Climate Change and Vulnerability Analysis for Four Species in Three Southwestern Utah National Parks/Monuments

Final Report

December 7, 2011

Henry Shovic[1], PhD and David Thoma[2], PhD

[1]Henry Shovic, PhD is an affiliate researcher with the Dept. of Ecology, Montana State University in Bozeman, Montana and the Rocky Mountain Cooperative Ecosystems Study Unit at The University of Montana, Missoula (http://www.shovic.com).
[2]David Thoma, PhD is a Hydrologist with the National Park Service, Northern Colorado Plateau Network, in Bozeman, Montana.

Rocky Mountains Cooperative Ecosystem Studies Unit (RM-CESU)
RM-CESU Cooperative Agreement Number: H1200090004 (IMR

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Acknowledgements

I appreciate the contributions from these individuals, and all others who supported this work.

Located at ZION, proponents and project initiators: Kristin Legg, Matt Betenson, and David Thoma, PhD.

Administrative Contact: Dave Sharrow, Resource Management and Research, ZION

ZION specialists: Cheryl Decker, Claire Crow, Greg Comer, Dave Sharrow, Becca Lieberg
BRCA specialists: Laura Schrage, Sarah Haas.

Contributing Scientists: David Thoma, PhD, Northern Colorado Plateau Network, NPS; Patrick Gonzalez, PhD, Climate Change Response Program, Washington Office, NPS; Ken Nuessear, PhD, Western Ecological Research Center, USGS; Erik Beever, PhD, Northern Rocky Mountain Science Center, USGS.

Reviewing Scientists: David Thoma, PhD, Northern Colorado Plateau Network, NPS; Erik Beever, PhD, Northern Rocky Mountain Science Center, USGS; John Gross, Washington Office Natural Resource Stewardship and Science Inventory and Monitoring Program, NPS.

Park Superintendents Jeff Bradybaugh, BRCA and Jock Whitworth, ZION and CEBR.
Resource Management Staff: Sean Eagan, BRCA and Bill Cox, ZION.

Lapse rate calculations: Emily Wellington, Great Northern Landscape Conservation Cooperative, USGS.

Executive Summary

Vulnerability assessments are useful tools in planning for our adaptation to the effects of climate change. They are designed primarily to identify *which* species are likely to be at risk and *why* they may be vulnerable. This study takes another step. Its purpose is to estimate *where, when,* and *how much*, which should provide managers with enough detail to explore management responses to a reasonable suite of potential futures.

Three units of the National Park System in southern Utah were selected for this project: Zion National Park, Bryce Canyon National Park, and Cedar Breaks National Monument. They represent part of the range for each target species, are in close proximity and share administrative and environmental factors, and their total area is at an appropriate scale for this analysis. A buffer of surrounding lands is included for context.

The four target species were: American pika (*Ochotona princeps*), Desert tortoise (*Xerobates [Gopherus] agassizii*), Shivwits Milk-vetch (*Astragalus ampullarioides*), and Great Basin bristlecone pine (*Pinus longaeva*). This selection offered the opportunity to broadly test project methods for both plant and animal species across NPS boundaries, and therefore should demonstrate the opportunity for transferability to other species and NPS units.

This one-year study was primarily a modeling exercise. Three levels of models were developed; first to estimate the degree of climate change, then to create a local physical proxy for that change, and finally to predict the effects of modifying that proxy for each species/habitat response model. Climate was represented by Mean Annual Temperature (MAT), based on local applications of current predictions from the IPCC (Intergovernmental Panel on Climate Change). Local annual lapse rates were used to relate the predicted change in MAT to an effective elevation change, which was then used in each model to predict shifts in quality and location of predicted habitat or populations. These shifts were quantified and mapped on a local level for the range of predicted changes.

Results using annual lapse rates showed significant shifts in species habitat. American pika, though likely present in the area, are at risk within Zion National Park and Cedar Breaks National Monument boundaries, as is their habitat. However, local topographical factors may mitigate that risk. The Threatened desert tortoise is present in Zion National Park and its habitat within and near Park boundaries is improving and expanding. Bryce Canyon National Park and Cedar Breaks National Monument provide significant potential refugia for Great Basin bristlecone pine, especially when allied with probable changes in other species distribution patterns. The habitat for the Endangered Shivwits milk-vetch is improving and likely is critical for species survival.

However, using summer lapse rates rather than annual rates changes the picture. Since summer temperature regimes may be more important than MAT in the desert Southwest, changes were also estimated on that basis. American pika face extirpation from the area. Desert tortoise habitat is largely lost, and the remainder may be too fragmented and isolated for natural migration. Bristlecone pine may expand its habitat to physical limits. Shivwits milk-vetch is at high risk of extinction, since most potential habitat is within Zion National Park, and temperatures will probably be too high within those boundaries.

The above discussion of the use of summer lapse rates may make the lapse rate/elevation association used in our modeling too conservative. Local data show the historical temperature increase is higher than our models present. Our “reasonable” futures may be too reasonable. Even so they are a starting point in developing a range of appropriate responses for the changes to come.

Introduction

Change is coming to our world. Not only is that change well established in scientific literature, but is increasingly apparent in our daily lives. Longer summers, increasing intensity of storms, the swaths of dying trees in our coniferous forests, and increased wildfire activity are apparent to us all. Rapid climate change is also emerging as a paramount topic in wildlife conservation, both in scientific and management arenas. It is being addressed on all Federal lands, and particularly on those managed by the National Park Service (NPS). These preserved lands are particularly important, not only because they often represent unique environments that harbor unique species, but also because they may be the last refuges of potential habitat in an increasingly developed world.

Study Objectives

Though climate change is well-defined on a global and regional scale, it is still difficult to define what local effects might be and an appropriate management response at a National Park level. This short-term study is designed to provide information to help identify management opportunities as a response to the local effects of climate change, using existing data available at the National Park level.

Three units of the National Park System in southern Utah were selected for this project. They are Zion National Park, Bryce Canyon National Park, and Cedar Breaks National Monument. They represent part of the range of each target species. They are in close proximity and share administrative and environmental factors, and their total area is at an appropriate scale for a detailed, but time-limited analysis. A buffer of surrounding lands is included for context.

Four target species were chosen as flora and fauna known to occupy these units, specifically due to climate-related concerns. They have well-defined habitat parameters: American pika (*Ochotona princeps*), Desert tortoise (*Xerobates [Gopherus] agassizii*), Shivwits milkvetch (*Astragalus ampullarioides*), and Great Basin bristlecone pine (*Pinus longaeva*).

Although each of the four species is not found individually within each of the NPS units, this offers the opportunity to broadly test project methods for both plant and animal species, and across NPS boundaries, and therefore should demonstrate opportunity for transferability to other species and NPS units. Objectives include (from Appendix B, the project proposal):

1. Develop Habitat Models for Target Species: Develop spatially-explicit models of selected species habitat for the study area Parks/National Monuments. Extant, proven models may be adapted for use in this project. These models predict location of potential habitat for each species within and near the study area. Literature and consultation are used to determine relevant landscape factors. Data from existing monitoring programs will inform the models.
2. Climate-related Vegetation Change: Determine trends in greenness and productivity of the dominant vegetation types that occur within and around the study area. Isolate climate-induced change by combining normalized difference vegetation index (NDVI) trends with landscape data to isolate change from disturbance or land use- related change. Use I&M processed MODIS satellite NDVI to identify spatial and temporal trends in vegetation change over the last eight years.
3. Climate-related Habitat Change: Identify intersection of spatially coincident areas of target species habitat and climate-related change in vegetation. Model and estimate

potential effects of these spatial changes on target species habitat present in the study areas. Estimate potential change or addition of habitat within or near administrative boundaries, given the inferred effects of climate change by feeding results from activity 2 into activity 1.

4. Develop Management Opportunities: Describe the location and extent of potential reduction or increase in habitat for target species. Describe alternatives for managing NPS resources to adapt to these effects for possible use in Scenario Planning.

This study was designed to be time limited, to ensure results are timely enough to provide feedback to the rapidly-evolving field of vulnerability analysis. One year was allotted for completion, including objective-validation, stakeholder input, discovery, field data collection, model-building, testing and validation, analysis, documentation, and presentation. Therefore the process steps were abbreviated to fit this time frame. It is also funding-limited ($64,000 direct cost).

The NPS has already developed programs to explore futures and develop policies and actions. But to explore futures, managers need to know what those futures might look like. Results from this project can be used by National Park management in their efforts to address adaptation to future climates, in vulnerability analysis, and scenario planning.

National Parks and Climate Adaptation

The presence of National Parks and Monuments are important in adapting the natural and cultural world to global climate change. Other than the traditional functions (preserving our natural and historic heritage, providing recreation and a calming escape from the human-dominated environment), they also play a role in providing an adaptation platform for the coming changes (National Parks and Conservation Association, 2007). Quoting from that publication:

> "National Parks play a role in "helping America's plants, animals, and ecosystems adjust to new climatic conditions. Large remote parks like Gates of the Arctic National Park and Preserve in Alaska, which encompasses more than 7.5 million acres and helps support three herds of caribou, may protect sufficiently large, intact, and diverse ecosystems to allow some degree of adaptation to occur within the park. Other parks, like the Appalachian National Scenic Trail, may provide a corridor to enable populations of plants and animals to shift their range northward as the climate warms. To the extent they provide refuge from other environmental stresses, such as habitat fragmentation and pollution, parks are places where natural communities have a better chance of coping with changing climate."

Climate-related changes in habitats do not occur in isolation. They combine with existing stresses and overlay on our complex, human-developed world. Hence any vulnerability assessment must contend with these additional stressors (ibid) just as any ecosystem must contend with these stresses. National Parks and Monuments are protected by law from unregulated development and can be seen as "refuges" or "islands" of insularity. They are effectively "ecosystems" to the extent they are unique environments and have artificial, real boundaries to the movement of the species within them. To the extent they are surrounded by developed lands they represent "islands" of diversity (Radeloff, et. al., 2010). But they are increasingly threatened by a mono-cultural and restrictive environment, driven in part by housing (ibid). In some cases, development may even directly influence climate in the protected areas. In Rocky Mountain National Park, surrounding land use changes have been shown to be associated with the Park's climatic shifts (Stohlgren and Baron, 1997). Even in Yellowstone National Park, one of the largest and most intact sets of ecosystems in the world, there have long been concerns that it is not big enough to insulate its species from outside influences (Schullery, 1997). Hence National Parks and Monuments can be seen as sources of adaptation potential in the face of climate change, but they are also threatened by that change. Effectively managing for these complex changes requires new ways of thinking that can no longer be solely based on past data and equilibrium models.

Scenario Planning –A Way Forward

The National Park Service, in anticipation of the coming changes is developing ways of anticipating changes and practicing management responses to them. "Scenario planning" is one of those ways. It is an evolving program that has as a goal helping "managers identify actions that will be most effective across a range of potential futures" (http://www.nps.gov/climatechange/docs/SPlanningOverview.pdf).

"When future conditions are uncertain, formulating multiple scenarios and then finding the beneficial actions common to each of the potential futures becomes an efficient approach and will be utilized for park planning. This approach can best be summed up as being prepared—for worst-case scenarios, best-case scenarios, and a range of future alternatives in between" (http://www.nps.gov/climatechange/response.cfm).

"The National Park Service uses scenario planning as a tool to prepare for the long-range impacts of climate change on our natural and cultural resources. The process involves using current climate change projections to develop possible climate and ecological futures. Managers work through a variety of options for the future and develop responses and action plans to be used in each situation. Scenario planning allows park managers to plan for an uncertain future and maximize actions most likely to be beneficial" (http://www.nps.gov/climatechange/adaptationplanning.cfm).

As with many new programs, this one in flux, with changing expectations, goals, and data needs. And though change is certainly coming, the nature of its effects on Park species, habitats, and ecosystems is extremely uncertain. However, knowledge of the "range of potential futures" is still required to be able to reduce that uncertainty to a level where managers can create a range of potential management actions and test them against those futures. The analysis of species, habitat, and ecosystem vulnerability can inform this process.

Vulnerability and Climate Change: Scanning the Conservation Horizon

The National Wildlife Federation has published a comprehensive document dealing with what has become "the defining conservation issue of our generation" (Glick, et. al., ed., 2011). It organizes and develops concepts that appear useful in the assessment of the future for wildlife under climate change.

Management of climate-related changes is termed "adaptation", a term implying that our options are limited for manipulating the future. Rather we need to adapt ourselves and the species we manage to the future that is coming. We can no longer look to the past to guide our conservation and restoration goals, but instead we must anticipate an increasingly different and uncertain future.

But how do we address the unprecedented nature of that future? "Vulnerability analysis" is a tool to help provide some scientific basis for anticipating changes. Vulnerability itself is defined as "the extent to which a species, habitat, or ecosystem is susceptible to harm from climate change impacts". The scientific analysis of vulnerability helps to determine "which" species are likely to be affected, and understand "why" these resources are likely to be vulnerable.

"Vulnerability" in this context, has three components (sensitivity, exposure, and adaptive capacity). These are defined as follows (ibid):

> *"Sensitivity* generally refers to innate characteristics of a species or system and considers tolerance to changes in such things as temperature, precipitation, fire regimes, or other key processes. *Exposure*, in contrast, refers to extrinsic factors, focusing on the character, magnitude, and rate of change the species or system is likely to experience. *Adaptive capacity* addresses the ability of a species or system to accommodate or cope with climate change impacts with minimal disruption."

Though these three are important components, they are only part of the equation. To truly describe vulnerability, there is another step, the "Potential Impact" (Figure 1). A complete vulnerability assessment includes that additional step. Glick, et. al. refer to that step in general terms, by suggesting the application of climate models and ecological response models (also called species distribution models).

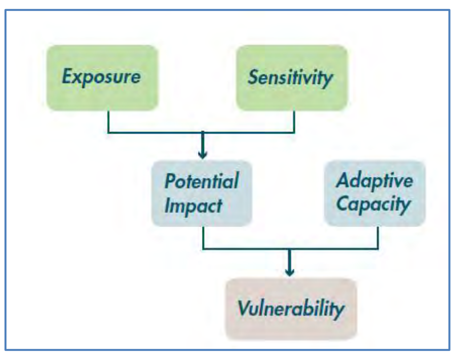


Figure 1. Key Components of Vulnerability (from Fig 2.1 in Glick, et. al., ed., 2011)

Vulnerability assessments can be related to a species itself, a given habitat, or an entire ecosystem. They provide a "factual underpinning for differentiating between species and systems likely to decline and those likely to survive, but do not in themselves dictate adaptation strategies and management responses." These responses may range from building resistance of species to change, to enhancing resilience, and if needed, managing the transition to other systems. The assessment provides information to develop those strategies and help create an environment for factual planning.

Assessments should be based on user needs, should have appropriate geographic and temporal scales, and should be reflect the availability of resources (time, money, and expertise), as well as the importance of the targeted resource.

Finally, uncertainty is an unavoidable aspect of all assessments. The literature (including Glick, et. al., ed., 2011) is rife with caveats about uncertainty. Un-anticipated species responses, effects of climate downscaling, simplifications in species distribution models, lack of adequate guidelines from the past, unknown interactions between species and habitats, and others; all are important to note. But one fact is certain: change is coming and we need to address it. We need a map of potential futures to reduce that uncertainty to manageable levels.

Managing without some form of plan is "akin to traveling in unknown territory without a map – one is not likely to arrive at the desired destination" (ibid). Vulnerability assessments are one way to help create a map. They may not provide *the* map of the future. They may not even provide a *good* map. But they give managers a place to start.

Vulnerability Analysis – Sampling of Other Work

Studies are now under way to explore aspects of vulnerability and to provide data for "scenario planning", future vulnerability assessments, as well as other planning efforts. Seven were reviewed in Glick, et. al., ed., 2011, and part of the summary table is shown here (Figure 2).

Table 7.1: Summary of Case Studies

	1. Nature-Serve Nevada Species Assessment	2. EPA Endangered Species Framework	3. Species Assessment for the Middle Rio Grande	4. State-level Habitat Assessment for Mass.	5. Coastal Habitats and Species	6. Integrated Framework for the Four Corners	7. Pacific Northwest Assessment
Location and Extent	Nevada, statewide	National	New Mexico, regional	Massachusetts, statewide	Chesapeake Bay Region (two studies)	Southwest, Four Corners region	Pacific Northwest, regional
Status	In progress	Completed	Completed	Completed	Completed	Phase 1 Completed	In progress
Targets	263 priority animal species (invertebrates and vertebrates)	Six threatened and endangered vertebrate species	Terrestrial vertebrate species occupying riparian habitats	20 habitats	5.1: Coastal wetland habitats 5.2: Marsh bird species of concern	Species and habitats identified as conservation priorities	Species and habitats
Climate Change Models?	Yes, down-scaled climate data based on ClimateWizard	No (used published projections)	Yes, down-scaled climate data based on ClimateWizard, and published projections	No (used published projections)	No (used published projections)	Yes, down-scaled climate data based on ClimateWizard	Yes, down-scaled climate data based on multiple model simulations
Other Models?	General characterization	General characterization, expert opinion	General characterization, expert opinion	General characterization, expert opinion	Habitat and occupancy model (SLAMM)	General characterization, expert opinion	Climate niche, habitat, and hydrological models
Detail	Low	Moderate	Low	Moderate	Moderate	Low	High
Work/ Time	Low (application time per species = 30-45 minutes)	Moderate	Moderate	Moderate (1 year)	Low-Moderate 5.1=1 year 5.2=4 months	Moderate (2.5 years)	High (3-4 years)
Cost	$160,000	$60,000	$60,000	$70,000	5.1: $40,000 5.2: $25,000	$200,000	$800,000

Figure 2. Partial table of Selected Case Studies on Vulnerability from Glick, et. al., ed., 2011).

Two additional example studies and an index-based vulnerability assessment system were discovered during this project. A project at Badlands National Park (BADL) is underway (http://www.geospatialservices.org/BADL_CCVA.html). It involves identifying species, habitats, and other resources likely to be most affected by climate warming; describing the underlying reasons, and developing guidance for future assessments. It is a cooperative project between the National Park Service and St. Mary's University of Minnesota. Conversations with the Principal Investigator (Barry Drazkowski) indicate they are looking at many species and rating vulnerability using downscaled climate data and geospatial data to help stratify future detailed assessments.

A second study led by Dr. Diane Debinski is underway at a much more detailed level in Grand Teton National Park. (http://www.public.iastate.edu/~debinski/trophicinteractions.html). Objectives are to estimate the changes in soil temperature and moisture, timing of plant phenology, and response of a butterfly species in a set of 25 m^2 plots simulating earlier snow melt and ground warming by snow removal and passive heating.

An assessment system has been developed by the U.S. Forest Service for rating numerous species using a scoring system (http://www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/). Twenty-two criteria are rated using factors informed by published materials, expert knowledge, or consultation; and a relative index of vulnerability is determined.

Projects #1 through #4 in Figure 2 are relatively broad in scope (coarse filtered), and rely on general characterizations for assessments. Study #5 is more detailed, applying a model to predict characteristics associated with sea level rise, applied to habitat types and waterfowl species, though no climate downscaling is used. Project #6 is also broad in scope, and is in process. As in #1 – 4, it uses general characterization and expert opinion for determining species response. Study #7 is in also in process. It is large in scope and project leaders expect to assess many species using a variety of models and downscaled climate data.

The BADL study is a survey project that will narrow down the search for vulnerable species. It is moderate in scope and uses downscaled climate data. It is designed to further future detailed work. Dr. Debinski's project is at the other end of the spectrum, working directly with ground data and building a model of a few species and their measured response to simulated warming.

Study Area and Ecological Context

The Study Area consists of three geographically closely-associated National Park Service (NPS) Units in southern Utah (Figure 3). These are Zion National Park (ZION), Bryce Canyon National Park (BRCA), and Cedar Breaks National Monument (CEBR).

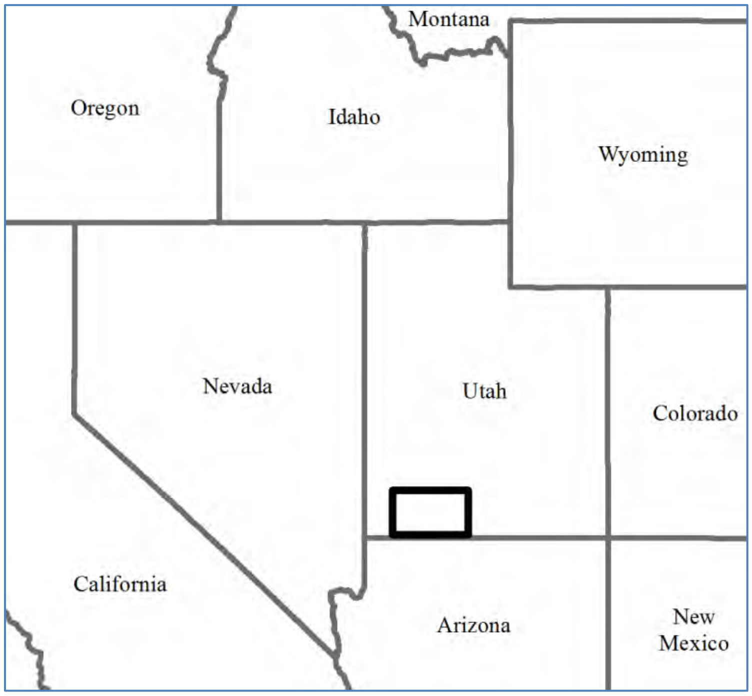


Figure 3. Study Area Location

The three units' location and context are shown in Figure 4. The units are of moderate size, with a total of 77,229 ha (Table 1), and have a wide range in elevation, from 1,115 m in ZION to 3,247 m in CEBR (Table 1).

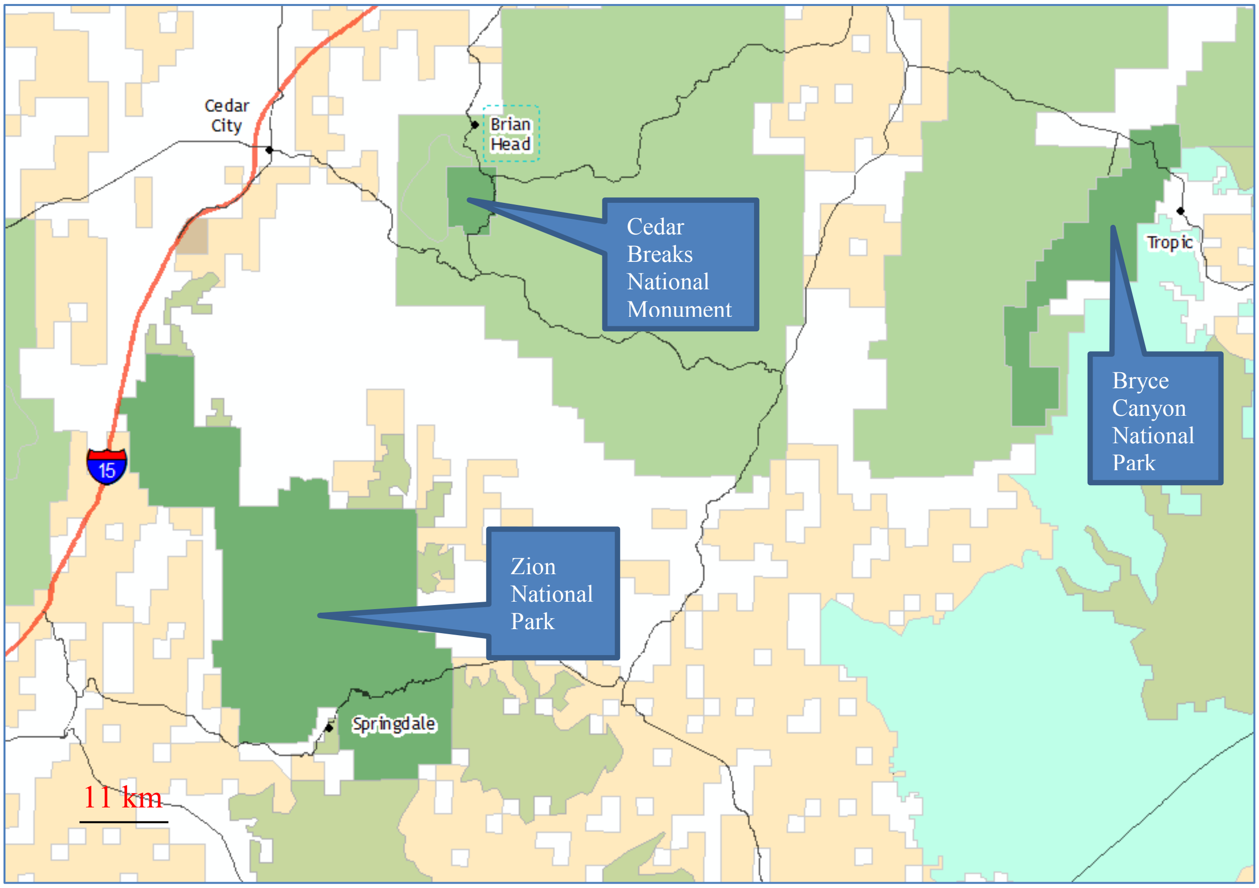


Figure 4. Study Areas and Context: Dark green is National Park Service, light green is National Forest, tan is Bureau of Land Management (BLM), olive green is wilderness study area, blue is National Monument land (BLM), white is private land, black lines are major road, and the red line is Interstate 15.

Table 1. Area, Elevation, and Latitude of Units

Unit	Elevation Range (m)	Elevation Range (ft)	Elevation Mean (m)	Elevation Mean (ft)	Area (ha)	Area (ac)	Latitude Range (Dec. Deg.)
Bryce Canyon National Park	2,004 - 2,777	6,613 - 9,164	2,367	7,765	14,556	36,029	37.441 - 37.698
Cedar Breaks National Monument	2,465 - 3,247	8,134 - 10,715	2,913	9,557	2,483	6,146	37.604 - 37.663
Zion National Park	1,115 - 2,660	3,680 - 8,778	1,816	5,958	60,190	148,985	37.141 - 37.505
Total or Max Range	1,115 - 3,247	3,680 - 10,715			77,229	191,160	37.141 - 37.698
Note: Elevation from 30 m DEM from Utah GIS; Area from NPS Administrative Boundary Shapefiles (from Betenson, ZION Staff), Latitude from GIS.							

Units are surrounded by both private and Federal lands (Figure 4), which both limit and enhance in-Unit management. ZION has significant surrounding private land as well as private inholdings, and is subject to continuing development pressure and habitat loss. CEBR is totally surrounded by U.S. Forest Service lands (USFS), thus preserving its boundaries from housing development, though USFS multiple-use management philosophy and CEBR's small size may result in more impacts than in other parks. BRCA's perimeter adjoins USFS or Bureau of Land Management (BLM) ownership in various stages of protection status. In terms of predicting effects, the present study is limited to NPS lands, but all models consider lands outside of those boundaries for the modeling process.

A general land cover map (Figure 5), (USGS, 2001) shows both ZION and BRCA are transitional to sage and scrub lands and all three have significant barren land. All contain significant evergreen forest and are partially surrounded by an evergreen forest environment. Physiography (Figure 6, based on a 10 m DEM) shows relatively high relief in all three Units, surrounded by more gently-sloping terrain. Geology includes primarily slightly tilted beds of sedimentary sandstones and limestones with some volcanic rocks (Kiver and Harris, 1999).

