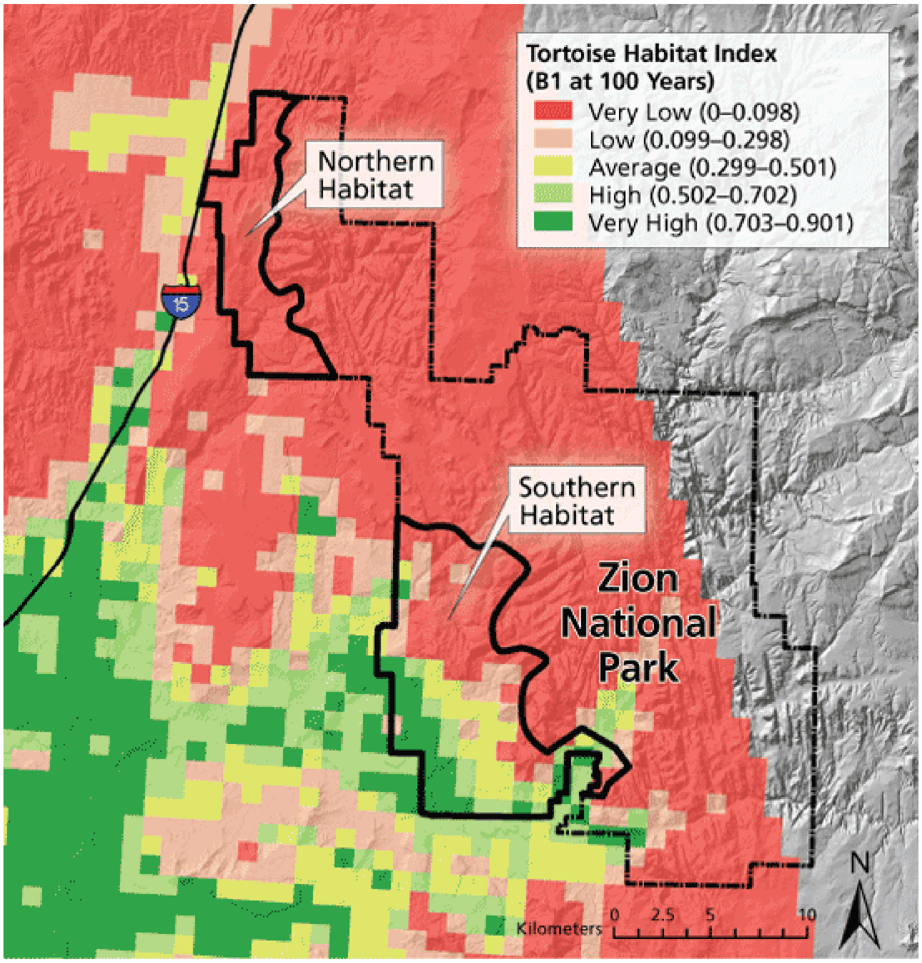

Figure 3. Suitability of potential desert tortoise habitat today and in 2100 under emission scenarios B1 (this map) and A2. Potential is rated "low" (red) to "high" (green). Northern and southern habitat zones are based on vegetation and slopes appropriate for potential habitat.