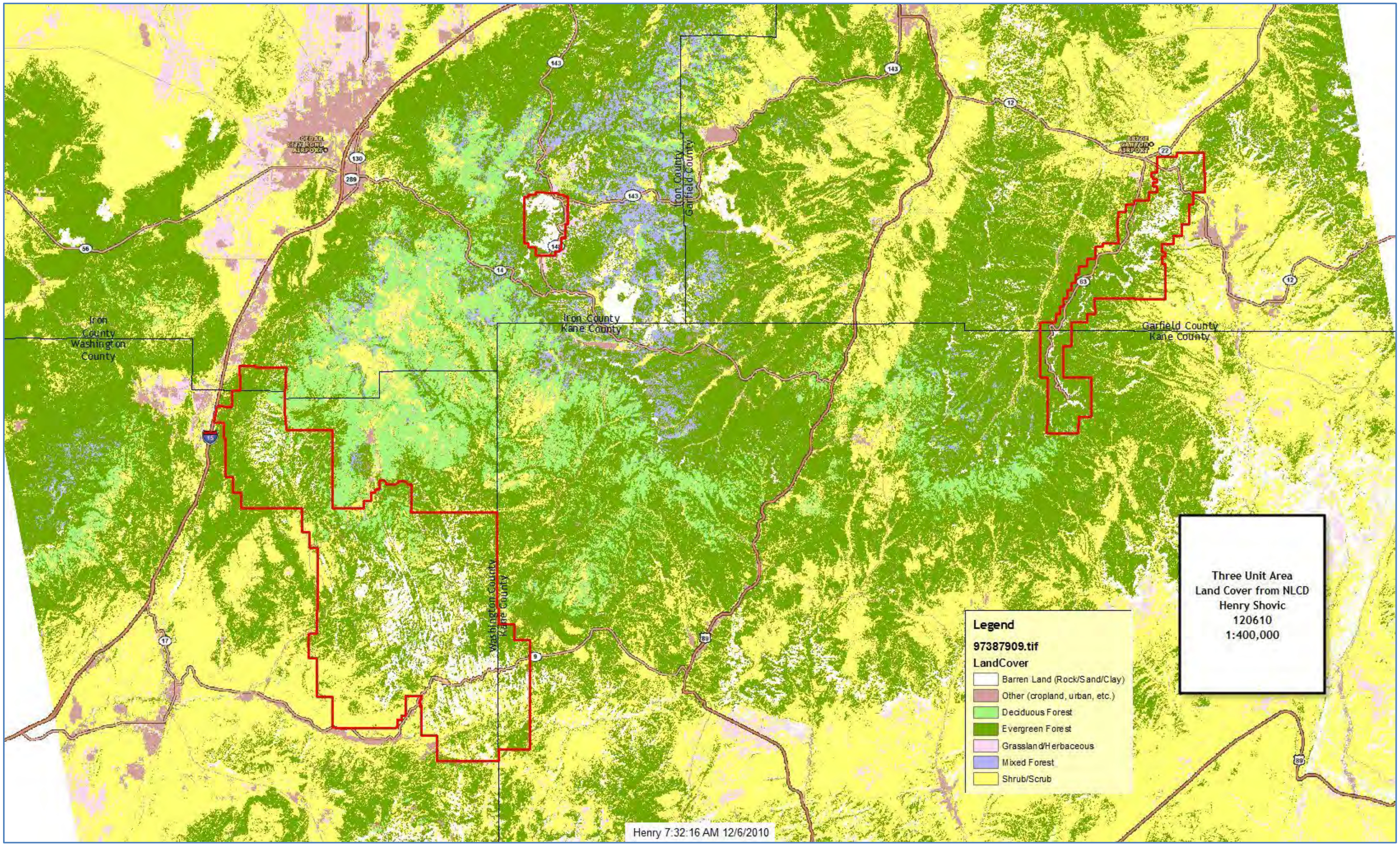


Figure 5. General Vegetation in the Study Area

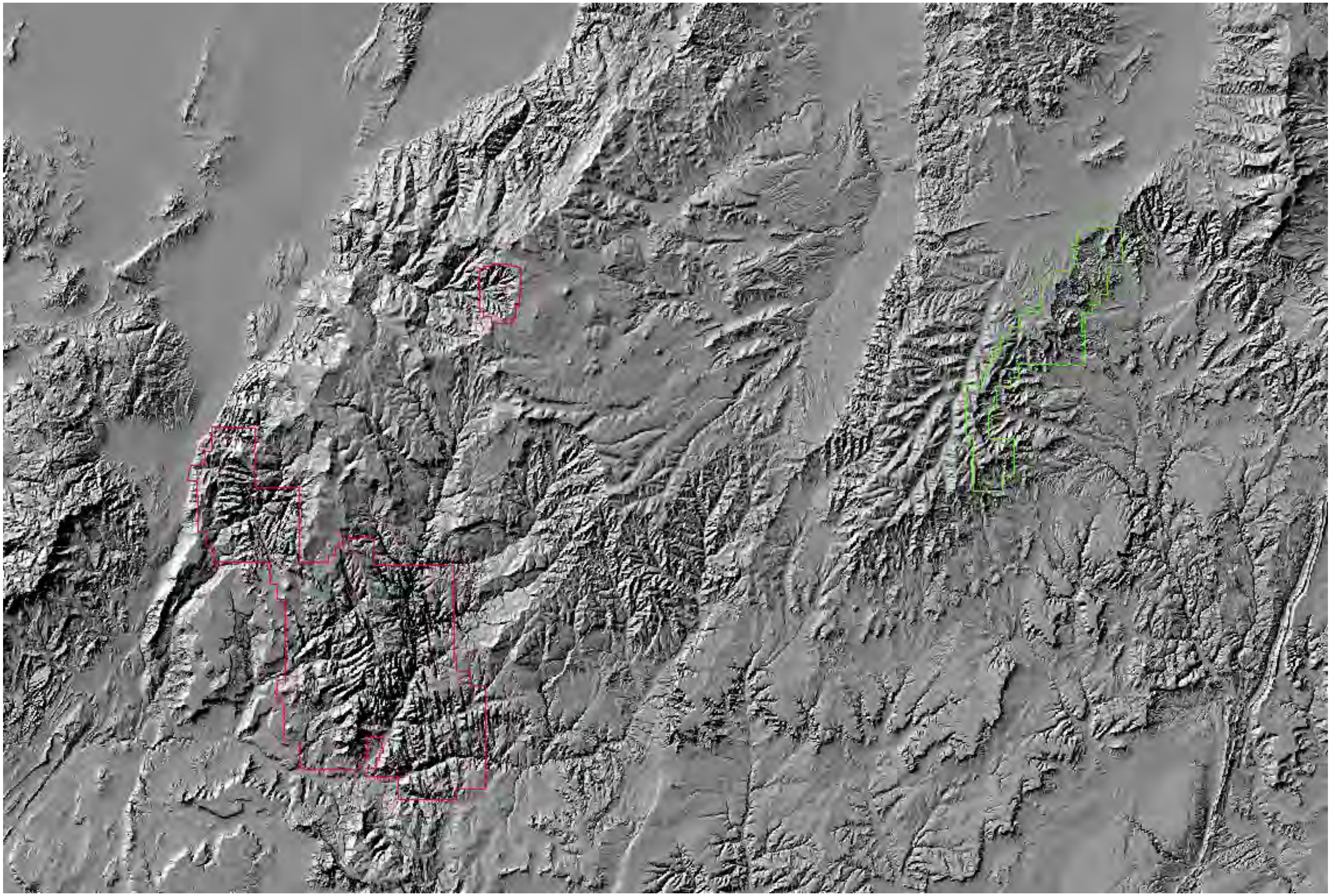


Figure 6. Physiography of the Three Units

Methods

Modeling

The concept of modeling is central to this project. Species habitat and climate's effect on that habitat are all a set of cascading models. Even the selection of species was modeled, using defined criteria to meet the study's purpose. These three activities are important to the study's utility in Park management, scenario planning, and as an example for future work. Therefore, the modeling process and its application here are discussed briefly to provide context, then the process of species selection, and finally the process used to apply the chosen climate change model to habitat models. Specific model development, validation, and outcomes are discussed under Results.

General Considerations in Modeling

Modeling and Simulation (M & S) is a discipline that engages in the prediction of the future. The development of models (approximations of the real world), simulation (the process of learning how the model responds to events), the attendant analysis (drawing conclusions), and visualization (communication of results) are all necessary parts of that discipline (Banks and Sokolowski, ed, 2009).

Our core concept is that models are only approximations of the real world, made for a particular purpose. As approximations they are by nature imperfect. But they can be useful. It's their "appropriate" use of that is critical to their success in producing useful results. That success is related to using an appropriate modeling process. Though there are many descriptions of that process, but a well-organized one for natural resource management is given in Jakeman, et. al., 2006. They also suggest a group of standards that should be addressed in all modeling efforts. These standards include:

- A clear statement of the objectives and clients of the modeling exercise;
- Documentation of the nature (identity, provenance, quantity and quality) of the data used to drive, identify and test the model;
- A strong rationale for the choice of model families and features (encompassing alternatives);
- Justification of the methods and criteria employed in calibration;
- As thorough analysis and testing of model performance as resources allow and the application demands;
- A resultant statement of model utility, assumptions, accuracy, limitations, and the need and potential for improvement;
- Fully adequate reporting of all of the above, sufficient to allow informed criticism.

Defining the model's objectives is paramount. These may include increasing understanding of a system, elicitation of knowledge, assessment of data, summarizing of data, focusing discussion of a problem, prediction, hypothesis generation, forecasting (short term prediction), providing guidance for management, or interpolation (estimating variables, or data-gap filling), as well as others. The kinds of models specified are highly dependent on its purpose. The modeler also needs to know client requirements, their level of technical knowledge, and requested time frames.

The context of the modeling effort represents the scope, constraints, and available resources in the modeling effort. The expected accuracy, the specific questions asked, the temporal and spatial scope, scale, and resolution are stated here. What is the project's time frame? Who are the interest groups? The model's usability and flexibility is also important. Can it be easily modified with new data? Should it be designed to do so?

The rationale for the choice of model structure and implementation should be a strong point in the analysis. This includes defining the multitude of factors involved in model development. What is the nature of the data? What kind of "canned" models may be available, and are they sufficient for the purpose? What spatio-temporal linkages are needed? What outputs are needed? What level of detail is needed in those outputs?

Model selection includes defining what kind of model features are needed to reach objectives. What level of uncertainty is acceptable? Here, the concept of white/gray/black boxes is important. The term "white box" is applied to models based on theory and process. "Black box" models are primarily empirical, and "gray" boxes are a mix of the two. There are many model families, including empirical (statistical), stochastic (rule of thumb), those based on theory and process, or rule-based. Some may be based on spatial relationships, or have a spatial component. The choice of model type is dependent on the purpose of the project, and the simplest structure that meets objectives is usually best.

The last four of the above standards are "validation" items. Model validation is concerned with verifying there is an acceptable level of reality in the model when used for its established purpose. This is not only for testing and revision of the model during development, but also for determining accuracy and precision of results, and establishing credibility with users.

Modeling and Its Application in This Study

The purpose of this study is to determine the level of vulnerability for certain species' habitats under various climate change alternatives. These create a framework for understanding and quantifying that vulnerability. There are three modeling instances: the model for selection of species (a stochastic one), the model (discussed above) for rating the effects of climate change (a theory-based one), and the four species distribution models (a combination of statistical, theory and process, and rule based models).

Criteria include local applicability, availability in the project time frame, quantitative prediction capability, relative simplicity, and appropriate spatial scale. Local data are used to validate them. Other models could have been selected, but these were best available given the short term nature of the study and the above criteria.

Model results are a reasonable place to the development of a management response. A "real" or even a "realistic" assessment of impacts is probably not feasible, since there are so many variables in predicting species response to climate change. However, these models are developed to be "useful" in predicting a set of potential futures that have some basis in reality. Hence they are designed to be reasonable.

Selection of species, climate change, and the effects of changes on species habitat are all part of the modeling effort. Each is described below

Selection of Species

Four target species were chosen for this project, as a model for a National Park level representation of climate effects. These are the American pika (*Ochotona princeps*), Desert tortoise (*Xerobates [Gopherus] agassizii*), Shivwits milk-vetch (*Astragalus ampullarioides*), and Great Basin bristlecone pine (*Pinus longaeva*). In terms of occurrence, the American pika is listed as present in ZION and CEBR, according to the official species lists for the three Units. The Desert tortoise is included only in ZION's list. Shivwits milk-vetch is on ZION's list, and Great Basin bristlecone pine is on both CEBR and BRCA's lists.

These species were selected to model an opportunity to broadly test project methods for both plant and animal species and across NPS boundaries. They therefore should demonstrate opportunity for transferability to other species and NPS units. Selection of species was completed by National Park resource specialists and external species/ecology specialists in contact with Park management before the study began (Appendix B).

Criteria for their selection generally address known occurrence in the Units, documented climate-related concerns, and the state of knowledge of habitat parameters. Species-specific criteria used to in Appendix B to justify individual species selection are shown below. Project-generated background data were used to test the selection models.

Selection of American pika

Photo courtesy of U.S. Fish and Wildlife Service (FWS) and National Oceanic and Atmospheric Administration (NOAA)

From Appendix B, the following are species-specific criteria:

- Currently under USFWS review for listing under the Endangered Species Act
- Generally at the southern edge of its western range
- Habitat and climate-related trends have been modeled in the research literature
- Presence documented at CEBR; Historically present at ZION, possibly still present; Not known in BRCA.

These criteria are supported by the following project-generated data.

Note: Unless otherwise cited, the information below was excerpted, quoted, and paraphrased from U.S. Fish and Wildlife Service, 2010, and personal communications with Erik Beever, PhD.

Currently under USFWS review for listing under the Endangered Species Act

A review in 2010 by the U.S. Fish and Wildlife Service concluded listing under the Endangered Species Act of 1973 was not warranted at that time, primarily because its wide-spread distribution. However, this situation has changed, and there are now efforts to revisit its status, especially in the southwest (National Park Service, 2011).

Generally at the southern edge of its western range

Habitat occupied by American pikas is patchily distributed (Figure 7), even though at first glance it is widely spread. The southernmost observed populations appear to be in the Sangre de Christos Mountains in New Mexico, and the southern Wasatch Range is rated as a potential analysis area. The Study Area is at the southwest edge of that range.

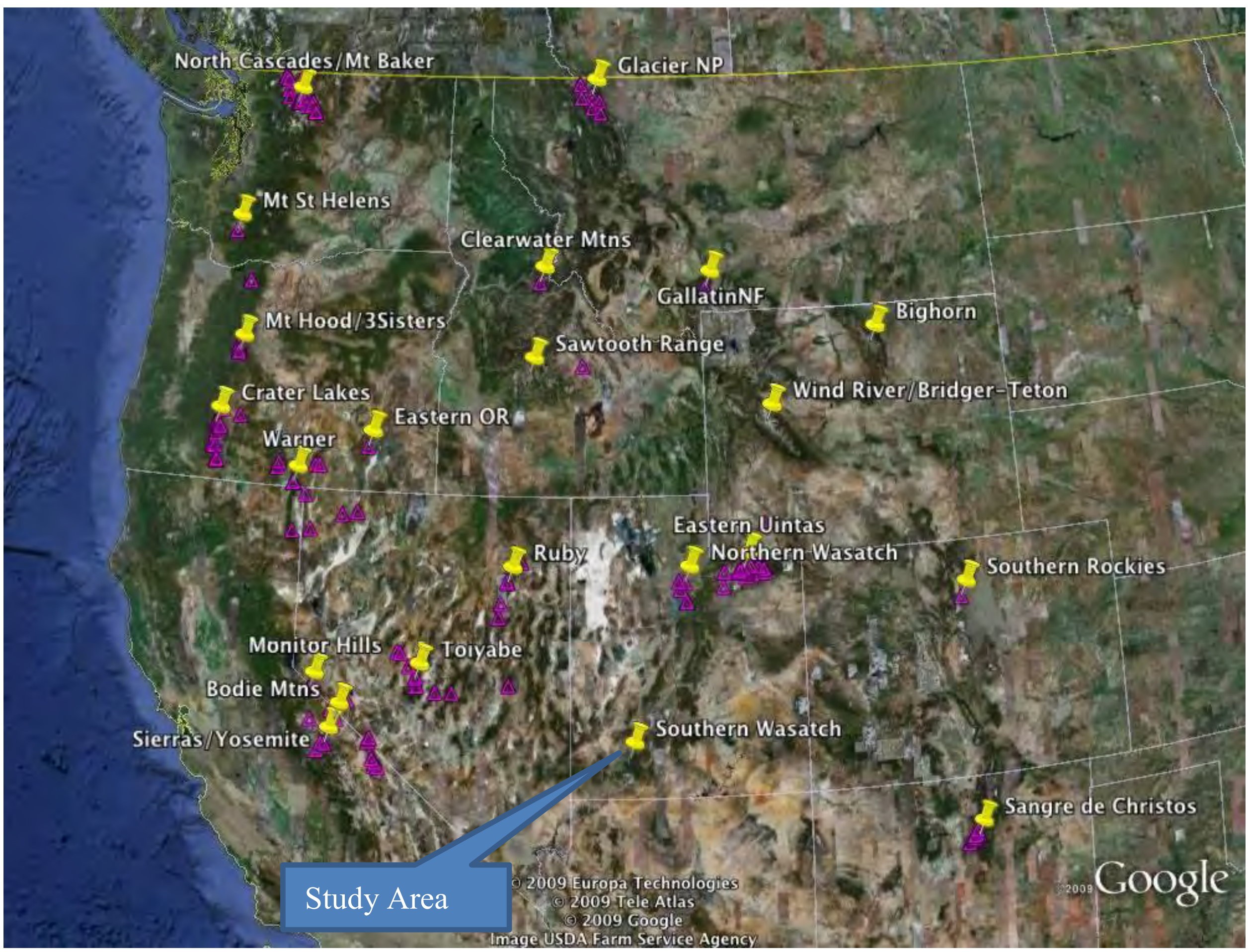


Figure 7. Western U.S. with pika observation locations in pink triangles and mountain range areas for analysis identified by the Fish and Wildlife Service indicated by yellow pins (Ray, et. al, 2010). The callout indicates the Study area for the current project.

Habitat and climate-related trends have been modeled in the research literature.

Great Basin pika populations have been shifting both pre-historically and historically. Grayson (2005) suggests based on a literature survey that average elevation for extant pika populations has increased from 1750 m (40,000 to 7500 years ago) to 2,168 m in the middle Holocene (7500 - 4500 years ago), to 2,220 m in the late Holocene (4500 - 200 years ago). More recently, Beever et. al. (2011) has modeled the pace and drivers of extinction in the Great Basin within the latitudes and elevations of CEBR, BRCA, and ZION, and has related physical factors to presence of populations. He and his collaborators have also completed a series of background studies, including testing various models of extirpation (Beever, et. al., 2010), and collection and analysis of extensive historical and recent field data in the Great Basin (Beever, et. al., 2003; Beever et. al., 2011).

Presence documented at CEBR; Historically present at ZION, possibly still present; Not known in BRCA.

Locally, pika have been observed near Alpine Lake and near CEBR (Conner, 1982; Oliver, unpublished report in 2007) and surveyed at the Alpine Lake area within CEBR (Waters, unpublished report in 2010). One was observed there during surveys in 2011 (Claire Crow, ZION, personal communication). This suggests that a pika population is established in this area.

In ZION, no individuals were observed in the 2010 survey (ibid), but pikas were observed in 1956 and before 1970 near Kolob Reservoir and at Lava Point in ZION (Stock, 1970). Ongoing surveys in 2011 have shown indirect evidence of probable recent pika presence (latrine, Figure 8, in talus body 17 shown in Figure 26 below and a probable sighting at Lava Point (in or near talus body 24 (Figure 26 below). The pika surveys were executed by a traverse through the candidate talus fields during the daytime. Another latrine (similar in appearance to Figure 8) was observed near Lava Point (north end of talus body 14 in Figure 26 below) in 2011 by the author during field review.

Figure 8. Pika Latrine observed Aug 2 2011 at Lava Point in ZION

Selection of Desert tortoise

(***Photo from Nussear, 2009***)

From Appendix B, the following are species-specific criteria:

- Federally listed as Threatened
- ZION is at the northern edge of its habitat, also at highest elevation in range of the species
- Have been identified in warmer and drier portions of ZION
- Active, established monitoring program

These criteria supported by the following project-generated data.

Note: Except where cited, the following information was excerpted, quoted, and paraphrased from U. S. Fish and Wildlife Service, (2008), Meyer (2008), field review, and Claire Crow, Wildlife Program Manager ZION, personal communication and unpublished documentation.

Federally listed as Threatened

The desert tortoise is a large, herbivorous reptile whose habitat is the Mojave and Sonoran deserts in the southwest United States and in northern Mexico. Its populations in the entire Mojave area were listed as "Threatened" by the U. S. Fish and Wildlife Service in 1990. A recovery plan was completed in 1994, with a draft revised plan completed in 2008 (U.S. Fish and Wildlife Service, 2008).

ZION is at the northern edge of its habitat, also at highest elevation in range of the species.

Present Tortoise habitat is shown in Figure 9. The Study Area is just outside of the northern limit of the established range.

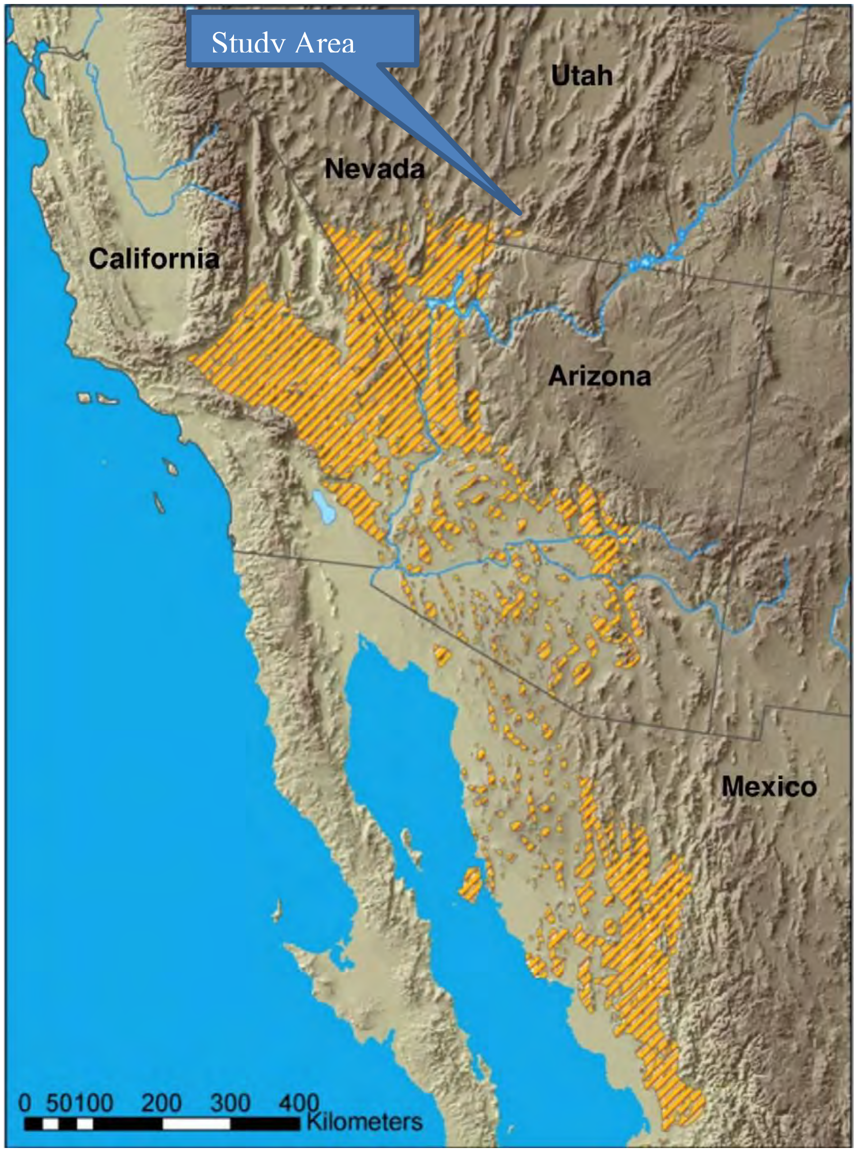


Figure 9. Map showing distribution of desert tortoise (from Nussear, et. al., 2009)

Records of desert tortoises range from below sea level to an elevation of 2,225 m, which is included in ZION's elevation range of 1,115 - 2,660 m (Table 1 above).The most favorable habitat occurs at elevations of approximately 305 to 914 m, however, based on current information and data from recent range-wide monitoring efforts, the species has consistently been documented above 914 m. In fact, surveys at the Nevada Test Site revealed that tortoise sign (*e.g.*, scat, burrows, tracks, shells) was more abundant on the upper alluvial fans and low mountain slopes than on the valley bottom. Current range-wide monitoring strategies do account for the possibility of tortoises occurring in mountainous habitats, ZION presents this kind of environment (Figure 6 above).

Have been identified in warmer and drier portions of ZION; Active, established monitoring program

Locally, (in ZION) tortoise habitat and presence has been reported. Populations and habitat have been extensively characterized by ZION staff (Claire Crow, ZION wildlife program manager, personal communication) and are summarized below.

The desert tortoise population in southwestern ZION and near Springdale, Utah, is at the present northern limit and maximum elevation of the range of this species. The local terrain is sparsely vegetated and includes steep slopes, large boulders, and a few flat open meadows (Figure 10). Soils are loose and friable. Vegetation is dominated by blackbrush *(Coleogyne ramossisima)*, with some areas of open-canopy juniper-pinyon woodland. Many types of native wildflowers and grasses, as well as prickly pear cactus flowers and pads, provide forage for the tortoises. Unfortunately, the invasive exotic cheatgrass (*Bromus tectorum*) also occurred in the habitat. Although tortoises prefer native plants, they are opportunistic consumers and will eat cheatgrass, the spiky awns of which can injure the mouth or intestinal tract of the tortoise. Cheatgrass also threatens desert tortoises indirectly, by providing a layer of continuous fine fuels that spread fire quickly.

Burrows, which provide shelter from the heat of summer and cold temperatures in the winter, are commonly dug beneath large boulders. In ZION near Springdale, a burrow was reported at the base of a shrub in sandy soils (Figure 10) (from field trip in 2011).

Tortoises in the Zion Canyon population are communal, sharing shelters in the heat of the summer (June through mid-August) as well as during winter brumation (mid-October through mid-April). During the spring and during the summer rainy season, they are more often above-ground and mobile. Home range sizes are small, averaging 21 hectares (sample size of 10). All of the 12 tortoises monitored for 18 months spent some of their time on privately-owned land, either developed, under development, or subject to development.

To date (in 2011) 22 tortoises in ZION have been marked, but this is probably a minimum population estimate. The population is probably reproducing, as copulations, yearlings and fragmented egg shells have been seen. Six females were marked, and tortoises have been observed in all age classes (adult, subadult, and immature) and tortoises are marked only if larger than 100 mm median carapace length. Additionally, tortoises have been observed that could not be marked, as no qualified person was on scene to mark them. It seems unlikely that all present individuals have been already marked, since a new, unmarked tortoise was just observed on 4 April, 2011.

Figure 10. Burrow near Springdale, on April Field Trip 2011

Selection of Great Basin bristlecone pine

Great Basin Bristlecone Pine, by C.J. Earle, 2001.09.27

From Appendix B, the following are species-specific criteria:

- Bryce Canyon NP and Cedar Breaks NM are near the eastern edge of its range
- Rare in Zion NP
- Distribution is generally limited by specific climatic and landscape requirements
- Highly at-risk with a warming climate.

These criteria are supported by the following project-generated data.

Note: Unless otherwise cited, this information was excerpted, quoted, and paraphrased from Fryer, 2004, which includes 154 references.

Bryce Canyon NP and Cedar Breaks NM are near the eastern edge of its range.

Great Basin bristlecone pine (*Pinus longaeva* D.K. Bailey (Pinaceae)) is a long-lived five-needle pine of highly-variable growth form. It is referenced by its Natural Resource Conservation Service (NRCS) plant code abbreviation PILO hereafter in this document. Trees are typically 9.1 m or less in height. Though low-elevation trees are typically tall and upright, at higher elevations they become twisted and distorted. The trees may have single or multiple trunks, thin bark, and a high proportion of dead trunk and branchwood. Needles are 2.5 to 4 cm long, with five needles per fascicle. Root systems are shallow and highly branched.

PILO and its relative the Rocky Mountain bristlecone pine (*Pinus aristata)* occur throughout the central western states (Figure 11), but are separated by the Colorado/Green river systems. PILO itself occurs in California, Nevada, and Utah, generally at relatively high elevation.