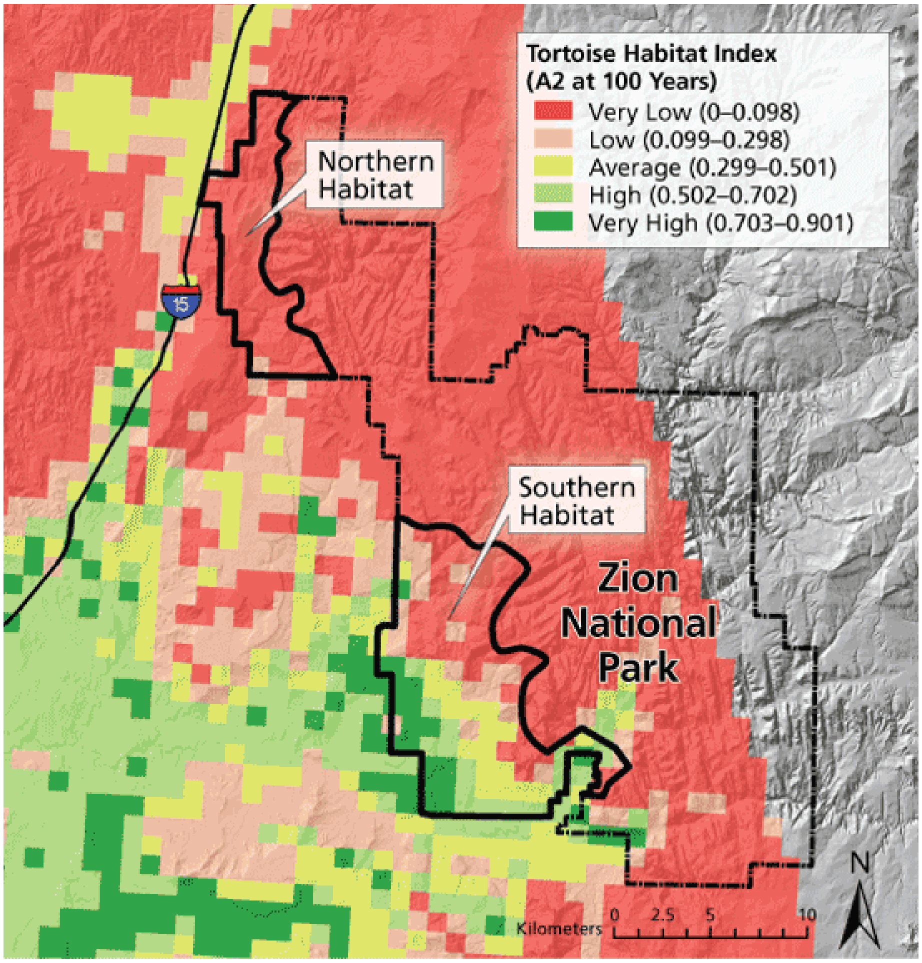

Figure 3. Suitability of potential desert tortoise habitat today and in 2100 under emission scenarios B1 and A2 (this map). Potential is rated "low" (red) to "high" (green). Northern and southern habitat zones are based on vegetation and slopes appropriate for potential habitat.

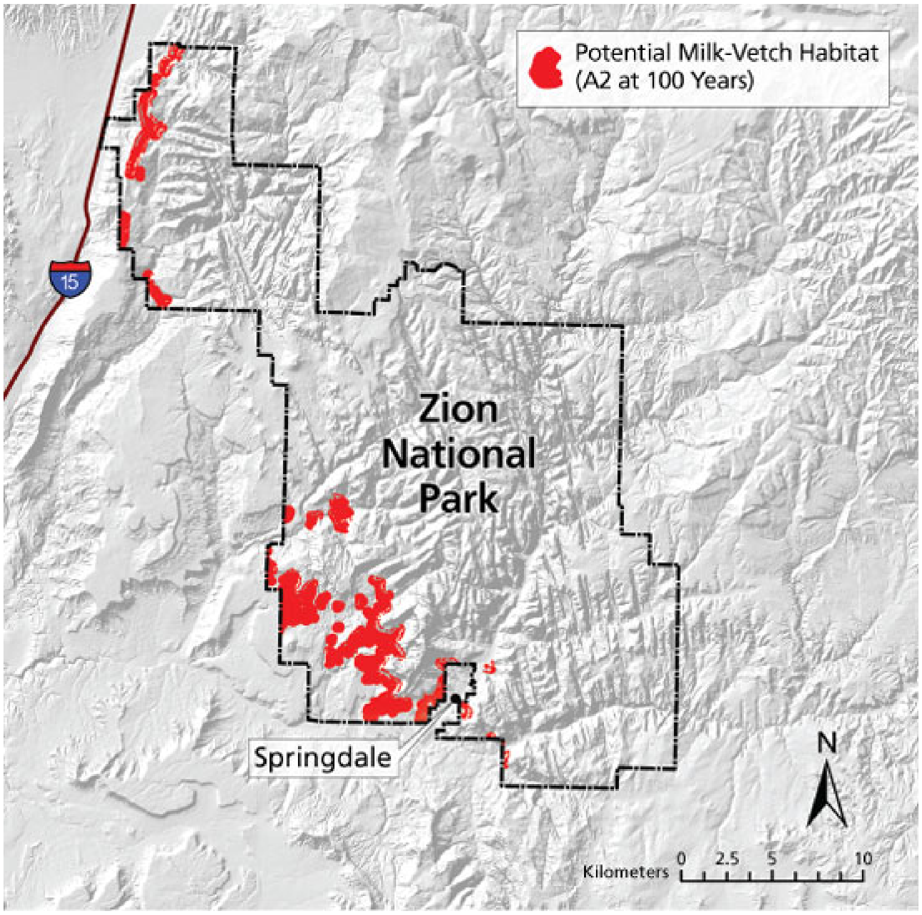

Figure 4. Potential milk-vetch habitat at present and in 2100 under emission scenarios B1 and A2 (shown here) in Zion.

Table 1. Species vulnerability to and potential impacts of climate change scenarios on species in Zion National Park in 2100

	Components of Vulnerability			**Potential Impacts on**		
Species	**Sensitivity**	**Exposure**	**Adaptive Capacity**	**Species Within the Park**	**Species in General**	**Park management**
American pika	high	moderate	low	high (–)	low (–)	moderate
Desert tortoise	moderate	moderate	moderate	high (+)	moderate (+)	high
Shivwits milk-vetch	high	moderate	low	low (+)	high (+)	high

Note: "+" indicates a positive effect of increased mean annual temperature under climate change, while "–" indicates a negative effect.

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