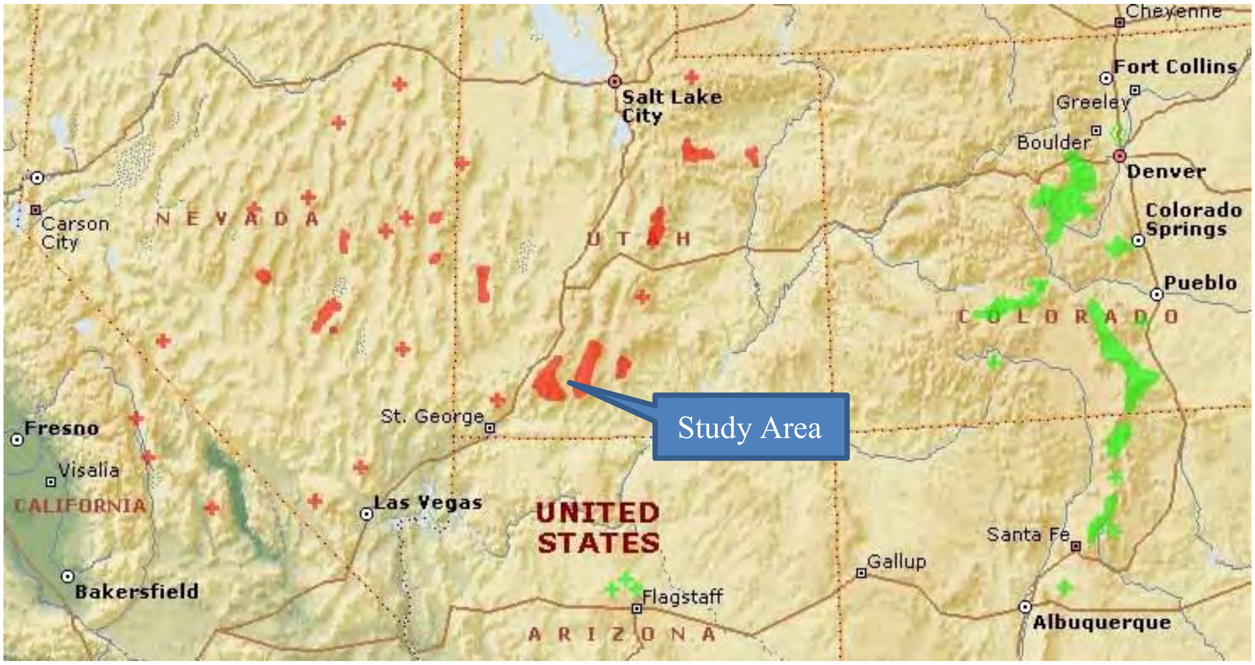


Figure 11. Bristlecone Pine Distribution from the Gymnosperm Database (http://www.conifers.org/pi/pin/longaeva.htm) Red indicates P. longaeva, green indicates P. aristata.

Across its range, PILO occurs from 2,200 - 3,700 m in elevation. Ranges by state are: California - (2,200-3,700 m), Nevada - (2,400-3,300 m), and Utah - (2,195-3,265 m). In Utah, Great Basin bristlecone pine-limber pine communities form a mosaic with several other communities. Except at high elevations, Great Basin bristlecone pine-limber pine is usually a topoedaphic climax community within the Engelmann spruce and interior Douglas-fir zones. Great Basin bristlecone pine-limber pine communities in northern Utah are found above and form stringers into Engelmann spruce-subalpine fir forest and mountain meadow communities. Likewise, Engelmann spruce, subalpine fir, blue spruce (*Picea pungens*), Rocky Mountain lodgepole pine (*Pinus contorta* var. *latifolia*), and white fir may finger into higher-elevation Great Basin bristlecone pine-limber pine communities. Silver sagebrush (*Artemisia cana*), heartleaf arnica (*Arnica cordifolia*), slender wheatgrass (*Elymus trachycaulus*), and Thurber fescue (*F. thurberi*) are common understory associates in Great Basin bristlecone pine-limber pine communities. Fire-disturbed areas are usually occupied by Rocky Mountain lodgepole pine or quaking aspen.

Pure PILO stands at high elevations may be species-poor. Stands are generally very open, with sparse understories. For example, a PILO community located between 2,700 and 3,200 m elevation in CEBR is composed of monospecific stands of PILO and a dwarfed paintbrush (*Castilleja* spp.). The understory is otherwise bare. Other similar areas have been observed to contain other tree species interspersed with the pines.

Great Basin bristlecone pine-limber pine communities on the plateaus of southern Utah typically have a diverse understory. Common shrub associates include true mountain-mahogany (*Cercocarpus montanus*), curlleaf mountain-mahogany, singlehead goldenbush, wax currant, and Wood's rose (*Rosa woodsii*). Common herbaceous associates include Ross' sedge (*Carex rossii*), slender wheatgrass, Salina wildrye (*Leymus salinus*), western yarrow (*Achillea millefolium*), and timber milkvetch (*Astragalus miser*)

In southern Utah, PILO occurs in diverse, mixed-conifer forests at low elevations, but in open stands at higher elevations. In BRCA and the surrounding Dixie National Forest, PILO occurs in mixed forests also composed of blue spruce, Engelmann spruce, limber pine, interior ponderosa pine (*P. ponderosa* var. *scopulorum*), Colorado pinyon (*P. edulis*), Rocky Mountain Douglas-fir, Rocky Mountain juniper (*J. scopulorum*), Utah juniper (*J. osteosperma*), and Gambel oak (*Quercus gambelii*). On the Wah Wah Mountain Research Natural Area of southern Utah, PILO occurs in an open, mixed-conifer forest. Interior ponderosa pine dominates the overstory; white fir and PILO form a subcanopy. On some sites in southern Utah, Great Basin bristlecone pine-limber pine forests merge with lower-elevation Rocky Mountain juniper, curl leaf mountain-mahogany, or quaking aspen woodland communities.

Rare in Zion NP

Locally, PILO may occur outside of BRCA and CEBR on the adjoining Dixie National Forest. A vegetation feature class obtained from the USFS website shows bristlecone pine stands scattered throughout the area. Figure 12 shows its distribution outside the two Units, inside the National Forest. However, it is attributed as PIAR (Rocky Mountain Bristlecone Pine or *Pinus aristata*), not PILO, which may be an error in classification since PIAR is not known to occur in Utah (Lanner, 2007), and is referenced in a CEBR flora as *Pinus longaeva* (Fertig, 2009). The species is probably very uncommon in ZION, as a search of the NPS vegetation map indicated no occurrence, and a search of a published flora of ZION shows Bristlecone pine as potentially present, but unconfirmed (Fertig and Alexander, 2009).

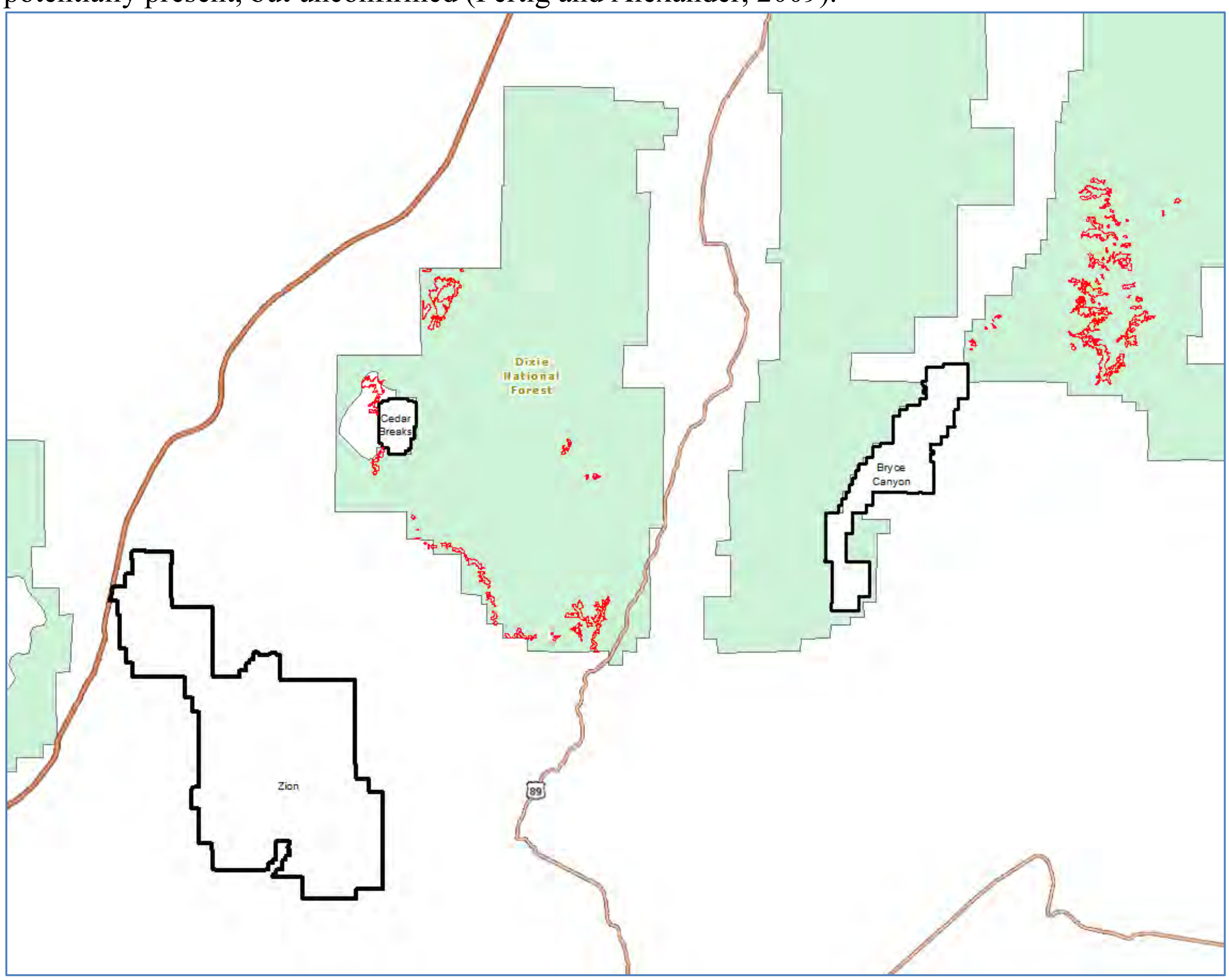


Figure 12. Bristlecone Pine (in red) near the three Units on the Dixie N. F. (in green)

Distribution is generally limited by specific climatic and landscape requirements

The species has low requirements for moisture and nutrients but high requirements for light. It grows on very dry, mid- to high-elevation, exposed slopes and ridges. PILO endures desiccating, often gale-force winds. Slopes are typically steep. Percent slope ranged from 10% to 50% on 8 PILO sites on the Snake Range. In the White Mountains, slopes of 30 degrees or more were found to be most likely to be forested with Great Basin and limber pines, while more gentle slopes were usually occupied by shrubs and herbs. It is most common on south and west aspects, although it can occur on any aspect with well-drained, droughty soil. In Bryce Canyon National Park, the species often occurs on east-facing slopes, but that is probably correlated to the location of barren soils.

PILO is most common on thin, rocky substrates. Soils are usually derived from limestone or dolomite, although some populations grow on sandstone or quartzite. In the White Mountains, communities occur on dolomite soils with a rock content of 50% or more. Dolomite soils are alkaline, high in calcium and magnesium, and low in phosphorus. Those factors tend to exclude other plant species. On the other hand, dolomite soils are light-colored, reflect more light, are cooler, and have a higher total water storage capacity (~20%) than surrounding soils, and those factors favor PILO establishment. For example, limber pine codominates or associates with PILO on dolomite soils in the White Mountains, but becomes the dominant species on granitic soils. Some PILO populations on Wheeler Peak occur on quartzite and monzonite soils, although most are on limestone. On Wheeler Peak, PILO dominated on high-elevation, limestone-derived soils, but was unable to compete with curlleaf mountain-mahogany on high-elevation monzonite-derived soils. On the Colorado Plateau of western Utah, PILO grows on limestone and, more infrequently, glacial till substrates that are "extremely low" in available nutrients. Except at highest elevations, the more nutrient-rich, mesic soils are occupied by Engelmann spruce. Isolated Great Basin bristlecone pines may occur on open mesic sites throughout the species' range.

Highly at-risk with a warming climate

Since PILO is a relatively rare and widely distributed species (Lanner, 2007) that occupies inhospitable and marginal environments, it may be at risk from climate-related changes. The spread of mountain pine beetle has been accelerating over the last 10 years (Evangelista, et. al., 2011), and has been predicted to continue with climate warming. PILO is in proximity to its predicted spread and occurs with other pine species. The mountain pine beetle prefers other species of pinus over PILO (Leatherman, et. al., 2007), but it is still vulnerable as a related species. It is probably at greatest risk where mixed with other species, as the beetles tend to fly the minimum distance to infest the next tree, resulting in expanding patches of dead trees. It is probably at lesser risk where it is the only species and is on scattered stands having low density.

PILO has low resistance to wildfire. Wildfire occurrence, intensity, and extent is predicted to increase with climate warming (McKenzie, et. al., 2011) particularly in closed canopy forest. Therefore, future wildfire risks are where mixed with other species in dense stands. BRCA is has extensive forested lands to the west, all at risk from wildfire (Figure 50 above). It is at lesser risk where it is in scattered, low-density stands with little surrounding vegetation. Almost all PILO stands in BRCA and CEBR are in this category.

Not all PILO is at risk from climate warming, in particular within the pure stands closest to upper timberline. Recent research using tree ring chronology correlated with climatic parameters has revealed some interesting trends (Salzer, et. al, 2010). At the upper tree-line limit, PILO has seen unprecedented growth increases over the last 50 years. This increase was correlated to a measured increase in temperature at these sites. The same growth increase did not occur at PILO sites below this level.

Populations are probably sensitive to fluctuations in climate. Paleo-studies show low seedling establishment of eastern Nevada populations during cool, dry periods approximately 900 and 2,500-3,000 BP. Poor PILO seedling establishment has been noted during the Little Ice Age.

Effects of current climatic conditions on species regeneration are uncertain. On dolomite soils in the White Mountains, seedlings are now establishing beyond both the current upper and lower elevational limits of mature Great Basin bristlecone pines. Regeneration is sparse, and within current elevational limits of mature trees on shale soils. However, there is some evidence that climate warming is hindering PILO regeneration on sites in the interior Great Basin.

Climatic change may affect this species directly, by increasing the growing season, increasing summer drought (if it occurs with a warming trend), or indirectly, by promoting competition from other species, or increasing chances of dying through insect infestations or forest fires (Lanner, 2007). Since the species is now at the colder, more extreme edge of the available environments, it may not have the opportunity to migrate to other sites. The climatic conditions favorable to its survival may be in question.

Selection of Shivwits Milk-vetch

Shivwits Milk-vetch in flower. NPS photo.

From Appendix B, the following are species-specific criteria:

- Federally listed as Endangered
- Most occurrences and highest populations are in ZION
- Occurrence is highly landscape specific, limited to certain geologic soils
- ZION, under USFW concurrence is propagating this plant in a nursery
- Active, established monitoring program

These criteria are supported by the following project-generated data.

Note: Unless otherwise cited or observed in field review, this information was excerpted, quoted, and paraphrased from an unpublished summary provided by Cheryl Decker, Zion National Park Botanist in January, 2011.

Federally listed as Endangered and Most occurrences and highest populations are in ZION

Shivwits Milk-vetch (*Astragalus ampullarioides* (Welsh) Welsh) is an herbaceous perennial legume listed as "Endangered" by the US Fish and Wildlife Service in 2001 with a final recovery plan published in 2006 (U.S. Fish and Wildlife Service, 2006). Known populations occur only in Washington County, Utah primarily on soils formed from exposures of the Chinle formation in and near the Mojave Desert (Figure 13). At the time of listing, there were approximately 1000 estimated individuals. However, in 2006 after a high precipitation water year, a survey estimated a total of 4,205 individuals distributed over 6 populations. Of the total number of individuals estimated, over 75 percent were distributed among three subpopulations in ZION and approximately 60 percent occurred at a single site within the park.

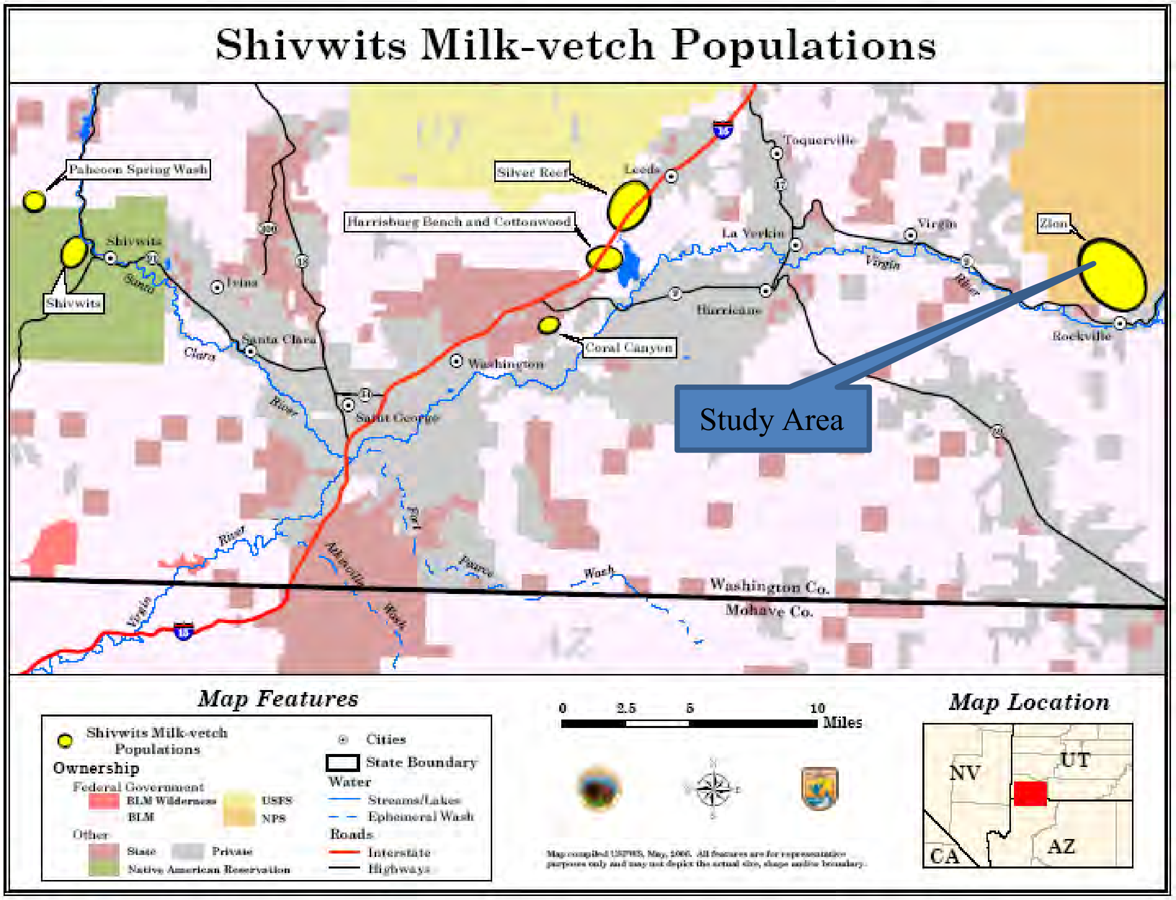


Figure 13. Map of all Shivwits Milk-vetch populations and Critical Habitat designations (U. S. Fish and Wildlife Service, 2006)

Occurrence is highly landscape specific, limited to certain geologic soils.

Shivwits Milk-vetch populations have been thought to occur between 920 - 1330 m on soft clay soils associated with isolated outcrops of the Chinle Formation at those elevations. Recent data show a slight expansion of range and habitat as noted below. The Chinle substrate, which is light, airy, and unstable when wet, expands greatly with precipitation, becoming slick, sticky, and highly compactable.

ZION, under USFW concurrence is propagating this plant in a nursery and Active, established monitoring program.

Preliminary greenhouse experiments have been carried out by ZION staff, and indicate that this species may be grown in other substrates, or at least in a mixture of native and non-native substrates, so it is possible that this plant is able to out-compete other native species only in this unusual soil type. Recent surveys show a somewhat larger population distribution in Zion National Park that is not necessarily tied to the Chinle Formation (Becca Lieberg and Cheryl Decker ZION staff biologists, personal communication, Jan 2011).

A field review by the author was conducted on April 14, 2011 to review habitat and populations in a known occurrence area in ZION, located by ZION staff in their monitoring program. Figure 14 shows a closeup of the plant and its local habitat. Parent material is weathered Chinle formation, a soft sedimentary rock. Slope is less than 3%. The type location shows pedoturbation (mixing of the top 5 cm of soil) possibly from frost and clay expansion. The top 5 cm of soil at this site is reddish very fine sand and silt, with clay loam below that depth. No rock fragments were present. Figure 15 shows the local landscape. The landscape is gently sloping with milk-vetch occurrence reduced above about 10% slope.

Figure 14. Landscape of Shivwits Milk-Vetch in ZION

Figure 15. Local habitat of Shivwits Milk-Vetch

Climate Change

Use of Mean Annual Temperature (MAT) as a Proxy for Climate Change

To be consistent with most climate science discussion, mean annual temperatures (MAT) rather than growing season temperatures are used to provide input for this analysis. Downscaled climatic change predictions are used for this project, provided by Patrick Gonzalez, PhD, National Park Service Climate Scientist (Gonzalez, personal communication). Dr. Gonzalez based his predictions on Gonzalez, et. al. (2010). Table 2 contains predictions for 110 years for both MAT and precipitation, downscaled to five 50 km blocks in the three Unit area and converted to a 100 year basis. The lowest potential MAT increase was taken from the lowest greenhouse gas emission group (B1) output, and the highest was taken from the highest emission group (A2). These values are in the range predicted by McWethy, et. al. (2010) for the western U.S.

Use of MAT as an indicator is a base assertion in this project. Climate change may be better expressed in future studies as extremes in temperature rather than the MAT, or even growing season temperatures as noted above. We recognize there are other limitations to this proxy, as discussed below. Future work may include these considerations.

Table 2. Downscaled Climate Projections from Gonzalez for the Three Unit Area

	Temp. increase	Temp. increase	Temp. increase	Temp. increase		Precip. change	Precip. change	Precip. change	Precip. change
	(ºC century^{-1})	(ºC century^{-1})	(ºC century^{-1})	(ºC century^{-1})		(century^{-1})*	(century^{-1})	(century^{-1})	(century^{-1})
	minimum	maximum	mean	standard deviation		minimum	maximum	mean	standard deviation
Historical									
1901-2002	0.27	0.87	0.58	0.25		-0.11	-0.05	-0.08	0.03
Projected									
1990-2100									
IPCC B1	3	3.1	3	0.02		-0.02	0.01	-0.0006	0.02
IPCC A1B	3.9	4	3.9	0.03		0.04	0.08	0.06	0.02
IPCC A2	4.5	4.6	4.6	0.03		0.08	0.13	0.11	0.02

*The unit of inverse century (century ^-1) means fraction per century. For example, -0.05 century ^-1 means a 100-year precipitation decrease of 5% of the mean annual precipitation.

To gain more insight the 100 year predicted change was divided into 50 year increments. Using the Climate Wizard (www.climatewizard.org) to estimate change in southern Utah for 50 and 100 year periods, 61% of the total predicted change for a given point was in the first 50 years. Therefore this factor was used in proportioning the increased temperatures for 50 and 100 years (Table 3). These values are close to the proportional range in other publications, in particular Garfin et. al. (2010) where the average increase is given as 2.55 deg. C by 2050 and a total of 3.95 deg. C by 2100. Though predicted change at 20 years was not a part of the original analysis, an estimate was later made for that period to give managers and the public a more immediate timeline. This was calculated as an arbitrary proportion of the 50 year change with no range.

Table 3. Time Periods for Predicted Mean Annual Temperature Increase

Time Period (years)	Range of Predicted Change in Mean Annual Temperature (^oC)
20	0.74
50	1.8 - 2.8
100	3.0 - 4.6

Elevation as a Proxy for MAT Change

A change in MAT modeled by a change in effective elevation is the chosen method for relating climate change to habitat. Other model factors (slope, geological substrate, precipitation, aspect, landform, latitude, and statistical correlations) are held constant. Elevation is easily measured and accurately mapped with digital elevation models. It is a parameter included in all four species models and is available for all study areas. At smaller scales it has been suggested as a proxy for mean annual precipitation and mean annual temperature (Miller, draft 2010) for the Shivwits Milk-vetch. Elevation is a critical factor in pika research (Beever, et. al., 2010), and is a significant factor in desert tortoise modeling (Nussear, et. al., 2009). Populations of PILO also have distinct elevational relationships (Fryer, 2004). These are discussed in detail in model development.

However, there are at least two significant problems. Even though elevation is used here because of its consistency, measurability, and general relationship to climatic factors, there are many confounding factors in applying it as a blanket proxy. Topographic effects, weather patterns, and large scale landscape factors make it ineffective as a proxy for climate change in large areas. However, these models are rather local in development and spatial extent, and elevation may be more appropriate to use here than in larger studies.

Within boundaries set by other constraints (e.g. soil type), elevation may not linearly affect habitat potential. This may be due to local topographic factors or physiological requirements. This concern is indirectly addressed in this study by modeling species requirements using physical landscape factors rather than just elevation. This may indirectly integrate some of these potentially complex relationships and thus make the application of elevation envelopes that include specific habitat requirements more credible at local scales.

Another dilemma is evaluating the species' response to climate change. Is the species limited by high or low temperatures, or both? Does the subsequent modeled elevation range shift the species lower limit, shift the upper limit, or does the range itself shift from both ends? In this study a decision was made for each species based on published literature on potential effects of climate change, estimated by physiological needs, or by local distribution of habitat parameters.

Then there is the temporal factor. How fast does the species move to locations, both by individuals and through reproduction? Is it mobile? Is it possible for it to shift its range in response to climatic change within the time frames given in this study? Using 50 and 100 year climatic ranges may reduce the extent of this potential problem, as this is long enough for even non-mobile species to potentially migrate the distances in these local areas.

Finally there is the potential variability in the lapse rates themselves. They may shift over time, especially with potential climate changes. However, it was beyond the scope of this report to account for these potential changes in lapse rate, so lapse rates were used that were derived from the most recent 10 year historical weather station records.

Association of Temperature and Elevation via Lapse Rate

The decrease in near surface temperature with increase in elevation is primarily due to air mass expansion at higher elevations. The rate of decrease with elevation is described by the lapse rate, determined as the temperature difference divided by the elevation difference between two sites. There are many factors that affect the rate of expansion and cooling with increasing elevation which is why lapse rates vary regionally and even locally.

Elements affecting near-ground temperatures across landscapes include site radiation load, soil moisture levels, and cold-air drainage, in addition to elevation (Fridley, 2009). Surface lapse rates can also vary with diurnal, seasonal, and annual changes in weather and are affected by inversions, wind, humidity, cloud cover, aspect, and surface reflectance (Minder et al 2010; Gardner et al., 2009). After reviewing 9 other studies, Rolland (2003) concluded that spatial variability was shown to be a potential source of variation when the region of interest exceeded a width of 1° latitude, though longitudinal change appeared less influential. The weather stations this study have a maximum latitudinal range of 0.8° so appear reasonable to use.

Some of the factors that introduce variability in lapse rates can be mitigated by parsing and screening temperature data depending on the intended use for the lapse relationship. For instance, seasonal variability can be minimized by computing lapse rates by season. Weather variability can be minimized by computing "clear-sky" lapse rates by eliminating rainy or cloudy days from the lapse rate determination. Including temperature data from multiple locations minimizes the effect of outlier temperature data sets if any one station records anomalously high or low readings. Though relative humidity is also a factor in lapse rates, climate in this area is relatively dry, and therefore was not used in this local study. With consideration given to the factors above, lapse rates offer a reasonable way to estimate surface temperatures in the absence of temperature measurements at all elevations across geographies that exhibit high vertical relief.

Predicting vertical range shifts due to predicted temperature change relies on knowing an organism's thermal tolerance limits and the local surface lapse rate. This requires two assumptions. Horizontally temperatures are relatively consistent across the study area and vertically temperature variation is described by the lapse rate equation (Ray et al., 2010). The vertical range shift is determined as

Eq. 1 $dE = 1000*(dT/L)$

where,

dE = vertical range shift, m

dT = predicted temperature change, ^{o}C

L = lapse rate, °C km^{-1}

This relationship is the model used to estimate the vertical range shift with temperature projections. Both the lower and upper thermal limits of an organism's tolerance can be determined as an effective change in elevation where those temperatures are likely to occur in the future as warming shifts the thermal habitat bounds upward (ibid).

Determination of Lapse Rate

In this study we developed estimates of lapse rate using 10 years of daily mean temperatures from seven stations within the bounds of the study area. A recent period of record was used for lapse rates in this study because lapse rates can change over time. A network of local weather stations (Table 4 and Table 5) was identified with an elevation and location range that spanned the three Units (Figure 16) and included much of the habitat ranges modeled. Daily average temperatures (2000-2010, from NOAA's National Climate Data Center (NCDC)) were screened to remove flagged data (reported as "9999" observations), and then the average of differences between daily maximum temperatures was divided by the difference in station elevations to determine the lapse rate between those two stations (Table 6 and Table 7). Station pairs that differ by more than 500m can be excluded to minimize influence of temperature measurement errors related to instrument sensitivity (Gardner et al., 2009). However in this study we chose to use all station pairs for the lapse rate used in modeling, but present lapse rates for the subset of station pairs that differ by less than 500m for sensitivity analysis. The lapse rates determined under different sky conditions and for different seasons were to aid the lapse rate sensitivity analysis. Depending on station data quality, the number of paired station temperature records used to determine lapse rates ranged from just under 1500 to over 3600 observation days.

Table 4. National Weather Service weather stations used in lapse rate calculations.

Station	National Weather Service station no.	elevation (m)	latitude	longitude
St. George	427516	844	37° 6´N	113° 34´W
La Verkin	424968	982	37° 12´N	113° 16´W
Zion	429717	1230	37° 13´N	112° 59´W
Alton	420086	2145	37° 26´N	112° 29´W
Bryce Canyon	421008	2412	37° 38´N	112° 10´W
Cedar City	421259	1856	37° 40´N	113° 2´W
Brianhead	420900	2978	37° 42´N	112° 51´W

Table 5. Elevation differences between station pairs used in lapse rate calculations. Pairs highlighted in pink differ by less than 500m vertically.

Station		St. George	La Verkin	Zion	Cedar City	Alton	Bryce Canyon	Brianhead
	elevation (m)	844	982	1230	1856	2145	2412	2978
St. George	844		138	386	1012	1301	1568	2134
La Verkin	982			248	874	1163	1430	1996
Zion	1230				626	915	1182	1748
Cedar City	1856					289	556	1122
Alton	2145						267	833
Bryce Canyon	2412							566
Brianhead	2978							

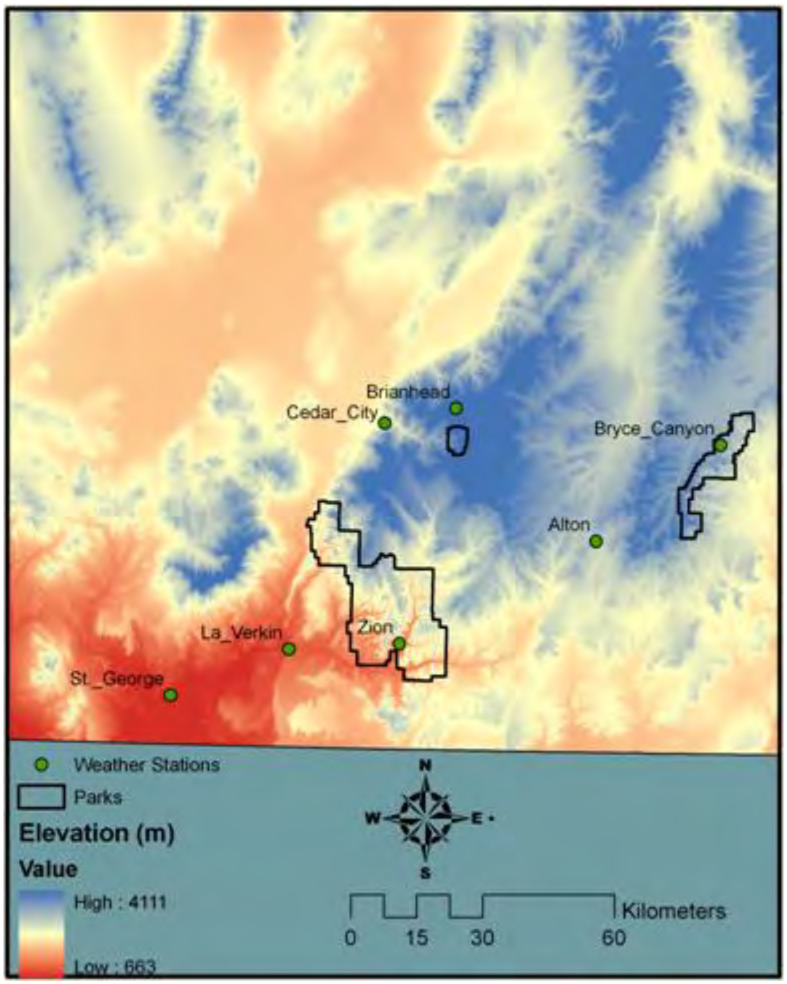


Figure 16. Location of weather stations used to determine lapse rates for the three Units displayed with the 30m digital elevation model as background.

Lapse Rate Results

The IPCC climate projections used in this study are for average annual temperature projections. For this reason annual lapse rates are used in this report to be directly comparable to projections. We recognize that lapse rates for the active growing season may be more representative of conditions when biological activity occurs and air masses are better mixed than in winter when temperature inversions may occur. We also recognize that annual lapse rates are less related to biological activity and organism's thermal limits than seasonal lapse rates which are more directly comparable to organism's maximum or minimum limits. These limitations represent areas for improved model interpretation in future studies that may use estimates of seasonal or even monthly climate change projections.

The annual lapse rate that was used to model the vertical range shift of habitats was made using daily maximum temperatures for the station pairs under clear sky conditions (an average of **7.3 °C km^{-1}**, Table 6). The summer lapse rate determined from June, July, and August daily maximum temperatures was 2.2 °C km^{-1} (averaged from Table 7). The annual lapse rate for this study area is within the range cited elsewhere, though lapse rates vary geographically and are not directly comparable to those from other regions or latitudes (Fridley, 2009; Minder, 2010). The lapse rates reported by those authors are from regions where fog, inversions, and other local phenomena frequently affect weather data. Typical summertime values of the climatological free- atmosphere lapse rate are 5 – 8 °C/km (see Mote et al., 2009 for an explanation of the difference between free atmosphere and surface lapse rates). A NOAA status review of the American pika referenced that same free atmosphere lapse rate of 5.0 - 8.0 °C/km across its range (Ray et al., 2010). Monthly lapse rates in a Colorado study ranged from 2.1 to 6.5 °C/km (Bigler et al., 2007). Lapse rates calculated using daily maxima in Great Smoky Mountains N.P. averaged 6.8 °C km^{-1} (for more discussion on lapse rates using minimum temperatures, see Fridley 2009). Values reported by Rolland (2003) in the Northern Italian Alps ranged from 5.4 to 5.8 °C km^{-1} using 365 days of the year from many weather stations. Mean lapse rates calculated for the Cascade Mountains in Washington were between 4.3°C km^{-1} and 4.7°C km^{-1}. The Cascade weather data sets show similar seasonal and diurnal variability, with lapse rates smallest (2.5–3.5°C km^{-1}) in late summer using minimum temperatures, and largest (6.5–7.5°C km^{-1}) in spring using maximum temperatures (with 5.0°C km^{-1} being a value used for model inputs; Minder, 2010).

Table 6. Annual clear-sky lapse rates for all station pairs = 7.3 °C km^{-1}. Annual lapse rate excluding red shaded pairs < 500m different in elevation = 7.8 °C km^{-1}.

	Lapse Rate (deg C/km)						
Station	St. George	La Verkin	Zion	Cedar City	Alton	Bryce Canyon	Brianhead
St. George		6.26	1.60	6.72	7.24	7.84	7.00
LaVerkin			1.18	7.02	7.28	8.05	6.93
Zion				10.39	9.62	10.08	8.24
Cedar City					8.00	9.68	7.08
Alton						12.04	6.80
Bryce Canyon							4.12
Brianhead							

Table 7 Summer (June, July, and August) lapse rates using all weather conditions and all station pairs = 2.2 °C km^{-1}. Summer (June, July, August) lapse rate excluding red shaded pairs < 500m different in elevation = 2.5 °C km^{-1}.

	Lapse Rate (deg C/km)						
Station	St. George	La Verkin	Zion	Cedar City	Alton	Bryce Canyon	Brianhead
St. George		0.29	0.04	2.32	2.05	2.34	2.26
LaVerkin			0.03	2.58	2.24	2.56	2.36
Zion				3.70	2.89	3.14	2.72
Cedar City					1.16	2.56	2.27
Alton						4.05	2.59
Bryce Canyon							1.93
Brianhead							

The Climate Change Model

Using the above lapse rate, the conversion from predicted MAT change to an "effective" elevation change is straightforward. An increase in MAT (from Table 3) will result in a change in "effective" elevation (Table 8) which is then used as direct input to the models. For example, if a maximum elevation for a species is 1000 m (limited by cold temperatures) then the "effective" elevation limit will be 1,626 m as warming MAT increases its maximum limit.

The range of this elevation change is significant (up to 626 m), so they probably will be large enough to significantly affect model results. The range of elevation change was used in developing alternatives from the minimum (predicted MAT change over a 20 year period) to the maximum (maximum predicted MAT change over a 100 year period).

Table 8. Elevation change for Predicted Mean Annual Temperature Increase (Annual Lapse Rate)

Time Period (years)	Range of Predicted Mean Annual Temperature Increase (^{o}C)*	Elevation Change (m) for Minimum Predicted Temperature Increase	Elevation Change (m) for Maximum Predicted Temperature Increase
20	0.74	100	100
50	1.8 - 2.8	245	381
100	3.0 - 4.6	408	626

*Given values for each elevation are 0.4 % over calculated values because of modification of lapse rate calculations after modeling was complete.

Considerations in Modeling Climate Change

During our project we discussed potential limitations of our approach and include here a discussion of some of the more important limitations related to our historic climate analysis and climate projections. In addition to temperature, mean annual precipitation (MAP) influences species distributions. However, change in MAP in the past 100 years was greater than that predicted in the next 100 years from downscaled climate predictions. Use of annual lapse rates may not represent the effects of thermally-sensitive species that may respond strongly to seasonal effects such as summer or winter temperature extremes. Using local historical data we have discovered climate is warming faster than predicted by climate models in Table 2, and precipitation has increased historically whereas it is projected to remain flat in the future. All these factors influence our interpretations and conclusions.

Use of Mean Annual Precipitation (MAP) as a Proxy for Climate Change

Precipitation plays an important role in vegetation growth as evidenced by vegetation response to precipitation in time-series (Thoma, 2011) but given the complexity of the relationship between temperature and precipitation, the spatial variation in precipitation (which has not yet been well defined for this study area), we chose to leave that component of modeling for a future effort after those relationships are better defined. This rationale is explained further in following paragraphs.

Precipitation lapse rates can be determined in a manner similar to the methods used for determining temperature lapse rates (Bigler et al., 2007; Fassnacht, 2003). However, the inherent variability in precipitation makes lapse rates less reliable than temperature lapse rates. This in turn makes it more difficult to make projections about spatial shifts in habitat due to precipitation (Ray et al., 2010). Future climate projections for precipitation are generally considered to be less reliable than temperature primarily due to differences in both natural variability and model uncertainty (Hawkins and Sutton 2010, 2011). In Figure 17 the uncertainty is characterized by the model results (thin lines) that vary by different degrees around ensemble averages (thick lines)for temperature and precipitation. Our historic analysis of MAP and MAT from climate stations in the study area confirm this by greater scatter around the MAP regression line than around the MAT regression line (Figure 17). Generally speaking it is more difficult to model future precipitation than temperature which is further complicated by their interactions.

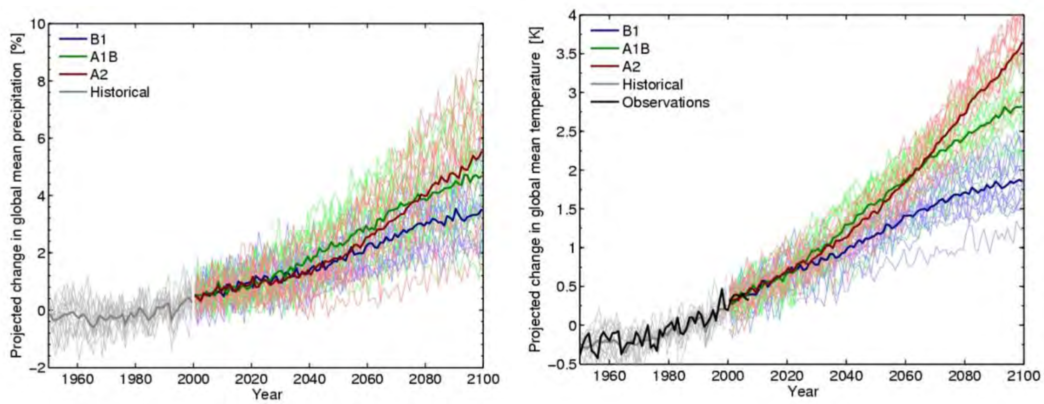


Figure 17. Uncertainty in climate projections for precipitation (left) and temperature (right) indicate it is more difficult to consistently model futures for precipitation than temperature. Source Hawkins & Sutton, 2011 left; Hawkins & Sutton, 2010 right.

The desert tortoise model discussed below is the only one in this study that is directly linked to precipitation. Productivity in the tortoise model is estimated by spatial distribution of Normalized Differential Vegetation Index (NDVI) which responds to soil moisture and indirectly to precipitation events. In the tortoise model NDVI is a proxy for both precipitation and temperature where the species composition and productivity at present result from the interactive effects of precipitation, temperature, and geographic variables such as soil texture, elevation, and aspect.

The relationship between NDVI and soil moisture is complex in semi-arid environments where temperature is a primary driver of evapotranspiration (Munson et al., 2011). In regions of low precipitation like tortoise and milk-vetch habitat small changes in temperature can have dramatic effects on abundance and distribution of soil moisture through time which in turn affects productivity. For this reason model results will likely be affected by temperature and precipitation interactions in the future.

Selection of Lapse Rate

The conversion from predicted MAT change to an "effective" elevation change is achieved via equation 1 above. An increase in MAT may result in an increase in the elevation that provides suitable thermal habitat in the future. Conversely, an increase in MAT may result in a decrease in effective elevation for a given site. These shifts are used as direct input to the habitat models. The amount of vertical change is a function of both projected temperature increase and the lapse rate.

It is somewhat counter intuitive that a smaller lapse rate results in a greater shift in elevation of suitable habitat, but that is because the vertical range shift is determined as the change in projected temperature divided by the lapse rate. A smaller lapse rate in the denominator of eq.1 results in a larger range shift.

A simple model was developed to improve our understanding of this relationship (Fig. 18). It illustrates the potential elevation shift under a wide range of projected temperature increases (0 – 5 °C) using the two lapse rate extremes determined for summer only all-sky (2.2 °C km^{-1}) and annual clear-sky lapse rates (7.3 °C km^{-1}). At the upper end of projected temperature increase from Table 2 (4.6 °C /century) the annual lapse rate predicts an upward habitat shift of 630 m whereas the summer lapse rate predicts an upward habitat shift of 2090 m. At the maximum projected temperature increase of 4.6 °C /century the large difference in these two modeled vertical shifts (1460 m) is purely a function of which lapse rate is used. The surprising range in vertical habitat shifts may provide some indication of the complexity of outcomes possible for different species depending on whether they respond more strongly to annual mean temperatures or seasonal extremes.

Understanding these relationships helps refine our understanding of potential changes and how they can be modeled more accurately even with inevitable uncertainty in climate forecasts. The sensitivity analysis suggests two important conclusions. First, the smaller the projected increase in temperature the smaller the difference in modeled range shifts regardless of using summer or annual lapse rates. This is apparent as the lines converge toward zero projected temperature increase (Figure 18). It also suggests that small discrepancies in lapse rate values determined for clear-sky conditions (7.3 °C km^{-1}) or all-sky conditions (7.4 °C km^{-1}) result in negligible modeled differences in range shift in this study area.

This implies that the use of seasonal lapse rates may be beneficial for modeling species that have high degree of seasonal sensitivity to temperature. For instance pika are affected by summer thermal extremes so a summer lapse rate may be appropriate for modeling habitat shifts that correspond to elevation ranges providing refuge from extreme heat. On the other hand Shivwits milk-vetch may be more affected by spring thermal regimes that affect evapotranspiration rates in soil moisture limited environments. Desert tortoise and great Basin bristlecone pine may be primarily affected by longer-term weather conditions that determine vegetation productivity through a much longer growing season. Other factors will likely influence actual habitat shifts caused by regional warming including those mentioned earlier including soil moisture, cold air drainage and slope aspect. These may be difficult to model without deploying a dense network of temperature sensors to evaluate the effects of topography that this study cannot address with the existing network of fixed weather stations (Fridley, 2009).

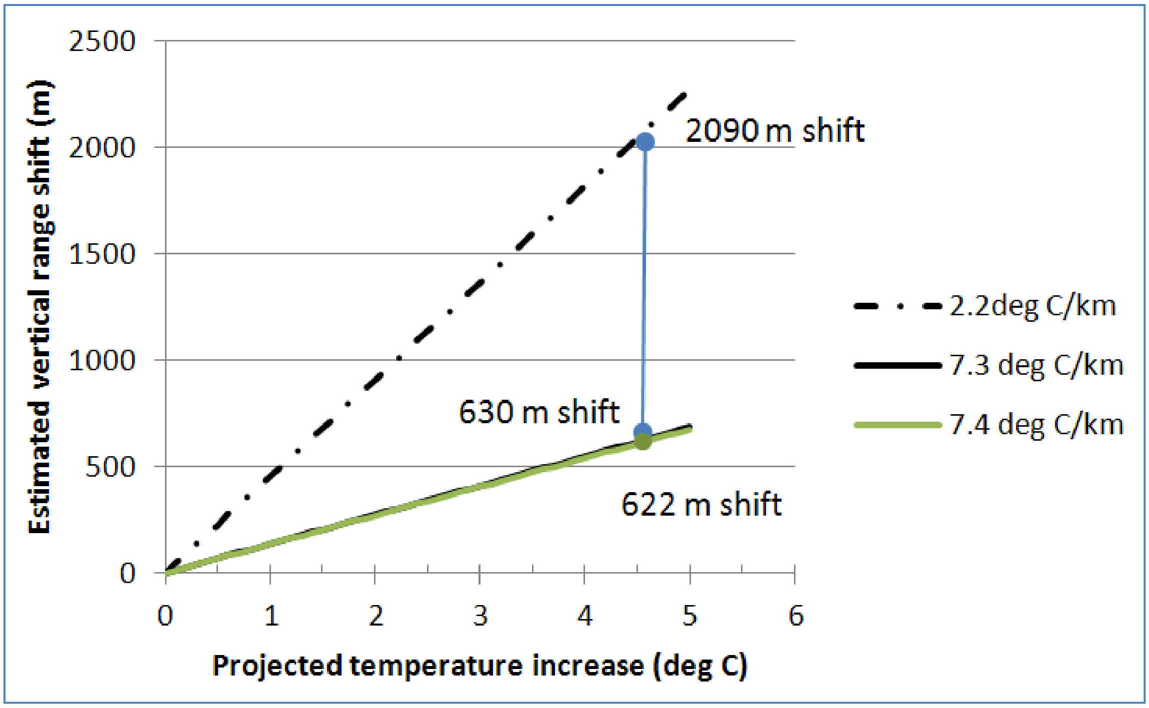


Figure 18. Sensitivity of modeled upward shift in suitable habitats under climate warming projections using lapse rates determined with temperatures during summer (2.2 °C km^{-1}), full year (7.4 °C km^{-1}) and full year clear sky conditions (7.3 °C km^{-1}) . The time over which the projected temperature increase occurs is not relevant in this figure.

Historical climate analysis

We determined long-term trends in average annual temperature and precipitation for weather stations used in the lapse rate analysis (Figure 19). This is intended to provide an historical perspective to compliment the climate change projections used in the models. Monthly values were calculated for months with no more than 3 missing values and annual means were computed only for years with 12 months of monthly data. Months and years that did not meet these completeness criteria were excluded from analysis. The station record lengths as well as data completeness were variable, but for consistency the magnitude of trends are reported as change per century to match the time horizon for this report. Due to the complexity of screening climate data for errors and inconsistencies from changing station locations and methods of measurement over the past century, these trend assessments must be considered provisional and subject to change.

State-wide versus local historical trends

Trend analyses were performed for the seven stations but Cedar City and Brianhead had less than 30 years of record and are not reported here. Trends in temperature were generally up while trends in precipitation were much more variable but generally flat or up by a few centimeters per century (Figure 19, Table 9). The stations with > 30 years of record indicated an upward trend in mean annual temperature that averaged 2.6 C/century with an average increase of +5.2 cm of precipitation per century. Although not directly comparable because of differences in climate regions, the rate of local temperature increase was more than double the state-wide rate (1.2 C/century, Figure 20, Table 9) (National Climatic Data Center (NCDC)). http://www.ncdc.noaa.gov/oa/climate/research/cag3/ut.html) and identical to the state-wide average rate of precipitation change. Some of the difference in local versus state-wide rates of temperature change is likely due to use of different stations in the analysis representing very different regional climates, while there may also be differences in data quality screening techniques used in the state-wide and local trend assessments. Nevertheless, the local temperature and precipitation trends are in the same direction as state-wide trends over the past century and are predicted to continue in the upward direction in the next century.

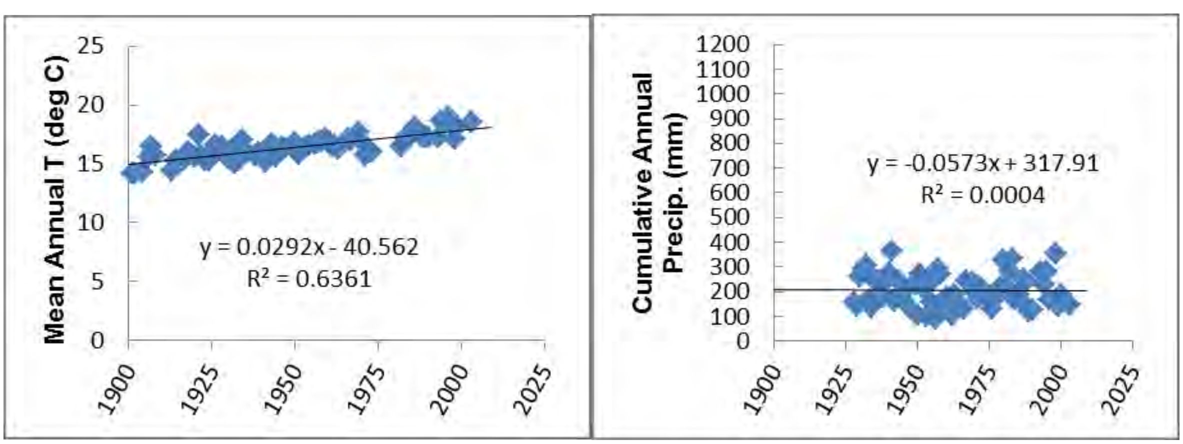
Downscaled versus local historical trends

The downscaled climate historical results indicated a mean 0.58 C/century increase in MAT since 1900 for the study area (Table 2 above) which is much less than the 2.6 C/century multi-station average MAT increase measured in the study area (Table 9). The downscaled climate historical results indicated a downward trend in precipitation since 1900, whereas the station data indicate an upward trend in precipitation. We do not know why the downscaled historic precipitation (mean -8 cm/century, Table 2) would indicate a direction of change at odds with what was measured at stations on the ground (+5.2 cm/century Table 9).

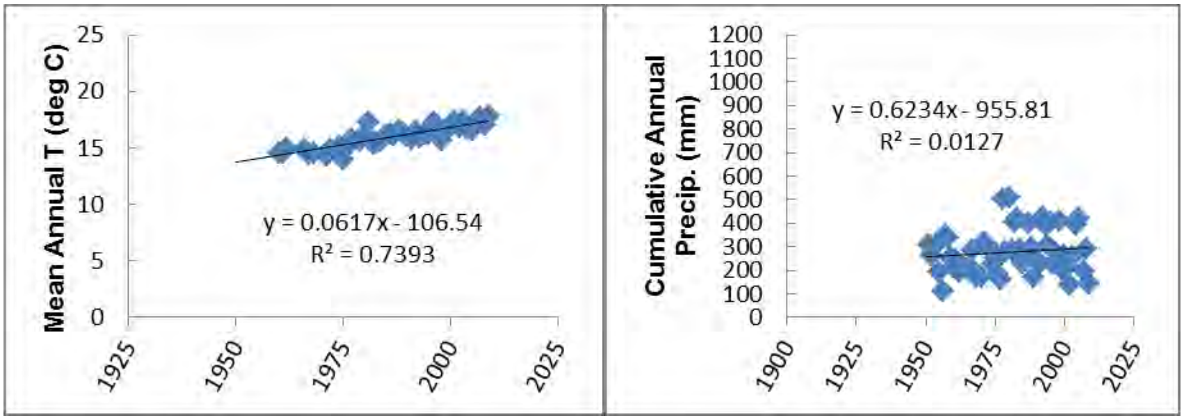
It is difficult for us to speculate why the trends for study area stations indicate magnitude of temperature change is greater in the local area than regionally or state-wide without a better understanding of how the downscaled historical estimates or state-wide estimates were made. However, three separate analyses (this one, Gonzalez in Table 2, and NCDC) all are consistent in concluding MAT has increased over the past century in this region.

Results of our precipitation trend analysis at local scale and NCDC at state-wide scale contradict those of Gonzalez, so it is less certain in our minds which direction precipitation trends have gone in the last 100 years and which direction they may go in the next 100 years. Precipitation in the historical record is more variable than temperature. This is consistent with the greater variability of modeled futures for precipitation than temperature as suggested earlier in Figure 18. This type of variability is why modeling effects of precipitation on habitat range is difficult at present and will be difficult to project into the future. Interaction between temperature and precipitation with landscape structure adds still more complexity but if considered collectively may reduce uncertainty in future studies.

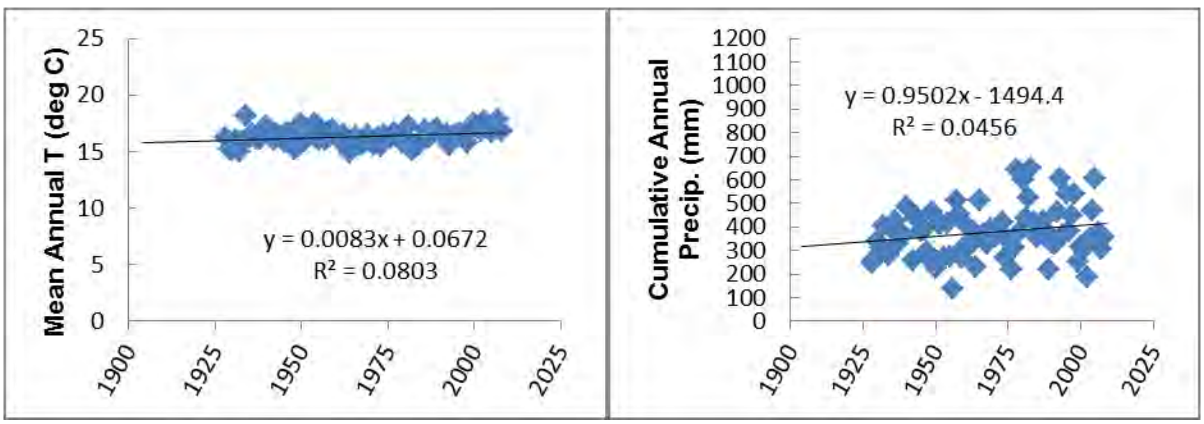
St. George



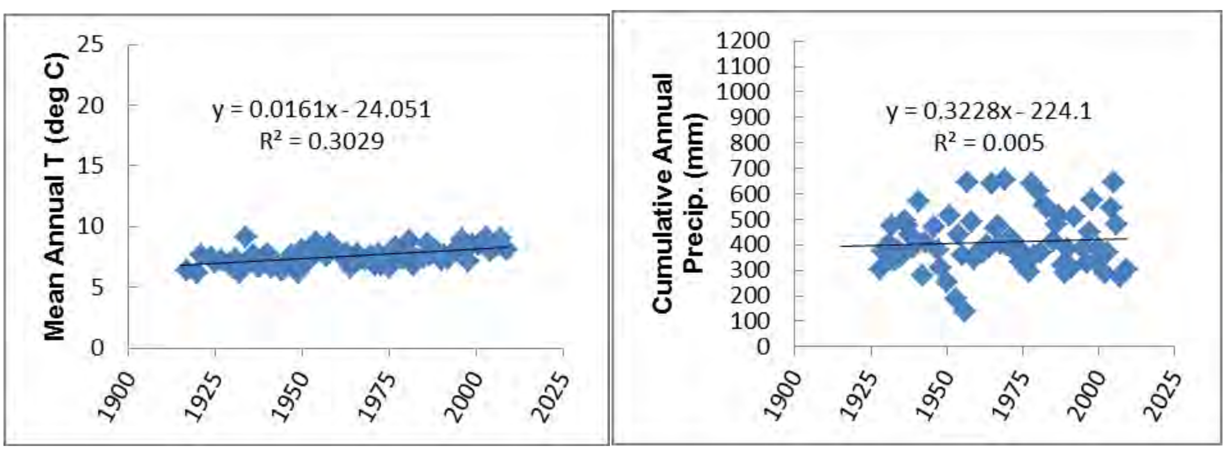
La Verkin



Zion



Alton



Bryce Canyon

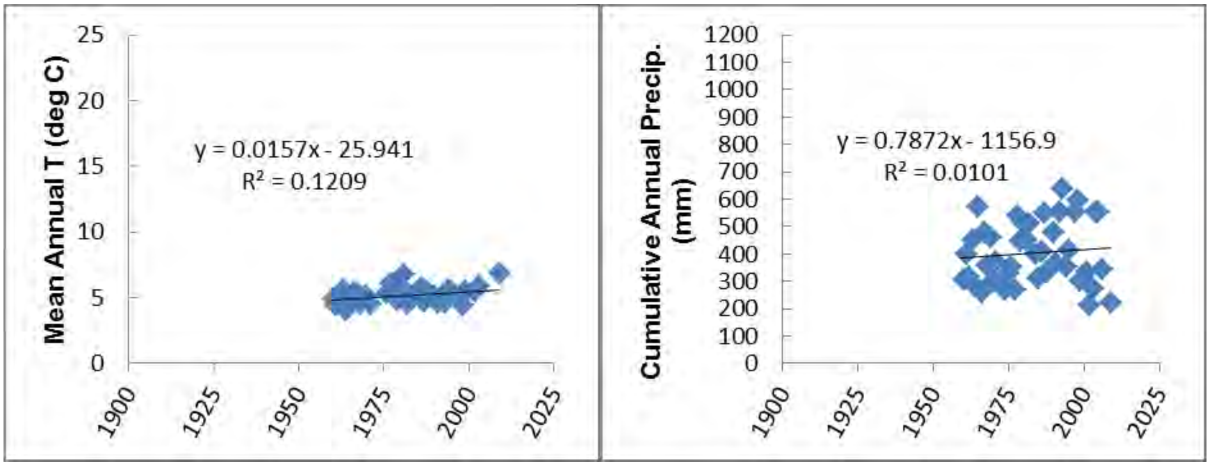


Figure 19. Long-term trends in temperature and precipitation at weather stations used to determine lapse rates for modeling vertical range shifts. The slope of the regression line multiplied by 100 is the rate of change per century reported in Table 9.

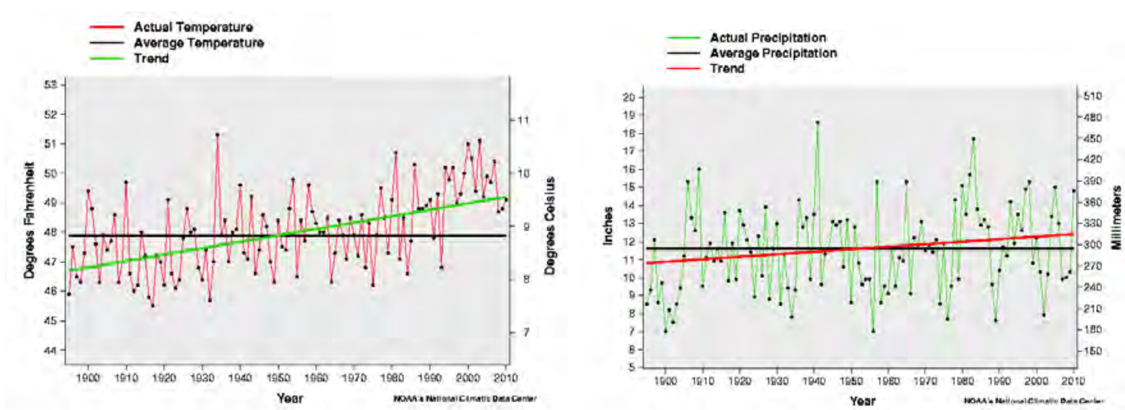


Figure 20. The state-wide mean annual temperature increased 1.2 C/century since the late 1800's. The state-wide mean annual precipitation increased 3.6 cm/century. Utah state–wide change in mean annual temperature and precipitation determined by National Climatic Data Center. http://www.ncdc.noaa.gov/oa/climate/research/cag3/ut.html

Table 9. Rate of change in temperature and precipitation observed at weather stations in the study area. Rate was determined as 100*slope of the regression line of mean annual climate variable on year.

Station	Station no.	Change in mean annual T (deg C) per century	Change in cumulative annual Precip (cm) per century
St. George	427516	2.9	-0.6
La Verkin	424968	6.2	6.2
Zion	429717	0.8	9.5
Alton	420086	1.6	3.2

Bryce Canyon	421008	1.6	7.9
Cedar City	421259	<30 years of record	
Brianhead	420900	<30 years of record	
		Average +2.62	Average +5.24

Species Model Development and Application

Species-specific based ecological data used not used in species selection above are described below. For each species, the development of the ecological response model (species distribution model) is reviewed. Finally, the effects of climate change alternatives are simulated.

American Pika

Additional Base Data

Unless otherwise cited, this information was excerpted, quoted, and paraphrased from U.S. Fish and Wildlife Service, 2010, and personal communications with Erik Beever, PhD.

Physiology and Ecology

The American pika has a hamster-shaped body with short legs, moderately large ears, and no visible tail. Fur color varies among subspecies and across seasons, typically with shorter, brownish fur in summer and longer, grayish fur in winter. The species is intermediate in size, with adult body lengths ranging from 162 to 216 mm and mean body mass ranging from 121 to 176 grams.

American pikas are generalist herbivores that select different classes of vegetation and use different parts of the same plants when grazing versus haying. Feeding (the immediate consumption of vegetation) occurs year-round; haying (the storage of vegetation for later consumption) and the creation of haypiles occurs only in summer months after the breeding season. The primary purpose of haypiles is probably overwintering sustenance (but this is debated in the literature), and individuals harvest more vegetation than is immediately consumed. Pikas feed an average distance of 2 m from talus and will travel an average distance of 7 m when haying. Data show no feeding occurs beyond 10 m from talus, but haying was observed up to 30 m.

Vegetative communities immediately adjacent to pika locations are often dominated by grasses, but less so in the Great Basin. When pikas are excluded from grazing near talus slopes, the biomass of forbs, sedges, and cushion plants increases. Therefore, foraging pikas influence the presence of specific plant classes or functional groups, vegetative cover, and species richness, and modify habitat in their quest for food and survival. Forbs and woody plants are typically found in pika haypiles, and provide the major source of sustenance for the winter.

Thermoregulation is an important aspect of American pika physiology, because individuals have a high normal resting body temperature of approximately 40 ^{o}C, and a relatively low lethal maximum body temperature threshold of approximately 43 ^{o}C. Most thermoregulation of individuals is behavioral, not physiological. In warmer environments, such as during midday sun and at lower elevation limits, pikas typically become inactive and withdraw into cooler talus openings. Pikas avoid hyperthermia (heat stroke) during summer months by engaging in short bursts of surface activity followed by retreat to a cooler microclimate beneath the surface. Pikas can be partially-nocturnal where daytime temperatures are stressful and restrict diurnal activity.

Historically, researchers hypothesized that American pika juveniles are philopatric (remain in or return to their birthplace), dispersing only if no territory is available within their birth place. However, it has been demonstrated that juvenile emigration to other population sites occurred over both long (2 km) and short distances, and acted to support population stability by replacing deceased adults. Territory availability is a key factor in determining dispersal patterns, and local pika populations lack clusters of highly related individuals.

Dispersal of American pikas is also influenced by physical limitations. It is difficult for juveniles to disperse over distances greater than 300 m in high-elevation (2,500 m) populations. Lower elevations are warmer in summer and represent the lower edge of the elevational range of the species. Dispersal distances of 3 km have been documented at other locations and elevational ranges.

Individual pikas are territorial, maintaining a defended territory of 410 to 709 m^2 but fully using overlapping home ranges of 861 to 2,182 m^2. Individuals mark their territories with scent and defend them through aggressive fights and chases.

Adults with adjacent territories form monogamous mating pairs. Males are sexually monogamous, but make little investment in rearing offspring. Females give birth to average litter sizes of 2.4 to 3.7 twice a year. However, fewer than 10 percent of weaned juveniles originate from the second litter. Adult pikas can be territorially aggressive to juveniles, and parents can become aggressive to their own offspring within 3 to 4 weeks after birth. To survive the winter, juveniles need to establish their own territories and create haypiles before the winter snowpack. However, establishing a territory and building a haypile does not ensure survival. Yearly average mortality in pika populations is between 37 and 53 percent. Few pikas live to be 4 years of age, however, some individuals survive up to 7 years.

Temperature restrictions influence the species' distribution because hyperthermia or death can occur after brief exposures (as little as 6 hours) to ambient temperatures greater than 25.5 ^oC if individuals cannot seek refuge from heat stress. Therefore, American pika habitat progressively increases in elevation in the southern extent of the distribution. In the northern part of its distribution (southwestern Canada), populations occur from sea level to 3,000 m but in the southern extent (New Mexico, Nevada, and southern California) populations rarely exist below 2,500 m. Some exceptions exist in the southern portion of the species' range. For example, pikas in 10 percent of 420 study sites in the Sierra Nevada Mountains, Great Basin, and Oregon Cascade Mountains occur below 2,500 m and as low as 1,645 m at McKenzie Pass in the Cascade Mountains of Oregon. Populations have been observed as low as 50 m in the Columbia River Gorge in Oregon. A new population of American pika was recently discovered in the Hays Canyon Range of northwestern Nevada at elevations ranging from 1,914 to 2,136 m.

Habitat

American pikas primarily inhabit talus fields fringed by suitable vegetation in alpine or subalpine areas. Alpine meadows that provide forage are important to pika survival in montane environments. The species also occupies other habitats that include volcanic land features and anthropogenic settings such as ore dumps, piles of lumber, stone walls, rockwork dams, and historic foundations.

Pikas use talus, which can include rock-ice features, and other habitat types for den sites, food storage, and nesting. Rock-ice features are defined as glacial- or periglacial- (i.e., around or near glaciers) derived landforms in high-elevation, semi-arid temperature mountain ranges and arctic landscapes. Talus, rock-ice feature till, and volcanic features (described below) also may provide microclimate conditions suitable for pika survival by creating cooler, moist refugia in summer months and insulating individuals in the colder winter months .

Pikas also inhabit more atypical habitats that include lava tubes, caves, valley trenches, fault scarps, fault cracks, and cliff faces, which provide suitable habitat and thermal refuge. For example, in Lava Beds National Monument in northern California and Craters of the Moon National Monument in southern Idaho, pikas typically inhabit large, contiguous areas of volcanic habitat (Rodhouse, et. al, 2010). Within this habitat type, forage vegetation is accessible within distances comparable to dimensions of home ranges. Pikas select habitat that includes topographical features characterized by rocks large enough to provide necessary interstitial spaces for underground movement and tunneling. Like talus and rock-ice features, these habitats provide pikas with cool refugia during conditions that may result in heat stress, which in addition to behavioral thermoregulation mechanisms, allow pika to persist in these low-elevation and potentially thermally challenging environments.

Model Development and Application

This model's objectives are to:

- Predict amount and suitability of pika habitat in the three-Unit study area (based on physical and climatic parameters).
- Predict the stability of existing or suspected pika populations in the three-Unit study area, given climate change continues.
- Estimate the three Units' capabilities for harboring pika in future climatic regimes.

Data Sources for this model are:

- Recent research by Erik Beever, PhD (Northern Rocky Mountain Science Center, US Geological Survey) on Great Basin population trends and physical parameters (Beever, et. al, 2011)
- 2011 Mapping of suitable physical habitat in the three Units (by Henry Shovic, PhD, Dept. of Ecology, Montana State University).
- 2010 and 2011 surveys of pika in the three Units and existing survey information (by National Park Service staff)

Dr. Beever's recent research appears applicable to our study area because of its close proximity to the study Units (Beever, et. al., 2011). His research is robust in terms of sample size and frequency. The major element needed to extend Dr. Beever's work is a local habitat map. This is addressed below.

Physical Pika Habitat

Mapping suitable physical habitat in the three units is used in three ways. First, existing habitat modeling by the state of Utah strongly overestimated habitat in this area, primarily because of lack of mapping of true talus slopes (personal communication, Claire Crow, ZION). This mapping may improve its future application in this area. Second, it provides a guide for 2011 surveys to optimize search locations, and third it helps in candidate areas for the three Units for use in the species distribution model. This mapping is based on multiple sources, including interpretation of digital aerial photography; use of existing soils, geology, slope, and vegetation mapping; and on-the-ground data. It includes characterization of talus bodies in terms of location, size distribution of fragments, depth, slope, aspect.

Mapping of Physical Habitat

The spatial distribution model for the pika applies only where appropriate physical pika habitat occurs. Certain kinds of talus slopes are required. This physical habitat was therefore mapped for the three units (ZION, CEBR, and BRCA). Though the term "talus" is mapped throughout the Study Area via the NPS-provided geology layers, almost all of this appears to be more closely related to colluvial slopes with finer-textured soils than to coarse talus slopes. Figure 21 shows vegetated, colluvial material mapped as talus in the south-central part of ZION. It is apparently a mixture of blocks of sandstone and underlying, weathered finer-textured rocks. Figure 22 shows a similar material in the north-east part of ZION, also mapped as talus. A review of aerial imagery shows this is very common throughout both ZION and CEBR. Therefore, these data sources were not used in this study.

Figure 21. Medium-textured Colluvial Material (mapped as talus (Qmt) near Kolob Terrace).

Figure 22. Medium-textured Colluvium (mapped as Talus (Qmt)) near Springdale.

The National Park Service (NPS) vegetation map of ZION provided more narrowly defined and mapped talus, which appears to be more closely related to pika habitat. In ZION, talus is only mapped in basaltic rock types. If unvegetated, this shows up well in color infrared imagery (Figure 23) as relatively brownish-gray areas in a light-colored matrix of vegetation and soil. Talus units were defined only if they showed those appropriate signatures in imagery.

The basalt rock type has been associated with pika in other low-elevation areas (Rodhouse, et. al., 2010) in lava flow form. In the ZION environment, the disintegrating margins of these flows appear to be associated with pika-favorable materials. Mapped units were field-verified in four areas (Figure 24) as being true "talus" with a matrix-free mix of angular boulders and cobbles, but with either basaltic or rhyolitic composition.

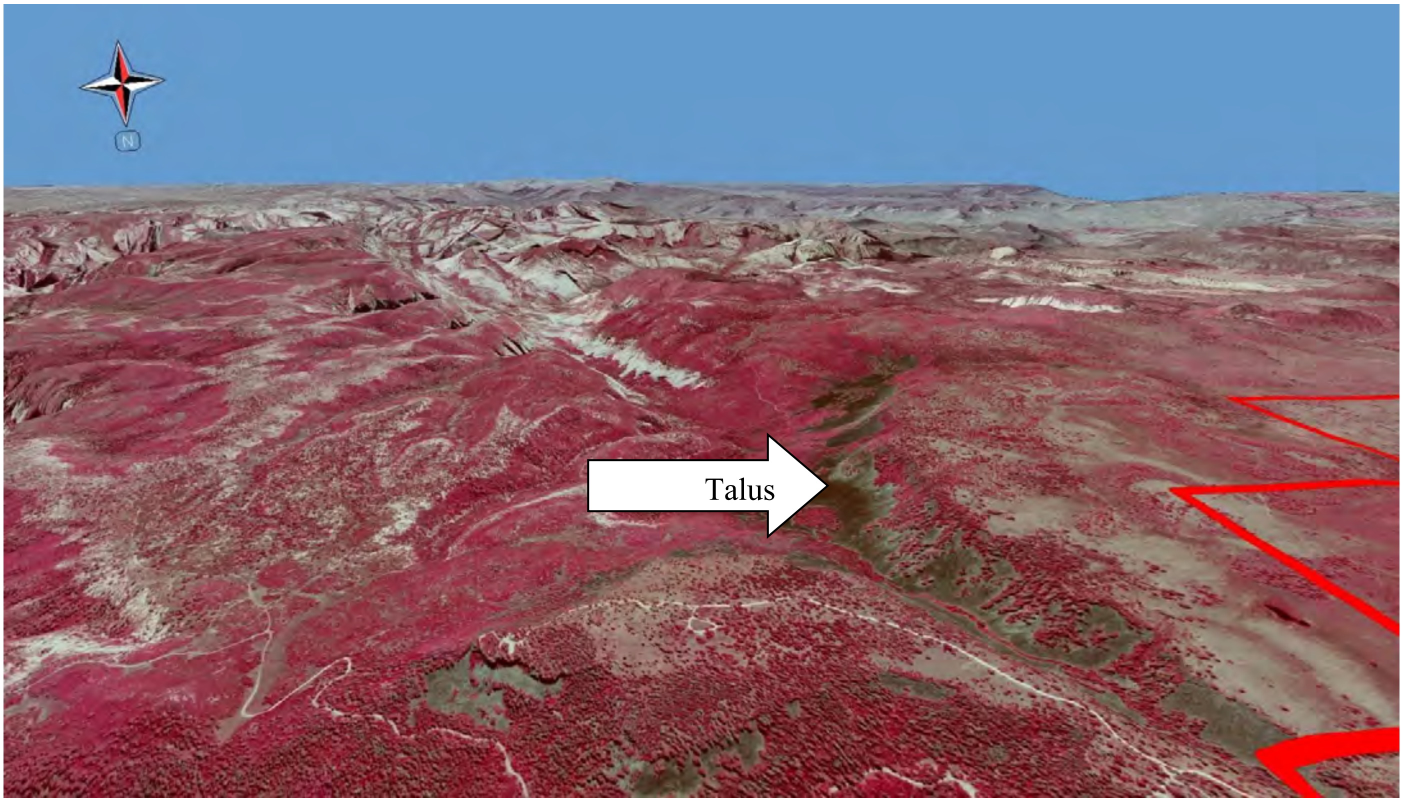


Figure 23. Talus slopes at Lava Point in ZION depicted with CIR (Color Infrared)imagery)

Figure 24. Talus slope images from ZION (UL - Coal Pits, Unit 127, UR – Jobs Head Unit 37, LL – Alpine Lake Unit 5, LR – Lava Point Unit 17), from a field review in August, 2011

These spatial data make up the potential physical habitat for pika in ZION (Figure 25). Detail views with ID's are in Figure 26, Figure 27, Figure 28, Figure 29, and Figure 30. Each delineation has a corresponding ID, geographic location of its centroid, average elevation, slope, aspect, and area in Table 23 (Appendix A). The 95 talus bodies range from 1143 to 2,443 m in mean elevation, 3 to 126% mean slope, 16 (NorthNorthEast) to 335 (NorthNorthWest) degrees mean aspect, and 0.1 ha to 19.2 ha in size with a mean area of 0.9 ha and a total of 87 ha. The included talus bodies' proximity is well related to their elevational characteristics (Table 10), making them a convenient way to reference ecologically-related groups.

Where present, the callout in each detail view figure refers to talus located using imagery and geological mapping outside of the Unit boundaries. These are used in model development below.

Table 10. Grouped Elevation Statistics for ZION Talus Bodies

Group	Elev. Mean (m)	Elev. Min. (m)	Elev. Max. (m)	# of Polygons	Total Area (ha)
Lava Point (Figure 26)	2334	2120	2414	27	63.7
Jobs Head (Figure 27)	2327	2144	2443	15	4.8
Tabernacle (Figure 28)	1608	1386	2002	19	4.1
Coal Pits (Figure 29)	1230	1143	1338	33	13.7
Verkin (Figure 30)	1950	1939	1965	1	0.5
Totals				95	86.8

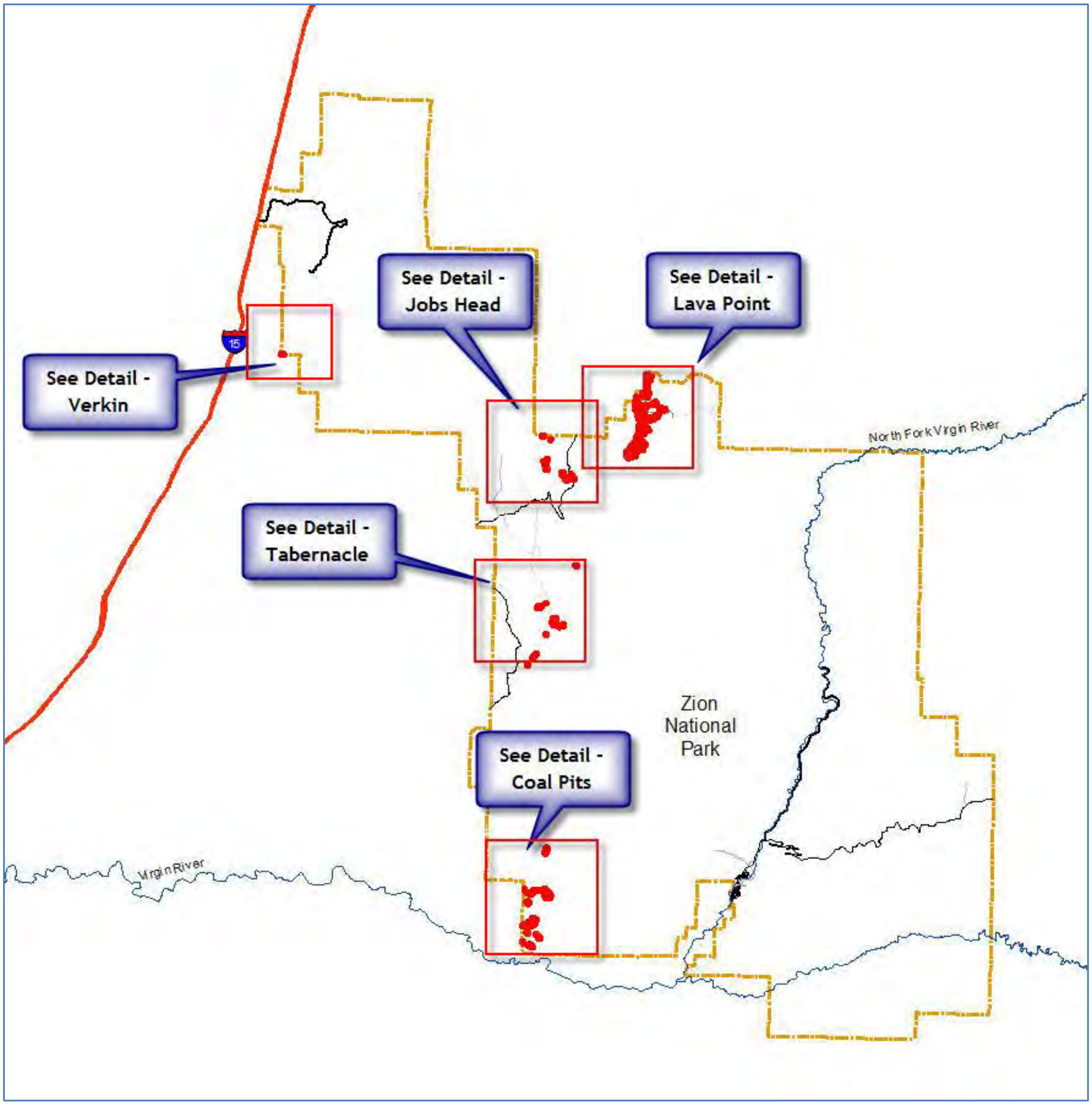


Figure 25. Mapped Talus In ZION – Overview (Brown Line is ZION boundary.) Detail maps refer to in Figure 26, Figure 27, Figure 28, Figure 29, and Figure 30. See Figure 7 above for location of ZION in the geographic range of pika.

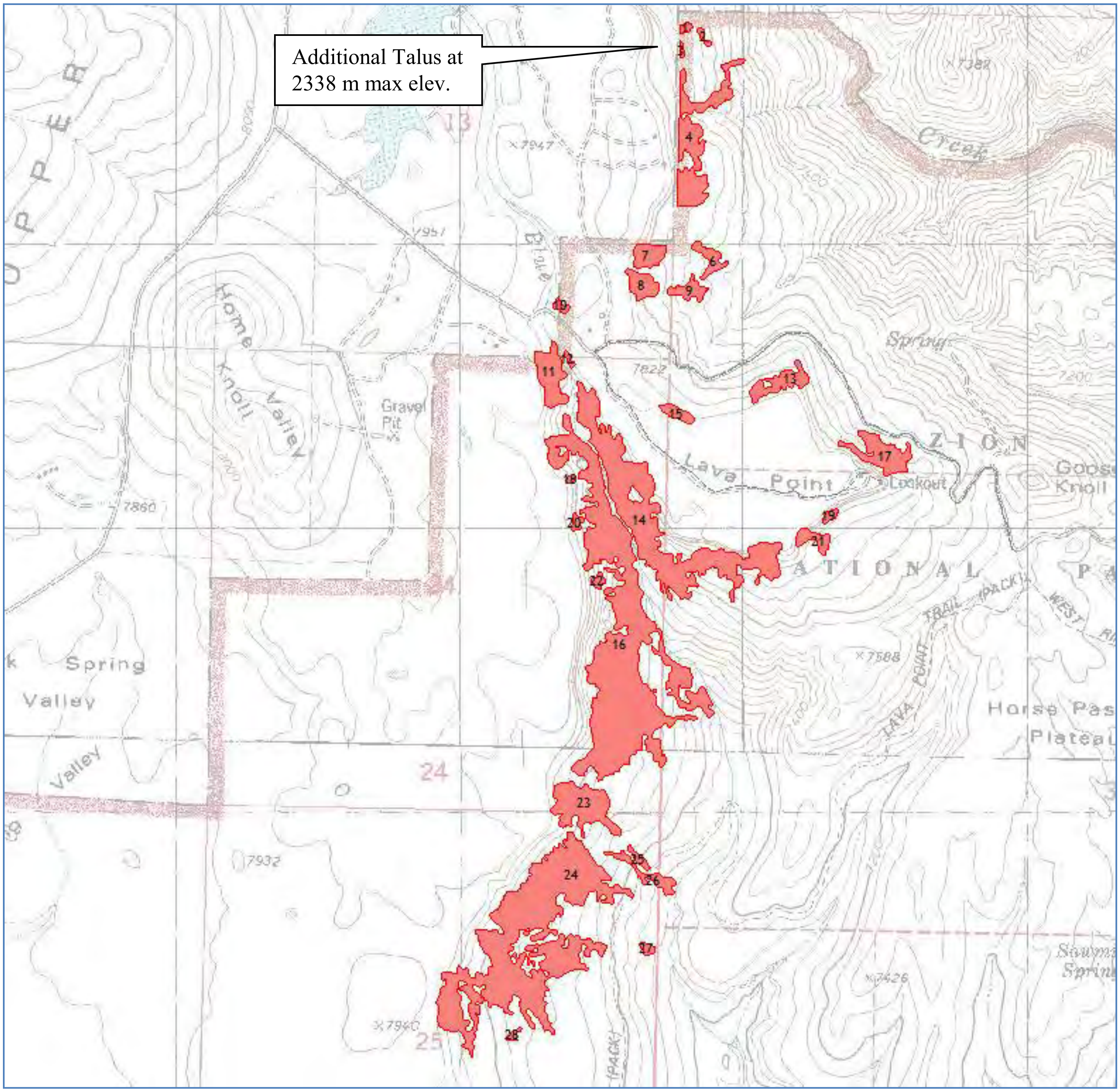


Figure 26. Mapped Talus In ZION - Lava Point (1:15000) with ID's

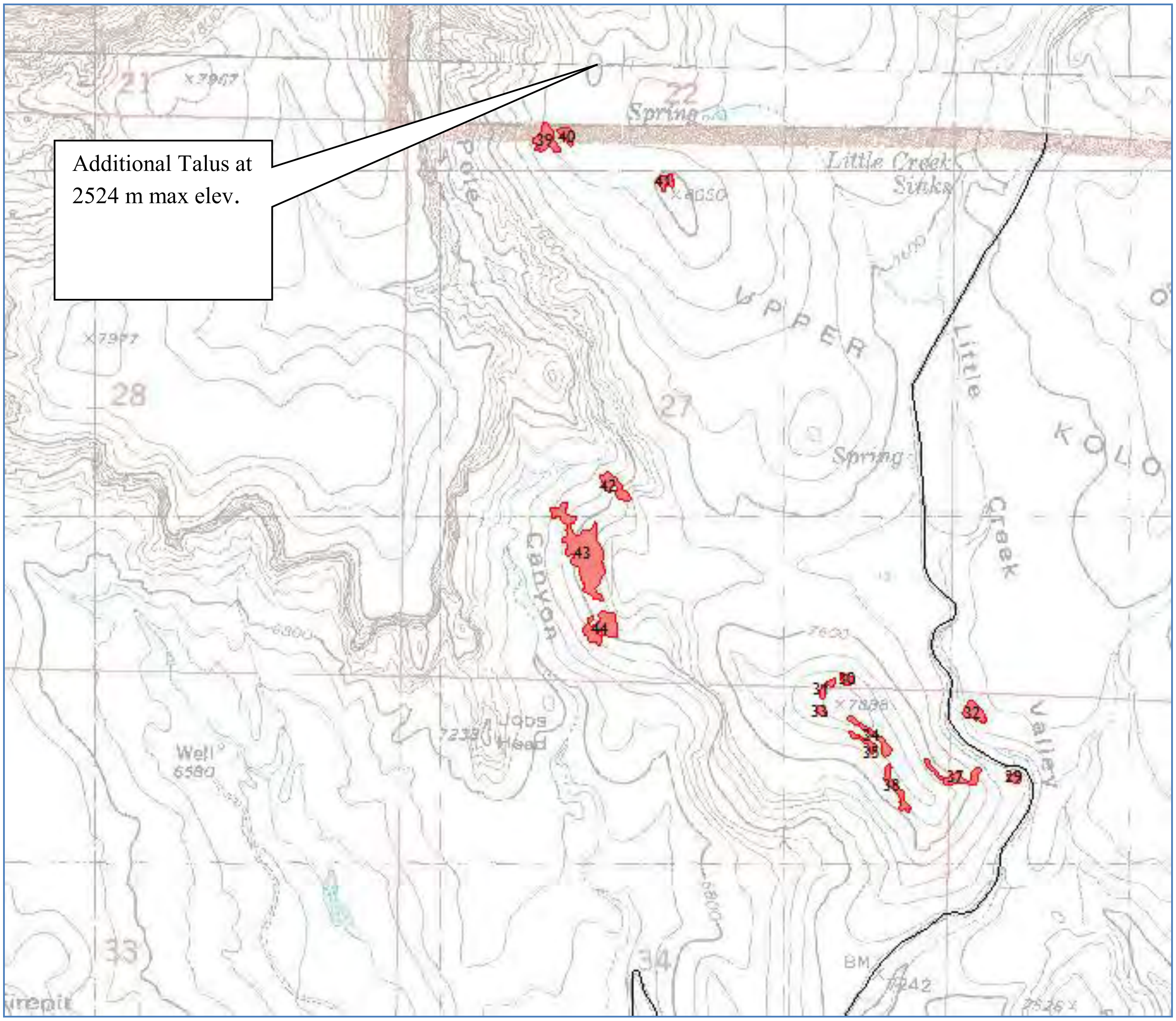


Figure 27. Mapped Talus In ZION – Jobs Head with ID's

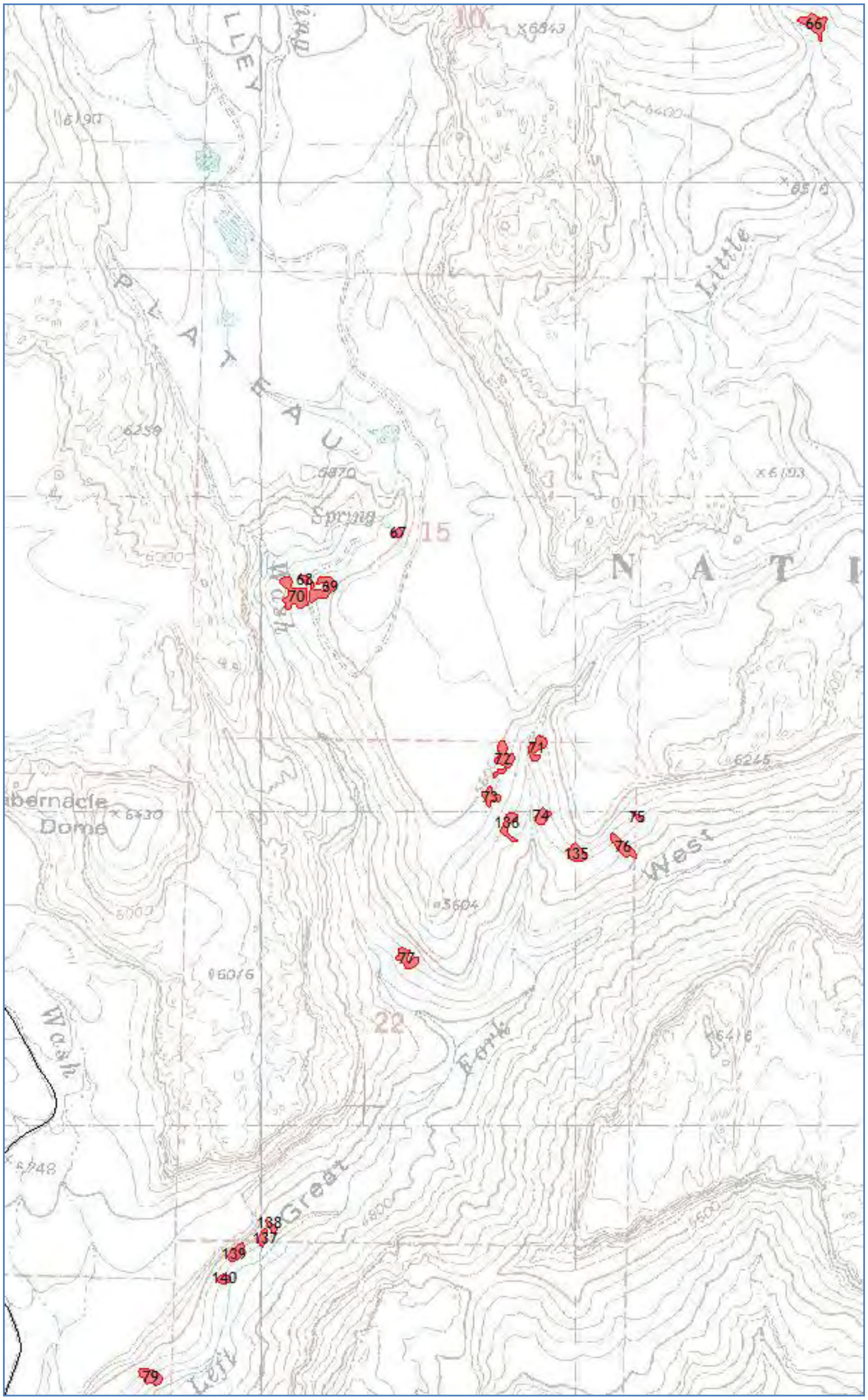


Figure 28. Mapped Talus In ZION - Tabernacle with ID's

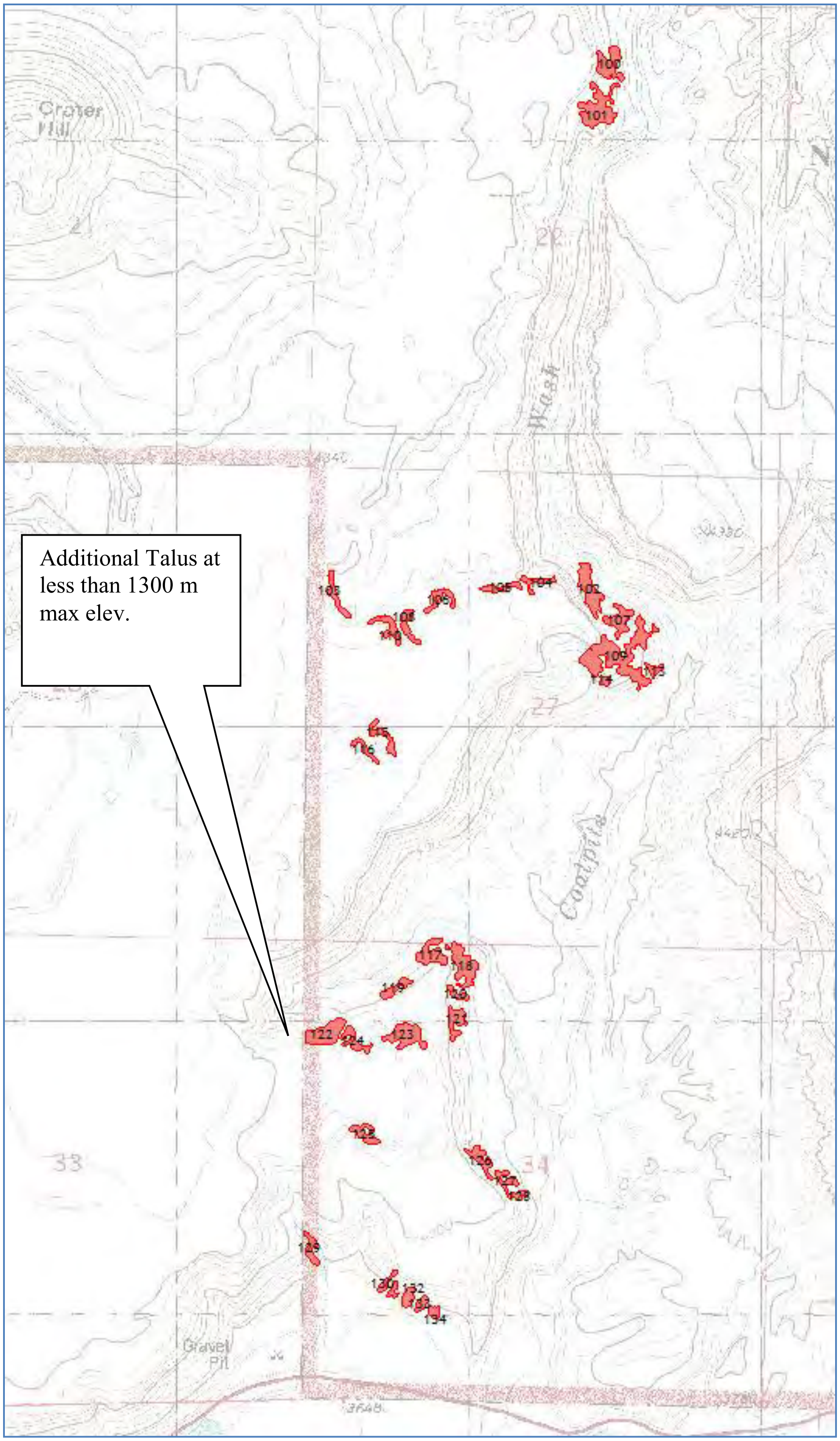


Figure 29. Mapped Talus In ZION -Coal Pits with ID's

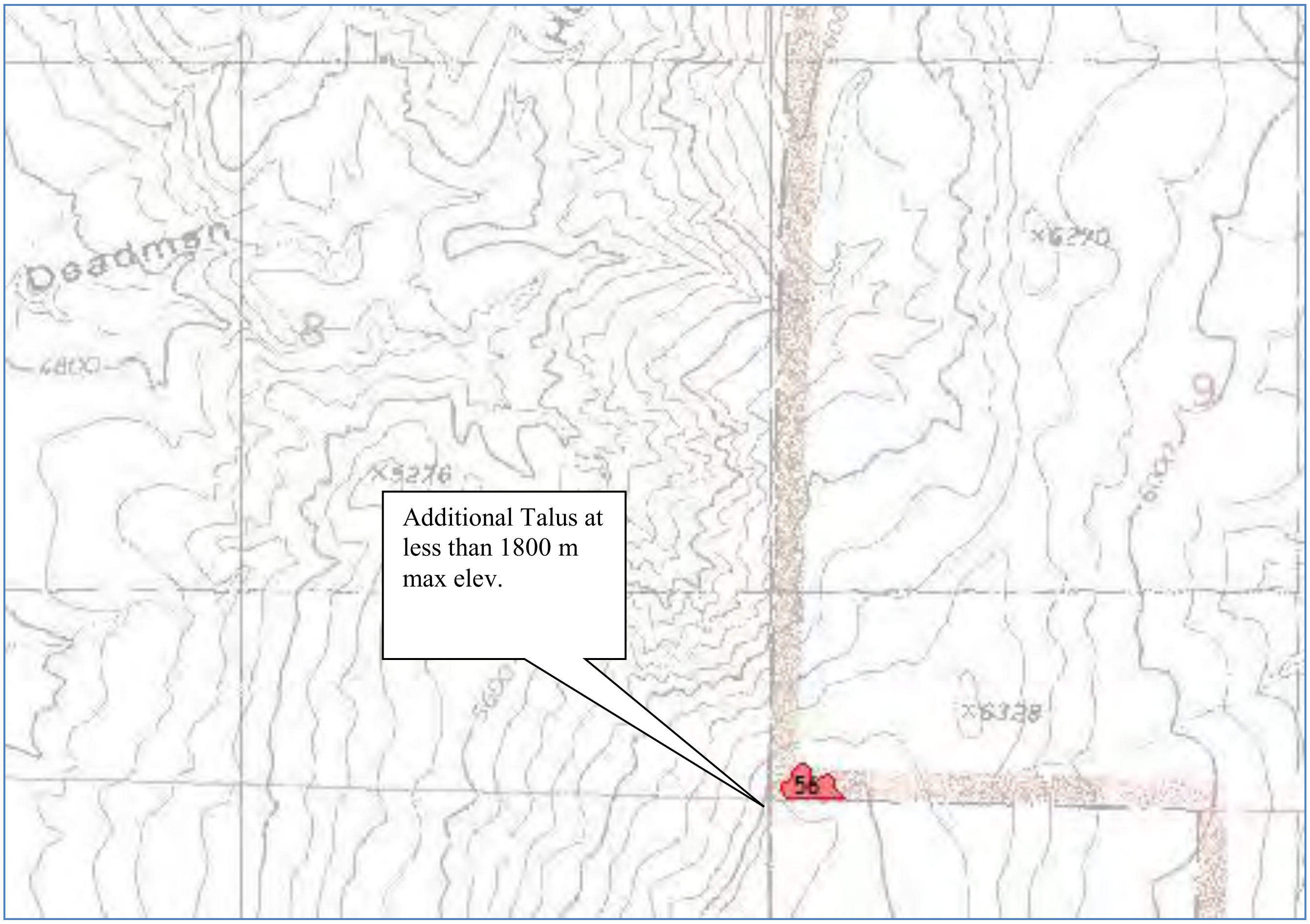


Figure 30. Mapped Talus in ZION - Verkin with ID's

Similar to geological mapping in ZION, mapped talus in CEBR was primarily finer-textured material similar to that found in BRCA (weathered material in the Claron formation). The vegetation map of CEBR provided more narrowly defined and mapped polygons, but no talus was mapped. The categories "Barren" and "Claron" were reviewed, as these are non-vegetated, but material appears finer-textured in particle size than one would expect in a talus field. ZION and CEBR staff indicated a small talus slope occurs near the Alpine Lake trail (Waters, unpublished report). Geologically, this is an edge of a volcanic megabreccia that is described as having house to boulder-sized basalt blocks. This area was reviewed with imagery and indeed appeared as talus. A photo taken there by CEBR staff (Figure 31) shows typical talus material, and this was verified on the ground by the author (Figure 24). This feature makes up the entire potential physical habitat for pika in CEBR (Figure 32). Mean elevation is 3213 m, minimum elevation is 3196 m, maximum elevation is 3221 m, mean slope is 23 %, mean aspect is 270, and area is 0.7 ha. Table 23 in Appendix A contains the geographic location of its centroid. The callout in Figure 32 refers to talus located using imagery and geological mapping outside of the Unit boundaries. This is used in model development below.

Figure 31. Pika and Habitat near Alpine Lake, CEBR

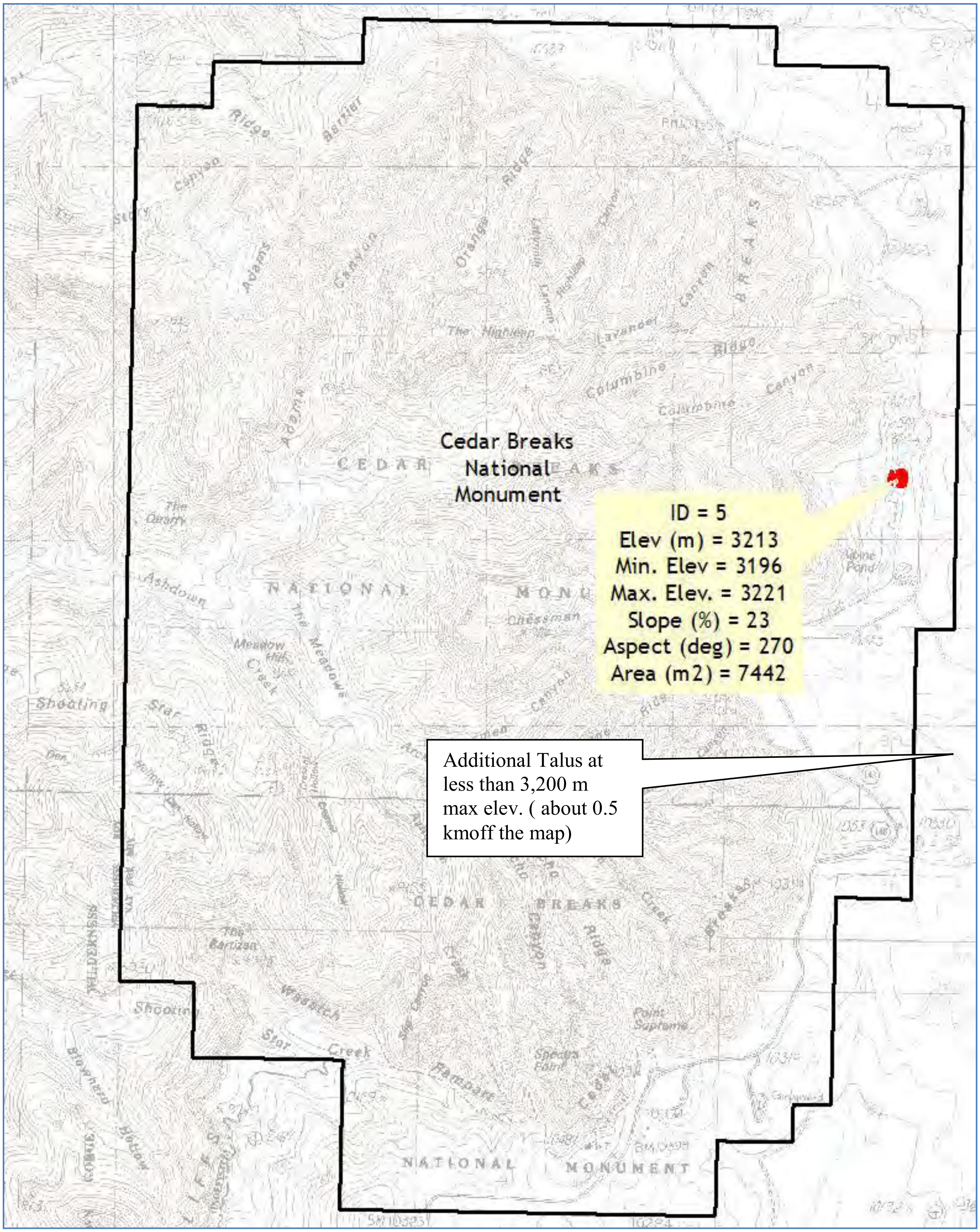


Figure 32. Mapped Talus In CEBR- with ID and Elevation (Min., Max., and Mean), and other Data.

No suitable habitat was located in BRCA, based on imagery interpretation and a one day field review in 2011, as well as conversations with BRCA field staff. Though there are a few isolated patches of talus less than 50 m^2[1] in area, geologic materials are not conducive to formation of true "talus fields" judged to be of sufficient size to be potential habitat.

Since the subject Units are at the edge of Dr. Beever's 2010 and 2011 study area, (Figure 7 above), the 2011 surveys of pika provides support for its use in this area, as well as provide systematic, documentation on minimum elevation of presence to supplement the existing information on pika occurrence. Documented presence also provides increased support for inclusion in scenario-based management.

Model Development

Two graphs in Beever's 2011 research illustrate our approach to using his research as the basis for the pika species distribution model (Beever, et. al., 2011). The first (Figure 33) illustrates that indeed pika populations in the Great Basin are at risk in the near term, based on pre-historical and recent data. Since the three study Units are at the edge of this area this graph is deemed applicable. Not only have the minimum elevations of extant populations increased over historical time (an average of 13.2 m/decade during the 20^{th} century), but the pace has accelerated to 145.1 m/decade since the 1990's. This supports the conclusion that pika are indeed at risk in the area with climate change as a driver.

The second graph (Figure 34) shows the variable MaxElev regressed against latitude for his study populations scattered across the hydrographic Great Basin. The Variable MaxElev is the maximum elevation of talus habitat, in m within 3 km of a historic site, to or from which individuals could potentially migrate, given a change in climate. The maximum elevation (MaxElev) of talus at local and mountain-range scales relates to climatic influence because it denotes how far up-slope pikas can probably migrate in relatively contiguous talus slopes under increased temperatures.

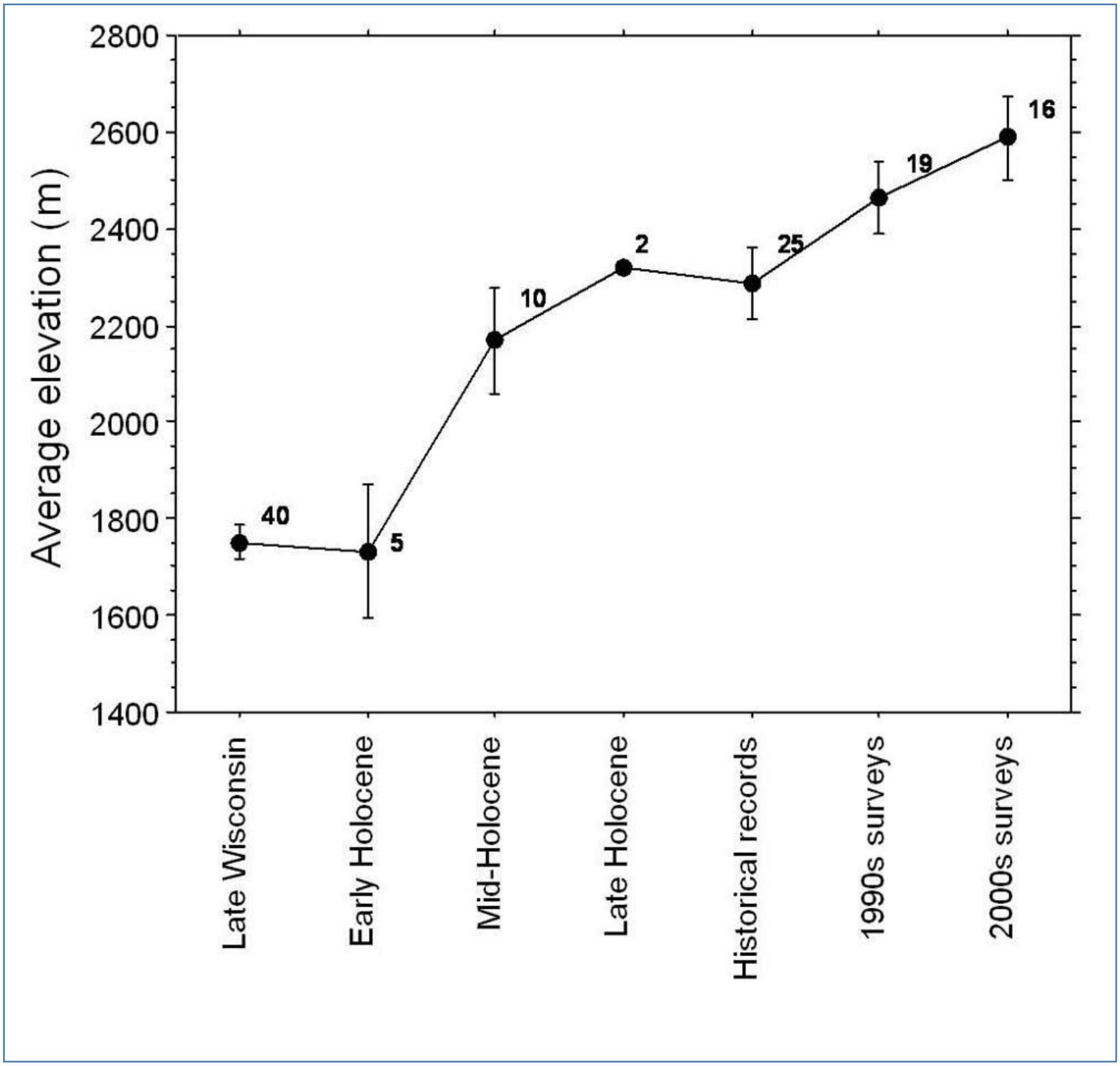


Figure 33. Comparison of minimum average elevations of pika occurrence over time from Beever, et. al., (2011). Numbers at the symbols refer to the sample size used to calculate each value. With the exception of the two right-most time periods, average elevation values are averages of all records. The right-most two are averages of the lower distributional limit within sample sites, and hence are more precise.

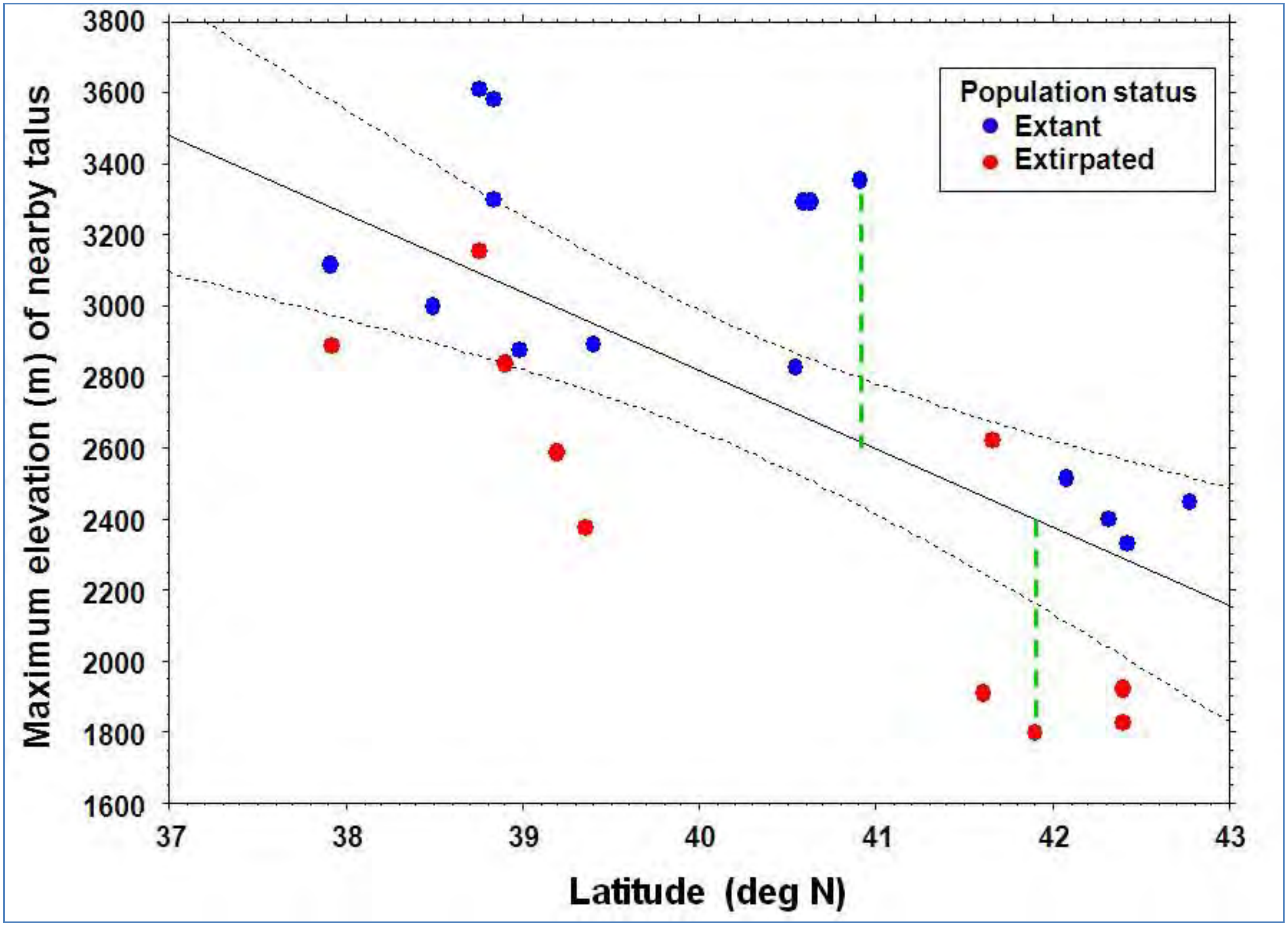


Figure 34. Maximum local elevation of talus regressed against latitude for study sites in Beever's research. Green dashed lines illustrate residuals both above and below the regression line

The regression line shows a trend upward in maximum elevation of nearby talus as latitude decreases. Extirpated populations (red dots) generally fall below the line. Based on this sample, environments having physical requirements for pika (talus) falling below the line in terms of elevation and latitude are likely to be at more risk than those above the line. The distance a population falls above the line (indicated by the exemplary green dashed line) may indicate its potential in terms of adapting to future climate change, as populations may be able to move up-gradient to higher talus environments. Those that are below the line are probably at higher risk to extirpation as climate continues to warm, with the risk being greater with higher residuals, as exemplified by the green dashed line below the regression line.

The relationships graphed here (Figure 34 above) are used as a general model of environmental suitability of environments in the subject Units. Each talus body from the mapping project above was evaluated (using geographic location and elevation) for its potential in a climatic setting using the above conceptual framework and Dr. Beever's work.

All talus polygons were first characterized for the MAXELEV parameter as described above. A circular 3 km radius graphic was placed on the centroid of each talus polygon, and used as a selection criterion at a scale of 1:40,000. The maximum elevation found within the group of selected polygons was used as MAXELEV (Table 22, Appendix A).

Some talus bodies occur outside of the Unit boundaries. These were not formally mapped but were evaluated for candidacy as a value for MAXELEV if within the 3 km limit. The Lava Point group (Figure 26) has additional talus outside the boundary of ZION. Though it falls within the 3 km limit, its maximum elevation (ibid) is below that in the unit talus polygons in that group (Table 22, Appendix A), so is not used in the model. The Jobs Head Group (Figure 27) has additional talus external to the boundary, and its maximum elevation is higher than that of the ZION polygons, so is used as the MAXELEV for that group. The Tabernacle group (Figure 28) has no external talus identified. Its MAXELEV values are split between 2002 and 1707 m. The Coal Pit group (Figure 29) has a small amount of talus outside ZION, but it is at lower elevation than that within the Unit. Similarly, the Verkin talus body (Figure 30) has a small amount outside but is also of lower elevation. CEBR's talus polygon (Figure 32) has a large lava field within 3 km. However, it is lower in elevation than the existing habitat so is not used.

Results

The 96 talus polygons (95 in ZION and 1 in CEBR) were then plotted on Figure 35, taken from Dr. Beever's graph. Those potential habitat bodies that fall above the line are considered to be relatively stable under climatic pressure. Those that fall below are at a level of risk. The CEBR Group falls within the area of uncertainty, so may be a stable situation at this latitude and elevation. The Jobs Head and Lava Point groups have similar positions in the graph, indicating pika both are at risk for extirpation as well as in potentially poor habitat. However, pika and pika sign have been observed in 2011 in talus bodies of the Lava Point group. This implies possible existing populations are at risk here. The Jobs Head group, since it is similar in elevation may also contain pika. If so, they are also at risk. The remaining talus bodies (Tabernacle, Verkin, and Coal Pit) fall below these groups. Any population there is likely to be highly at risk.

Strictly, only talus polygons having evidence of historical or present occupancy were used in Dr. Beever's research. The analysis completed in our study applies to potentials, rather than the probable future of existing populations. To apply this to existing populations, the analysis was then restricted to those polygons that have been either surveyed or otherwise documented to contain pika now. Pika have been observed and surveyed in CEBR at the Alpine

Lake talus polygon, and at Lava Point in ZION in or near talus polygons (discussed above). These polygons were therefore used as “occupied” habitat. These polygons are represented by the CEBR polygon and the Lava Point group in Figure 35. The Lava Point group falls well below the regression line, and is therefore a population at risk of extirpation. However, CEBR is within confidence limits so may be relatively stable.

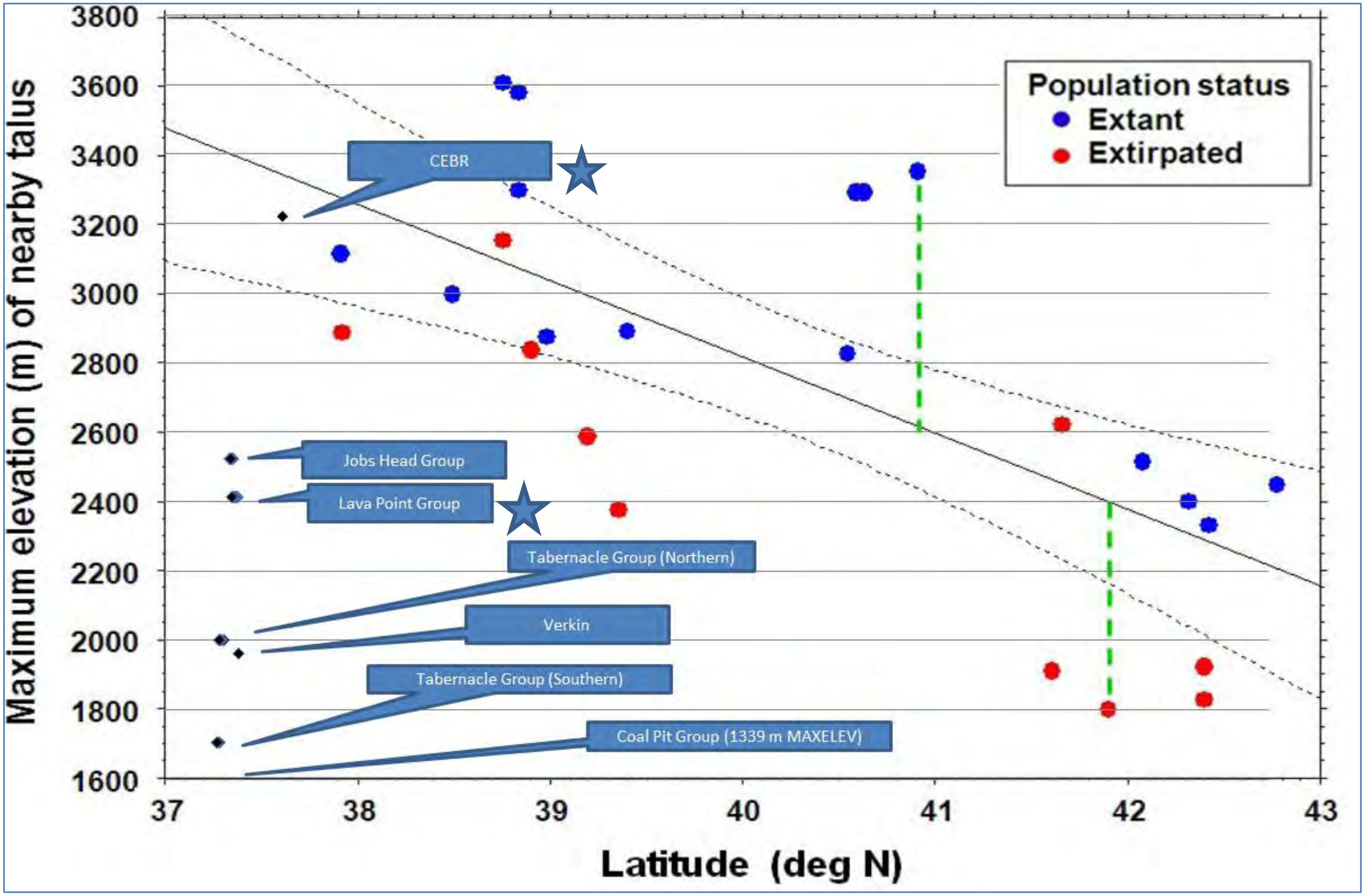


Figure 35. American Pika Habitat Analysis for ZION and CEBR using BEEVER's Research and Local Data. Blue callouts are talus body groups. Blue starts are talus body groups having evidence of present occupation.

Effects of Aspect

Local population resiliency is also highly aspect dependent (Beever, personal communication). A favorable aspect (with lower insolation) may influence a habitat's suitability in an otherwise low quality setting. Since measurement and depiction of numerical aspect measures are difficult to interpret, the influence of aspect was considered using solar radiation (insolation) on all potential physical habitat polygons. Spatial data were obtained from ZION staff representing cumulative solar radiation from March 1 through July 15, 2010. No insolation data were available for CEBR, so insolation was estimated from a polygon having similar aspect, slope, and as high an elevation as possible. This is an imperfect estimate, but is used here pending actual data.

The insolation grid was overlaid on a grid representation of habitat polygons and statistics (maximum, minimum, average, and standard deviation) were calculated by polygon (Relevant measures are in Table 22, Appendix A). Units are watthours/m^2. Variation in insolation is quite wide (maximum = 869,982; minimum = 455,694; Mean = 735,357; range = 414,288). Absent any other research guidelines, polygons within the lowest 1/3 of the range (up to 593,790) were flagged as potentially affected by aspect/slope/elevation factors. Only five polygons (104, 139, 107, 126, and 102) were in this group (ibid), indicating a significant skewing towards higher solar radiation on most sites. The Coal Pit group contains four of the five lowest sites. This appears to be because of their general north-eastern aspects (Figure 29 above). However, it is surprising that higher-elevation northerly-aspect talus bodies at Lava Point (e.g. 11, 13, and 17) are so much higher in insolation. The ARCMAP process used in calculating insolation accounts for atmospheric effects, site latitude and elevation, steepness (slope) and compass direction (aspect), daily and seasonal shifts of the sun angle, and effects of shadows cast by surrounding topography. This complexity may help explain these results. No further work was done here.

Trends in Occupancy

The above analysis approaches the quality of habitat that indirectly relates to climate change by simulating the potential effects on populations at various elevations and latitudes. A more direct comparison of habitat was made using Dr. Beever's analysis of historical trends (Figure 36). The graph shows an upward trend of minimum elevations over a rather long time scale. The mean elevation of the present occupied habitat in CEBR is 3,212 m, well above the average minimum for the recent past, and for the 27 polygons in the Lava Point group mean elevation is 2,334 m, about 300 m below the recent average minimum.

Mean elevations were then adjusted downward for the most extreme climate warming alternative in Table 3 in Climate Change Analysis (100 year, 4.6 ^{o}C or 626 m). CEBR still maintains a relatively favorable position above the average minimum line, but Lava Point's habitat is well below, under all alternatives in Table 3. The risk at Lava Point may be mitigated however, by the pika-favorable position and topography of some of its talus polygons in terms of slope, aspect, and protecting vegetation (e. g. Polygon 14, 16, and 17 (Figure 37 and Figure 38))

The above supports the conclusions that the CEBR populations may be stable for the present, and that the Lava Point group (and those below it) populations are now at risk, and may soon disappear, given the low probable population. Under increasing temperatures, CEBR still may maintain stability, but the Lava Point group's future appears grim.

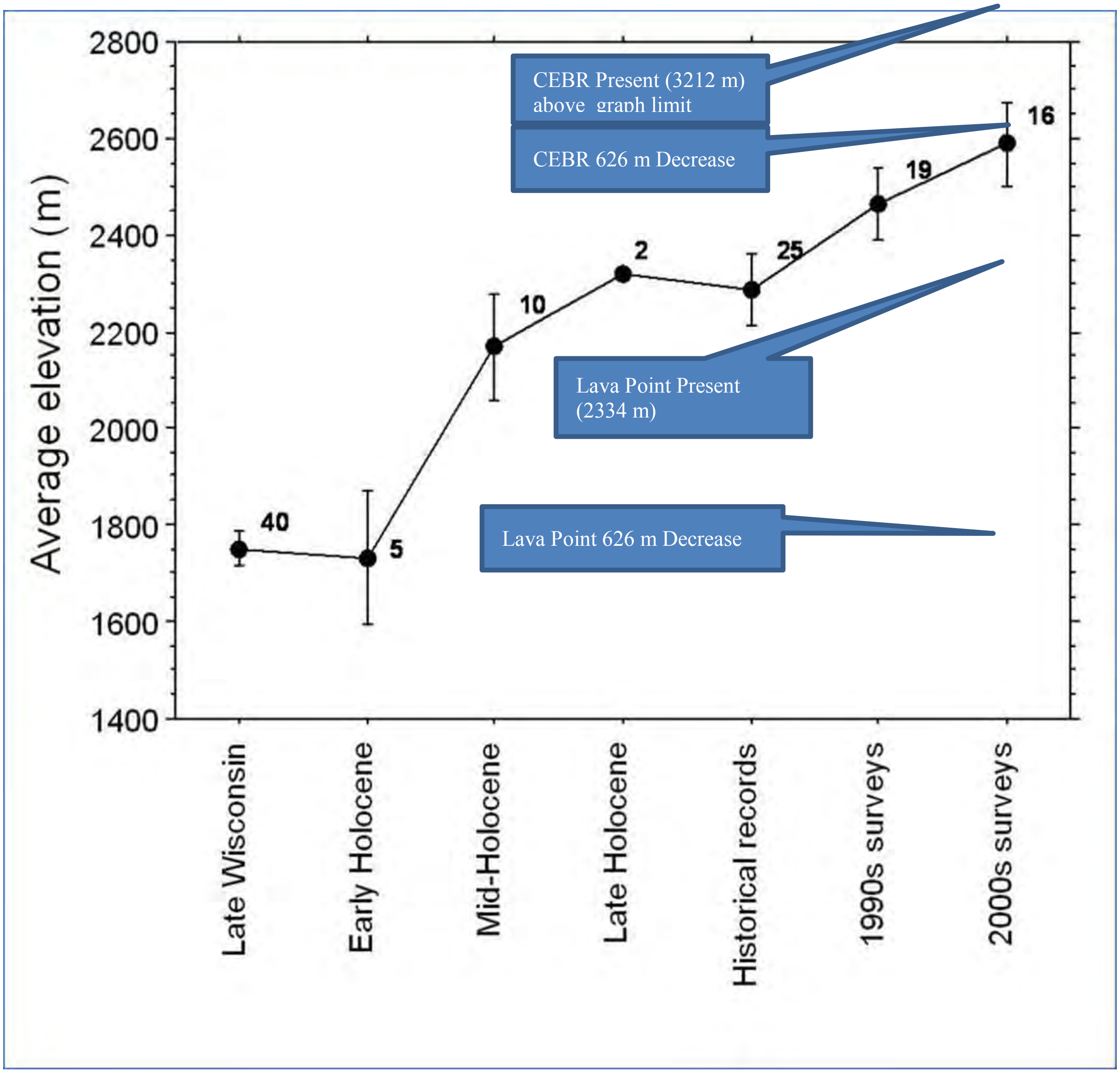


Figure 36. Comparison of minimum average elevations of pika occurrence over time from Beever, et. al., (2011) with plots of local populations for CEBR and Lava Point, and climate-adjusted values. Numbers at the symbols refer to the sample size used to calculate each value.

Figure 37. Talus Polygon 17 Landscape

Figure 38. Talus Polygon 14 and 16 Landscapes

Desert Tortoise

Additional Base Data

Except where cited, the following information was excerpted, quoted, and paraphrased from U. S. Fish and Wildlife Service, (2008), Meyer (2008), field review, and Claire Crow, Wildlife Program Manager ZION, personal communication and unpublished documentation.

Physiology and Ecology

Desert tortoises reach 20 to 38 cm in carapace (upper shell) length and 10 to 15 cm in shell height. Hatchlings emerge from eggs at about 5 cm in length. Adults have a domed carapace and relatively flat, unhinged plastrons (lower shell). Their shells are high-domed and greenish-tan to dark brown in color with tan scute (the horny plates on the shell) centers. Adult desert tortoises weigh 3.6 to 6.8 kg. The forelimbs have heavy, claw-like scales and are flattened for digging. Hind limbs are more elephantine.

Desert tortoises are well adapted to living in a highly variable and often harsh desert environment. They spend up to 95% of their lives in burrows, even during their seasons of activity. In late winter or early spring, they emerge from over-wintering burrows and typically remain active through fall. Activity does decrease in summer, but tortoises often emerge after summer rain storms. Mating occurs both during spring and fall. During activity periods, desert tortoises eat a wide variety of herbaceous vegetation, particularly grasses and the flowers of annual plants. During periods of inactivity, they reduce their metabolism and water loss and consume very little food. Adult desert tortoises lose water at such a slow rate that they can survive for more than a year without access to free water of any kind and can apparently tolerate large imbalances in their water and energy budgets as well as salt requirements.

The size of desert tortoise home ranges varies with respect to location and year and also serves as an indicator of resource availability and opportunity for reproduction and social interactions. Males have long-term ranges from 10 to 80 ha and females have long-term home ranges that are approximately half that. Over its lifetime, each desert tortoise may use more than 3.9 km^2 of habitat and may make periodic forays of more than 11 km at a time.

In drought years, the ability of tortoises to drink while surface water is available following rains may be crucial for survival. During unfavorable periods, desert tortoises decrease surface activity and remain mostly inactive or dormant underground, which reduces water loss and minimizes energy expenditures. Home range size, number of different burrows used, average distances traveled per day, and levels of surface activity have been shown to be significantly reduced during drought years.

Tortoises are long-lived and grow slowly. They can live over 30 years and possibly up to 50 years. They require 13 to 20 years to reach sexual maturity, and have low reproductive rates during a long period of sexual maturity. The number of eggs as well as the number of clutches (set of eggs laid at a single time) that a female desert tortoise can produce in a season is dependent on a variety of factors including environment, habitat, availability of forage and drinking water, and physiological condition. Success rate of clutches has proven difficult to measure, but predation appears to play an important role in clutch failure.

The desert tortoise occurs in the broadest latitudinal range, climatic regimes, habitats, and biotic regions of any North American tortoise species. The species occupies a variety of habitats from flats and slopes dominated by *Larrea tridentata* (creosote bush) scrub at lower elevations to rocky slopes in *Coleogyne ramosissima* (blackbrush) and *Juniperus* spp. (juniper) woodland ecotones (transition zone) at higher elevations. They have been observed in Joshua tree (Yucca brevifolia), shadscale (*Atriplex confertifolia*) scrub, saltbush (*Atriplex* spp.) scrub, alkali sink, cactus scrub, desert washes, and paloverde (*Parkinsonia* spp.)-mixed cactus scrub associations. They appear to prefer plant communities that have a sparse cover of low-growing shrubs, which allows establishment of herbaceous (non-woody) plants.

Habitat

Typical habitat for the desert tortoise in the Mojave Desert has been characterized as creosote bush scrub in which precipitation ranges from 5 to 20 cm, where a diversity of perennial plants is relatively high, and production of ephemerals is high. The Mojave Desert is relatively rich in winter annuals, which serve as an important food source for the desert tortoise. Tortoises will also forage on perennial grasses, woody perennials, and cacti as well as non-native species such as *Bromus rubens* (red brome) and *Erodium cicutarium* (red-stem filaree). Ninety percent of the precipitation that facilitates germination of important forage species for desert tortoise occurs in winter and sometimes in the form of snow. Tortoises in the eastern Mojave Desert are more likely to be subjected to freezing winter temperatures and prolonged drought than tortoises in the Sonoran Desert and Sinaloan region where freezing temperatures are rare and rainfall is more predictable.

Desert tortoises in the Mojave occur on valley bottoms much more frequently than desert tortoises in the Sonoran and Sinaloan regions. Sites in the Mojave near Goffs, California and Las Vegas, Nevada, had slopes of 4% or less, while Sonoran Desert sites had slopes of over 40%. In winter desert tortoises used 41% to 80% slopes of the Picacho Mountains more than expected and 0% to 20% slopes less than expected based on availability. In ZION, tortoises use moderately-steep, rocky, colluvial slopes. Large, angular boulders cover most of the finer-textured colluvium. They apparently favor burrows beneath these boulders (personal communication, Claire Crow, Zion National Park biologist).

Desert tortoises tend to use south-facing slopes, although they also use other aspects. In a community of mixed grasses, catclaw acacia, and velvet mesquite in southern Arizona, aspect at Sonoran desert tortoise burrows averaged 182 °S. Desert tortoises showed a significant ($P<0.0005$) preference for south-facing burrow entrances. In paloverde-creosotebush-saguaro habitat in southeastern Arizona, most desert tortoises hibernated in burrows on south-facing slopes. A model developed to predict important features of their habitat suggests that desert tortoises in the north-central Mojave Desert tend to use southwest-facing slopes and avoid north-facing slopes. Although not significantly different from random locations, most desert tortoise burrows faced south on a site that transitioned from Mojave to Sonoran Desert vegetation. Desert tortoises also used south-facing bajadas in southern California. However, use of northern and northwestern aspects in Pima County, Arizona, was also reported. In the Picacho Mountains, desert tortoise used different aspects throughout the year and avoided ($P<0.001$) south-facing slopes in winter. Most desert tortoise burrows on a site in Nevada occurred on north-, northeast-, and east-facing slopes.

Due to the importance of burrows for shelter, reduction of water loss, and regulation of body temperature, soil characteristics may have a strong influence on desert tortoise density and distribution. Burrow construction requires soil that crumbles easily during digging and is firm enough to resist collapse. Desert tortoises commonly use sites with sandy loam soils with varying amounts of gravel and clay, and tend to avoid sands. One explanation for fewer desert tortoise burrows than expected in a big galleta-white bursage community in the southwestern Mojave Desert was that sandier soils (90% sand) in these areas may have inhibited burrow construction. However, sands are used by desert tortoises in stabilized dunes in the Pinto Basin of Joshua Tree National Park. A model based on data from the north-central Mojave suggests that desert tortoises avoid stony soils and tend to use sites with loamy soils. Although hardpans (i.e., caliche layers) can limit desert tortoise burrowing, dens are sometimes constructed under exposed caliche layers in wash banks. During the winter, tortoises will opportunistically use burrows of various lengths, deep caves, rock and caliche crevices, or overhangs for cover.

A comparison of soil maps and desert tortoise distribution and density in southern Nevada suggested that the following soil characteristics were negatively related to desert tortoise abundance: low available water-holding capacity, shallow (< 100 cm) depth to a limiting layer, fragments larger than 8 cm on the surface, excess salts, soil temperatures below 15 °C at 51 cm depths, and soils prone to flooding. These factors may directly interfere with desert tortoise den construction and/or reduce cover and forage availability. Because desert tortoises may consume soil to maintain adequate calcium levels, they may prefer sites with high soil calcium content.

Model Development and Application

There have been at least two efforts in modeling spatial distribution of the species. The first used site data and associated spatial data from a GIS to statistically identify factors that influence distribution (Anderson, et. al., 2000) Their study suggests that ”tortoises tend to occur on southwest exposures and loamy soils, and are less abundant in stony soils, north exposure, and areas of very low plant cover.” This supports the conclusion that geologic and soil materials distinctly influence tortoise distributions in their study areas, but not necessarily on a spatial basis since even in the limited study area habitat was not explicitly mapped.

Regional modeling by Nussear, et. al. (2009) evaluated 16 environmental factors influencing the presence of tortoise in the Mojave Desert. Results showed the most important factors in predicting tortoise presence are elevation and annual growth potential. This is a spatially-explicit model, using the identified factors to predict habitat quality. Spatial data are at a rather coarse 1 km resolution. It did directly consider site-specific factors (other than tortoise presence data), but resulted in a statistically-based spatial depiction of habitat potential. This is a regional model, and ZION is at the far eastern edge of its application but within the study boundary.

The base model for ZION was developed and tested for tortoise populations in the Mojave Desert by the U.S. Geological Survey (USGS) (Nussear, et. al., 2009). Though revisions of this model are in process, it is used here without modification, since it meets the criteria for this project. It is published and peer reviewed, has a wide applicability, and incorporates ZION in its present extent.

The Nussear model is predicated on the use of a set of environmental variables. An interdisciplinary team was assembled to create the larger set of spatially-defined environmental variables at a common scale. The variables included those known or suspected to influence habitat, such as climate (winter precipitation, dry season precipitation, wet season precipitation, elevation, slope, aspect, surface characteristics (roughness), soils properties, perennial plant cover, and annual growth potential. Final common resolution of the data is 1 km.

A quality-controlled data set of over 15,000 points defining tortoise locations (presence data) was assembled in the study area. Eighty percent of the points were used for model development with the remaining 20% of points used for model testing. A probability is generated for overall habitat quality, given the values of these variables at any potential location.

Since no true "absence" data were available, a statistical model was applied that did not require them (MAXENT). The model, further described in Elith, et.al, (2011) uses Bayes rule to predict probability of occurrence in environmental covariate space given a distribution of presence data in geographic space. The equation is Pr(y given z) = f1(z)Pr(y)/f(z). Pr(y given z) is the probability of a species occurrence given a set of environmental factors (z) The first factor f1(z) is the probability of a given set of environmental conditions given the species is present,, the second (Pr(y)) is the probability of species presence (prevalence), and f(z) is the probability of a given set of environmental conditions. All factors but one can be estimated from available data on environmental variables, presence, and background data. However, the prevalence (Pr(y) cannot be directly estimated without knowledge of absences, which are not available. The MAXENT system estimates the value of Pr(y given z) independently using simulation techniques that attempt to minimize relative entropy in the covariate environmental space. This does not require absence data.

Application of the model is complex. It is not possible to compute results for a given cell independently of running the entire regional model, since there are many interactions possible between variables that vary depending on location. However, MAXENT provides a set of graphs that give some indication of variable effects (Figure 39). Each graph is shows the effects of variation on results, given other variables are held constant at their means. Ten of the original 16 variables were designated as significant in predicting habitat. A heuristic estimate of variable contributions is shown in Table 11. The two top variables appear to be elevation (ELEV) and Annual Productivity (ANNPROX), contributing a total of 79% to habitat potential.

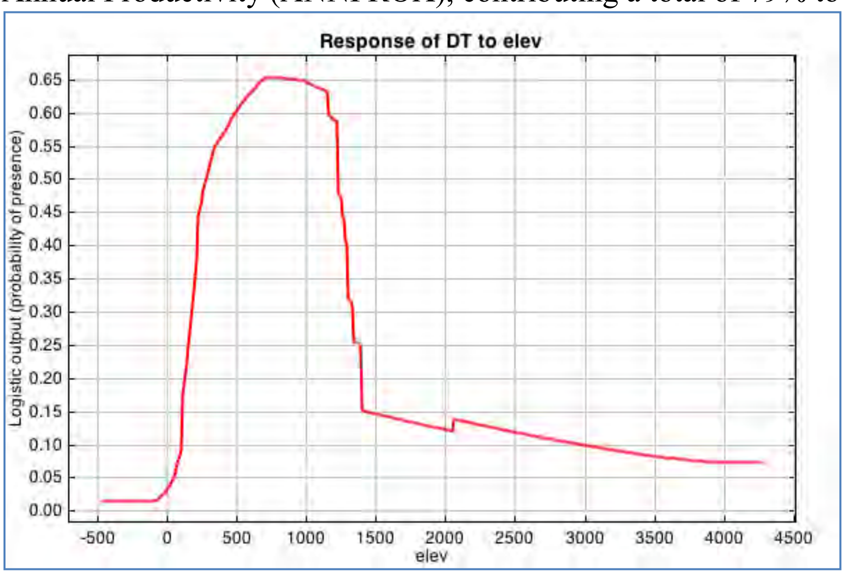


Figure 39. Regional Model Response Curve for Elevation (DT is habitat potential, elev is in meters)

Table 11. Contribution of Significant Variables for the Tortoise Regional Model

Variable	Percent contribution
elev	59.7
annProx	19.3
pctSmooth	6.3
wp30	5.7

rufAve	2.5
BlkDensity	1.7
Dpth2BdRk	1.5
sp30	1.3
pctCov	1.2
pctRocks	0.7

As elevation (ELEV) decreases from 1400 m to 800 m, habitat potential increases and from there, decreases rapidly as values pass 500 m (Figure 39). For ANNPROX, values increase to a mid-range productivity, then drop off. These two variables were carried forward in application of the model to ZION because of their dominant contribution and requirements for model simplification. They are also important climate proxies, with ELEV simulating temperature change and ANNPROX reflecting potential precipitation or vegetation productivity changes.

Though it is probable productivity may shift with long term climate changes and ten years of summarized local productivity data was available (Thoma, 2010), those data appear more suitable for measuring potential shorter term variation than that associated with climate change. Variation in ANNPROX effect at different elevations is possible, and it does have significant direct effects (Figure 40), but is of lesser importance (Table 11 above) so was not included in this approximation.

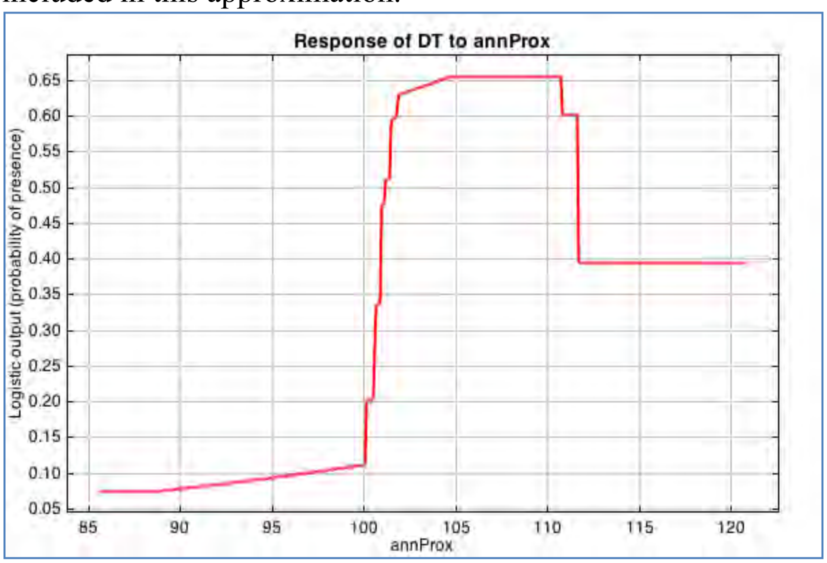


Figure 40. Regional Model Response Curve for Annual Productivity (DT is habitat potential.)

Calculations of the ANNPROX variable were made independently to validate its applicability. In Nussear's model ANNPROX estimates were made by subtracting NDVI at pixel scale in a wet year (2005) from a dry year (2002) (Nussear, et. al., 2009). The spatial distribution of productivity was validated by Thoma in a different manner at the pixel scale, which involved subtracting the lowest pixel value in the 10 year MODIS record from the maximum pixel value in the 10 year record. The difference in approach is subtle. Whereas Nussear assumed every pixel value in 2005 would be more productive than in 2001, Thoma recognized that within-year variability in the spatial distribution of precipitation could result in non-uniform distribution of NDVI pixels. By defining the maximum and minimum pixel values from any year in the 10 year record the spatial distribution of precipitation is inherently accounted for in the maximum minus minimum difference. It is reassuring that the results of the two approaches are visually similar (Figure 41) and lend credibility to the NDVI-derived productivity used by Nussear in his model.

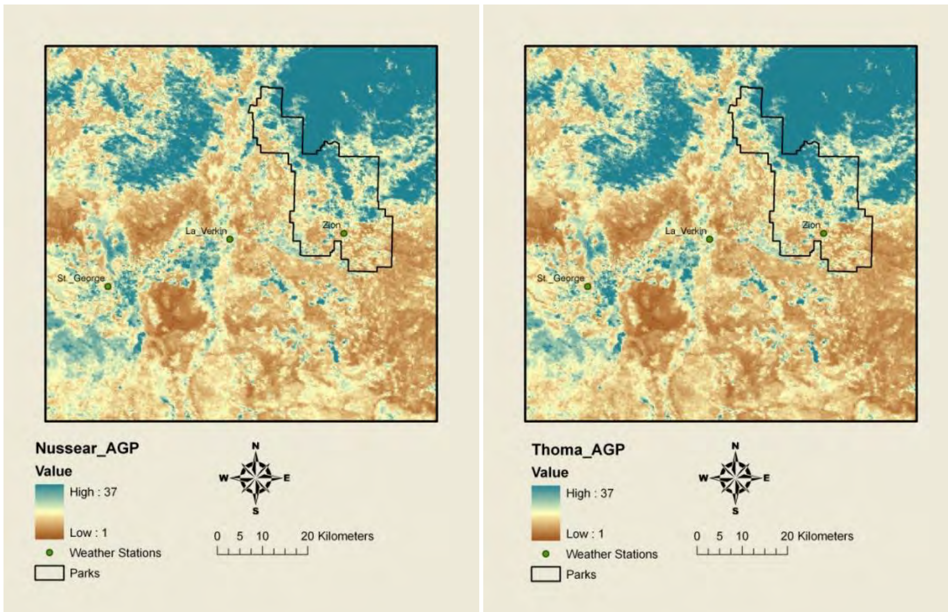


Figure 41. Visual comparison of vegetation productivity determined by Nussear and Thoma as 2005 minus 2001 NDVI and 10 year maximum minus 10 year minimum NDVI, respectively.

The original model's results for the area near ZION are shown in Figure 42. Results are, closely related to elevation in ZION with most of the viable habitat below 1500 m (compare Figure 42 with Figure 43) which fits well with the declining contribution of elevation above that value. There may also be changes in ANNPROX that affect results, as productivity may change as ecosystems vary with the rapid increase in elevation.

The same model using a 100 m decrease in elevation over the study area (simulating a warming climate) shows higher potential at lower elevations (compare Figure 44 with Figure 42). This is expected, because in the area where values increase, elevation changes from about 1200 m to 1100 m, which significantly increases the elevation component of habitat potential (Figure 39), thus suggesting model results are reasonable.

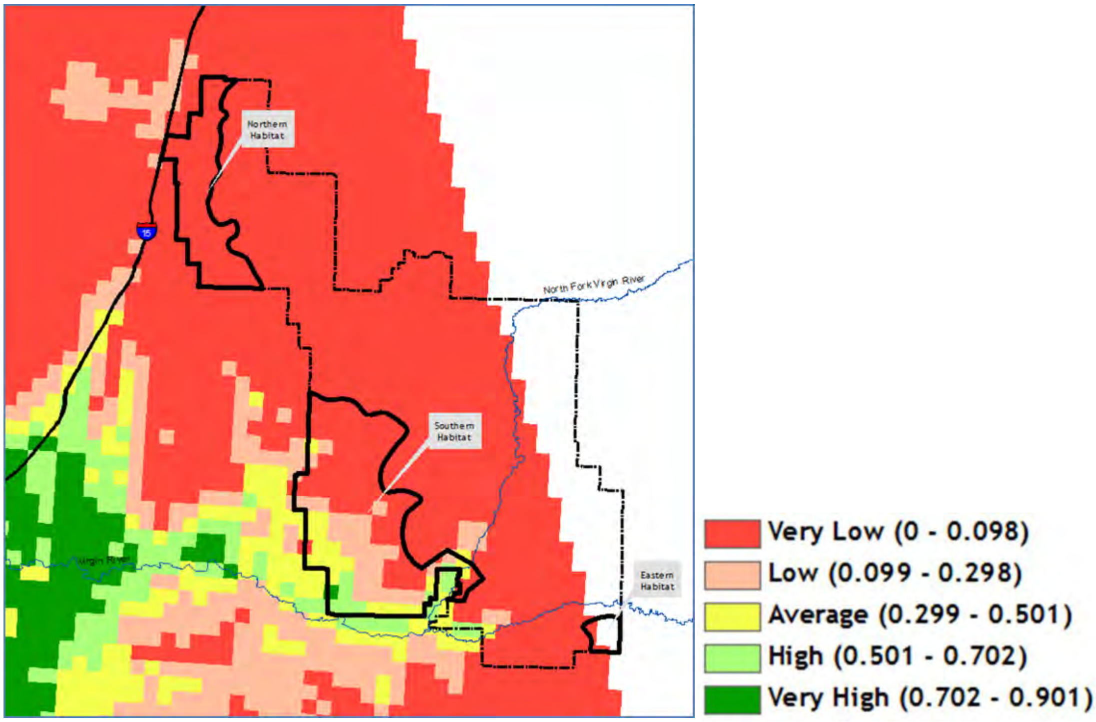


Figure 42. Regional Tortoise Model Habitat Quality (Present Condition) (Black-outlined polygons are generalized physical habitat areas discussed below)

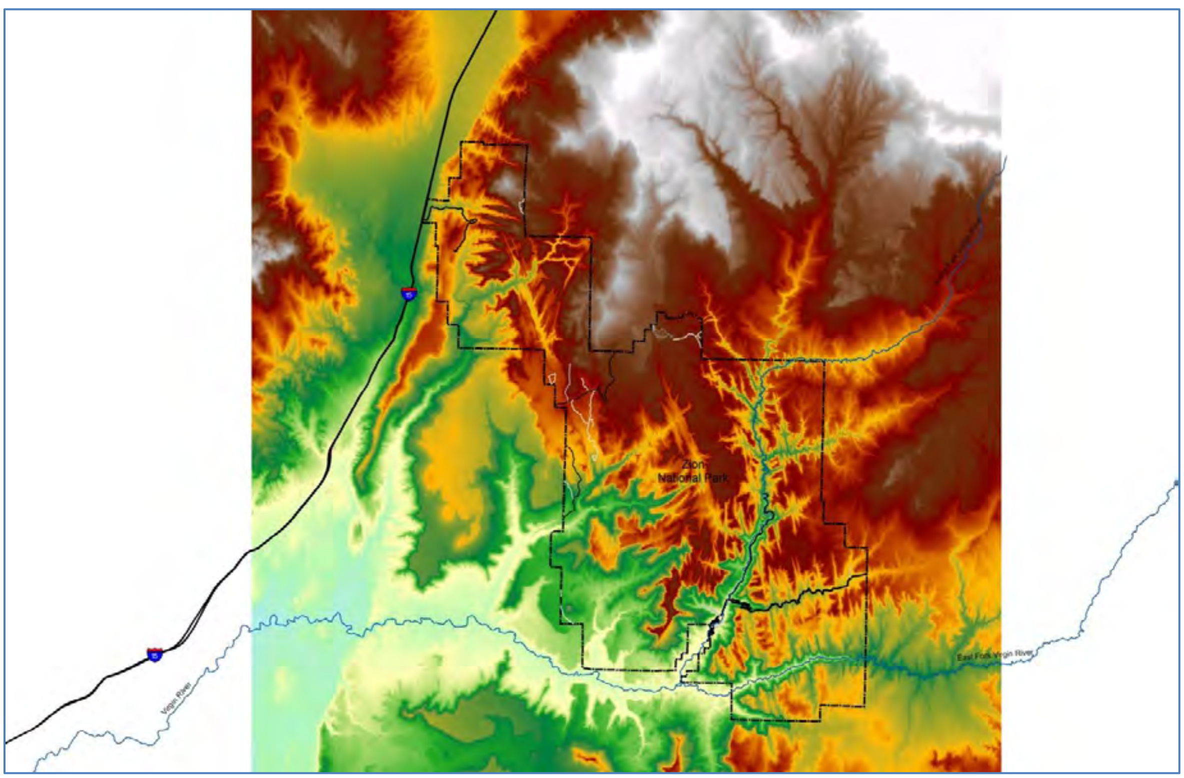


Figure 43. Elevations of ZION (light yellow = 1100 m, dark green = 1500 m)

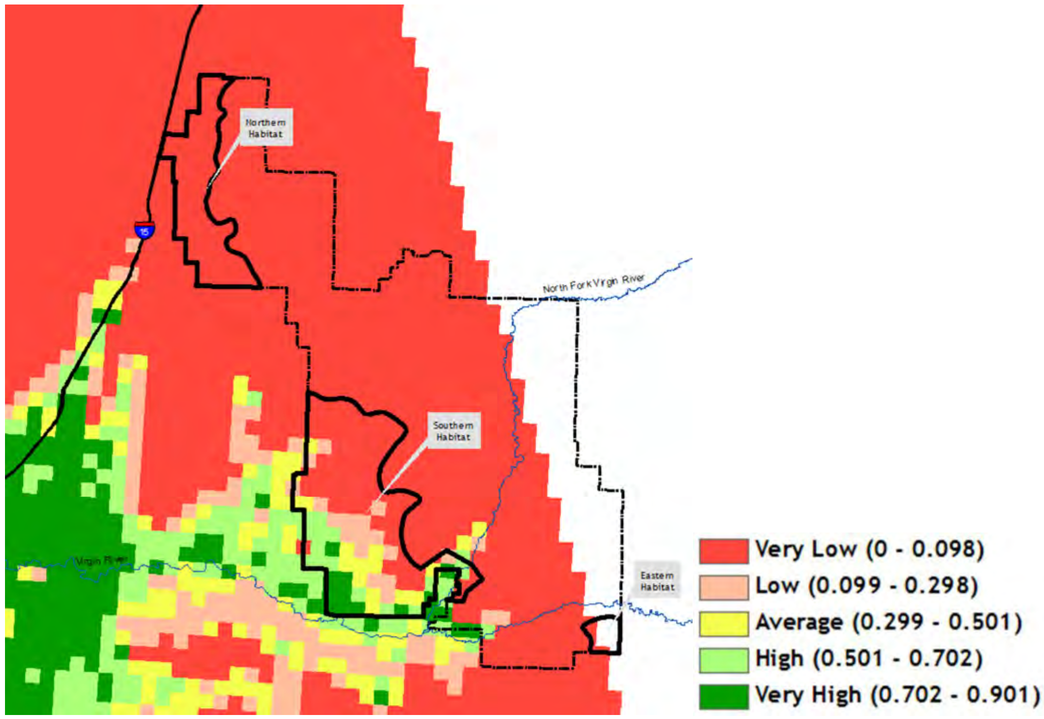


Figure 44. Regional Tortoise Model Habitat Quality (with 100 m Elevation Decrease (20 years, Minimum MAT Change))

The Nussear model is rather coarse in resolution, and does not reflect local habitat data in ZION, such as physical habitat factors not in the regional model. Therefore a filtering layer was developed for ZION. Criteria for the filter are 1) slopes less than 45%, and 2) vegetation types of blackbrush shrubland, desert shrubland, and juniper shrubland/open woodland. ZION staff provided the vegetation types favorable to tortoises. A field review with ZION staff in occupied tortoise habitat provided slope limits. The NPS ZION vegetation map was used to filter the vegetation types, and a 30 m digital elevation model was used to generate slopes. Using these together eliminates barren areas, slick rock, pine woodlands, and colder vegetation types that tortoises do not generally use. Small, isolated polygons were removed to show only major habitat areas.

Figure 45 shows physical habitat model results. This model's results are consistent with ZION's monitoring program. Field observations indicate populations in areas consistent with the habitat mapping (red polygons in Figure 45). There are current plans to field survey other higher rated areas within potential habitat (such as the average and high rated areas in SW ZION (Figure 42), indicating that local staff has also concluded there are potentials in those areas. This physical habitat model (Figure 45) also spatially included those higher-rated habitat quality areas in Figure 42 providing further support for its use as a model.

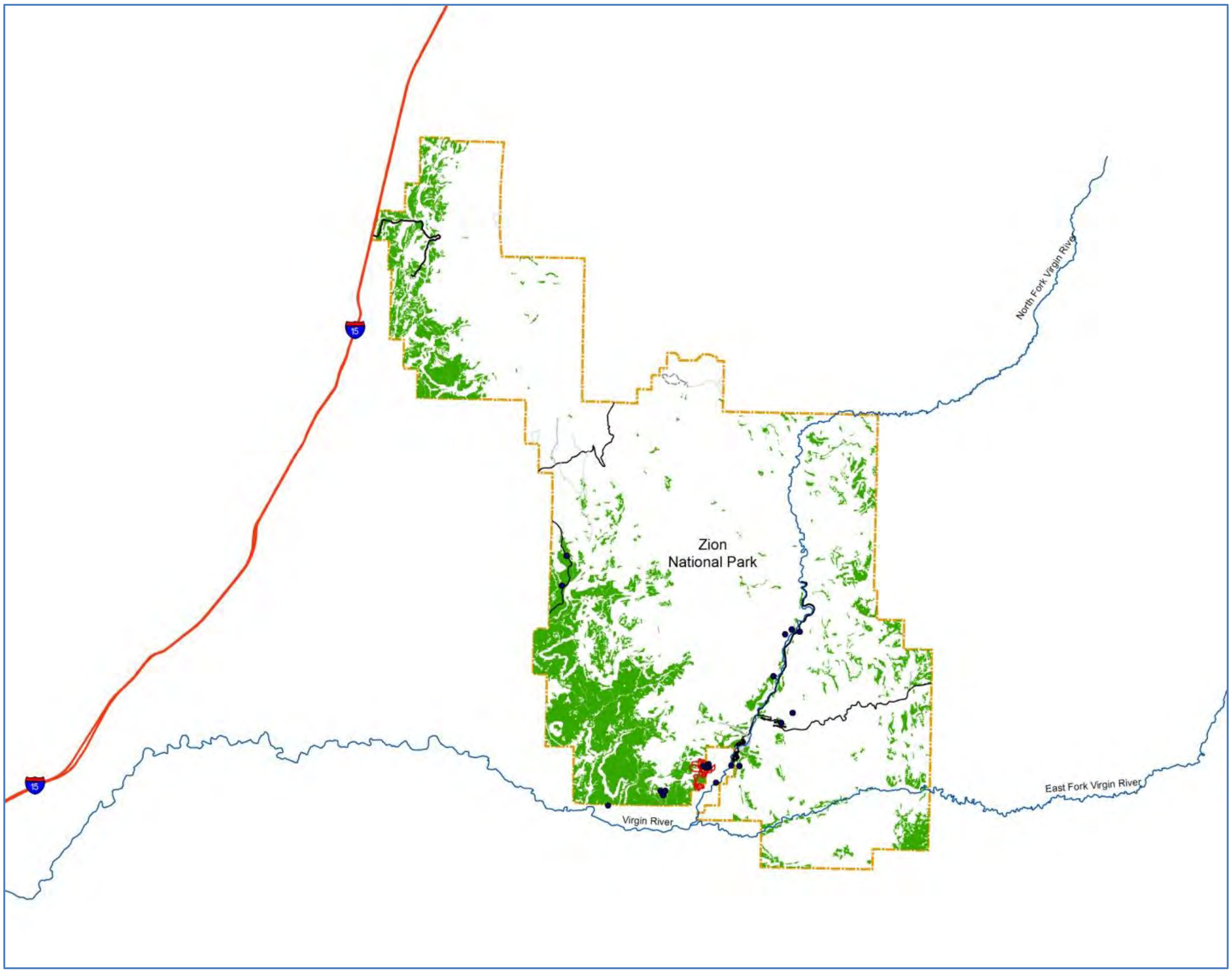


Figure 45. Physical Tortoise Habitat in ZION (black lines are ZION roads, Red polygons are currently observed populations)

This physical habitat model was used to clip the regional model for analysis. This made for a more realistic portrayal of actual habitat, and also to predict potential future habitat within the Park boundaries that may be available or desirable to tortoises in the future in terms of suitability and continuity. Clipped Nussear results are summarized by Northern, Southern, and Eastern habitat polygons (black polygons in Figure 42 and all subsequent Nussear outputs).

Results

Applying the model to predicted climate warming is relatively straightforward, but we did not run the model directly. Because of the complexity of the software, data restrictions on use, and Dr. Nussear's familiarity with the process, he volunteered to make the runs, varying elevation per our specifications. There were some complications due to some subtle file compression incompatibility, but we solved those problems over the course of the project. Elevation changes were taken from Table 3 above. Table 12 contains statistics, compiled by Habitat area (exemplified in Figure 44), habitat quality calculated by area, and the range of climate alternatives.

Table 12. Habitat Quality from Tortoise Regional Model for Climate Alternatives

Area	Min.	Max.	Range	Mean	Std. Dev.	% Change from Present	% Change from Previous
Present Condition							
Northern Habitat	.00	.00	0 .00	.00	.00	0.0	n/a
Southern Habitat	.00	.80	0 .80	.14	.20	0.0	n/a
Eastern Habitat	.00	.00	0 .00	.00	.00	0.0	n/a
with 100 m Elevation Decrease (20 years, MAT Change)							
Northern Habitat	.00	.02	0 .02	.00	.00	*	*
Southern Habitat	.00	.95	0 .95	.24	.28	76.1	76.1
Eastern Habitat	.00	.00	0 .00	.00	.00	*	*
with 245 m Elevation Decrease (50 years, Minimum MAT Change)							
Northern Habitat	.00	.05	0 .05	.00	.01	*	37.7
Southern Habitat	.00	.96	0 .96	.31	.31	128.4	29.7
Eastern Habitat	.00	.00	0 .00	.00	.00	*	2.5
with 381 m Elevation Decrease (50 years, Maximum MAT Change)							
Northern Habitat	.00	.10	0 .10	.01	.02	*	125.1
Southern Habitat	.00	.96	0 .96	.33	.31	139.9	5.1
Eastern Habitat	.01	.01	0 .00	.01	.00		94.5
with 408 m Elevation Decrease (100 years and Minimum MAT Change)							
Northern Habitat	.00	.10	0 .10	.01	.02	*	15.2
Southern Habitat	.00	.96	0 .96	.33	.31	141.5	0.7
Eastern Habitat	.01	.01	0 .00	.01	.00		1.1
with 626 m Elevation Decrease (100 years and Maximum MAT Change)							
Northern Habitat	.00	.10	0 .10	.02	.02	*	114.3
Southern Habitat	.01	.96	0 .95	.33	.29	141.3	-0.1
Eastern Habitat	.05	.05	0 .00	.05	.00	*	390.4
* not calculated; div by zero							

It is apparent from Table 3 above that only the Southern Physical Habitat area has any appreciable increase in habitat quality. The Northern and Eastern areas remain close to zero for the entire suite of predicted changes. The Southern area increases dramatically in the first 20 years (a 76.1 % change) and rates from Low at present to Average at the highest potential MAT increase and at 100 years. However, the rate of increase slows to below 6% under the maximum MAT change after 50 years, and no further improvement occurs after that. This is probably because elevations have decreased enough to move to the left shoulder of the elevation vs. quality curve in Figure 39.

Spatially, a different pattern emerges when sequencing Figure 42 and Figure 44 above representing present conditions and a 20 year change, and Figures 46, 47, 48, and 49 representing later changes. Though for the Southern Habitat area the overall change is only up to the Average class, the changes near the southwest boundary are much higher. They move from Average to Very High, both in Federal ownership (in ZION) and on nearby BLM land and private lands (Figure 4 above). This is estimated at an 800 fold increase in Very High class habitat quality for that boundary area. Furthermore, the small incursion of private land above Springdale in the south-central part of ZION markedly increases in quality after only 20 years.

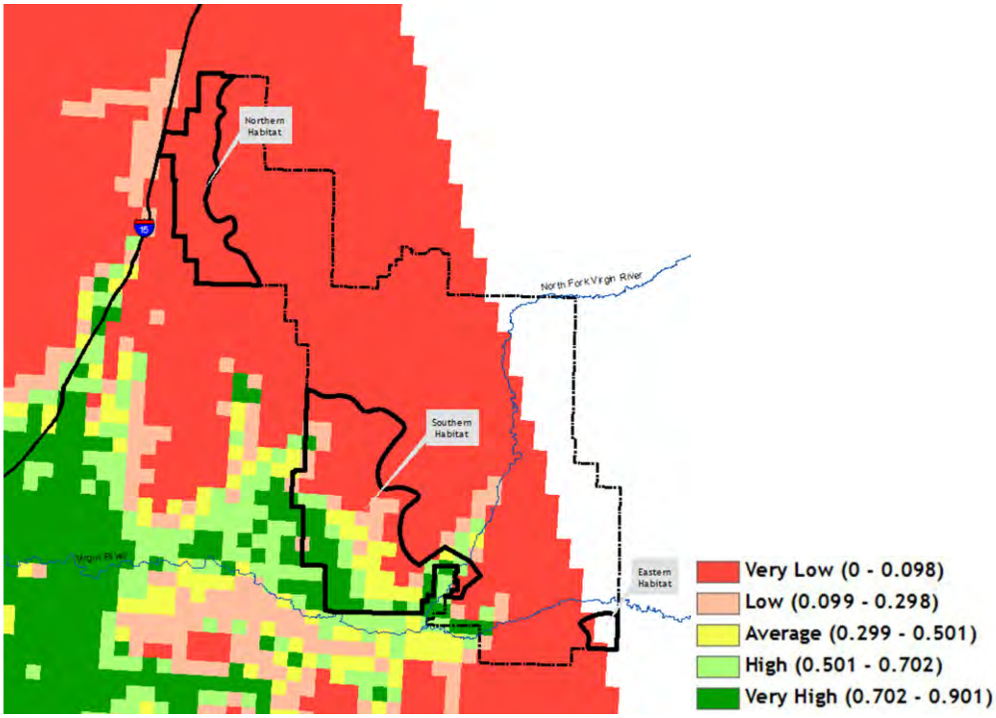


Figure 46. Regional Tortoise Model Habitat Quality (with 245 m Elevation Decrease (50 years, Minimum MAT Change))

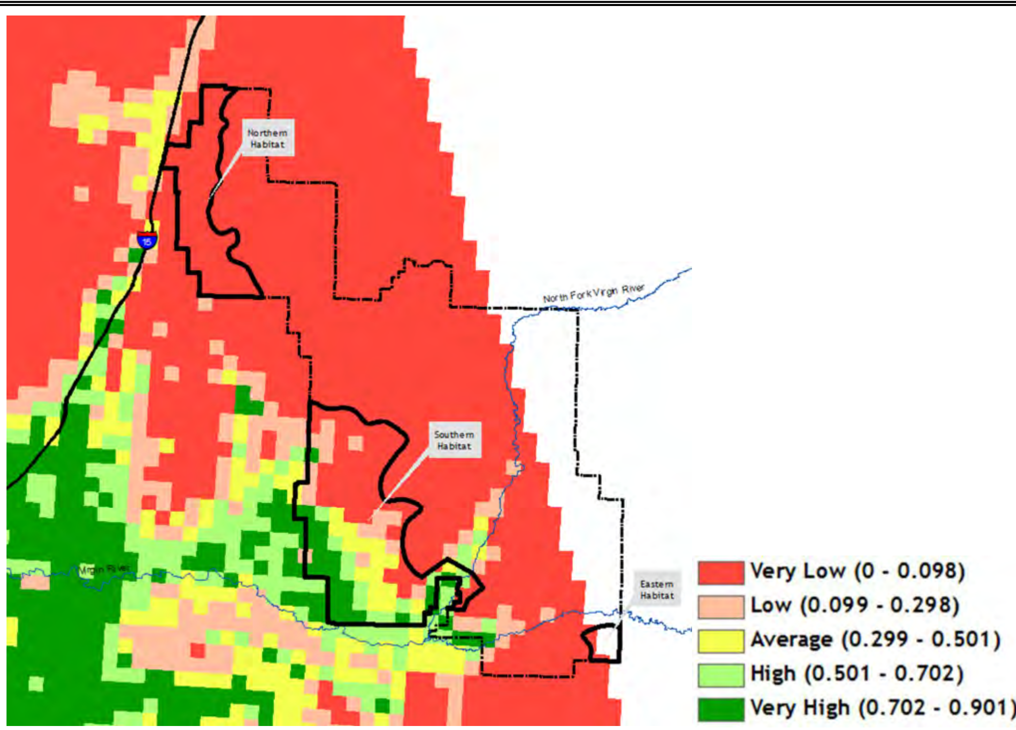


Figure 47. Regional Tortoise Model Habitat Quality (with 381 m Elevation Decrease (50 years, Maximum MAT Change))

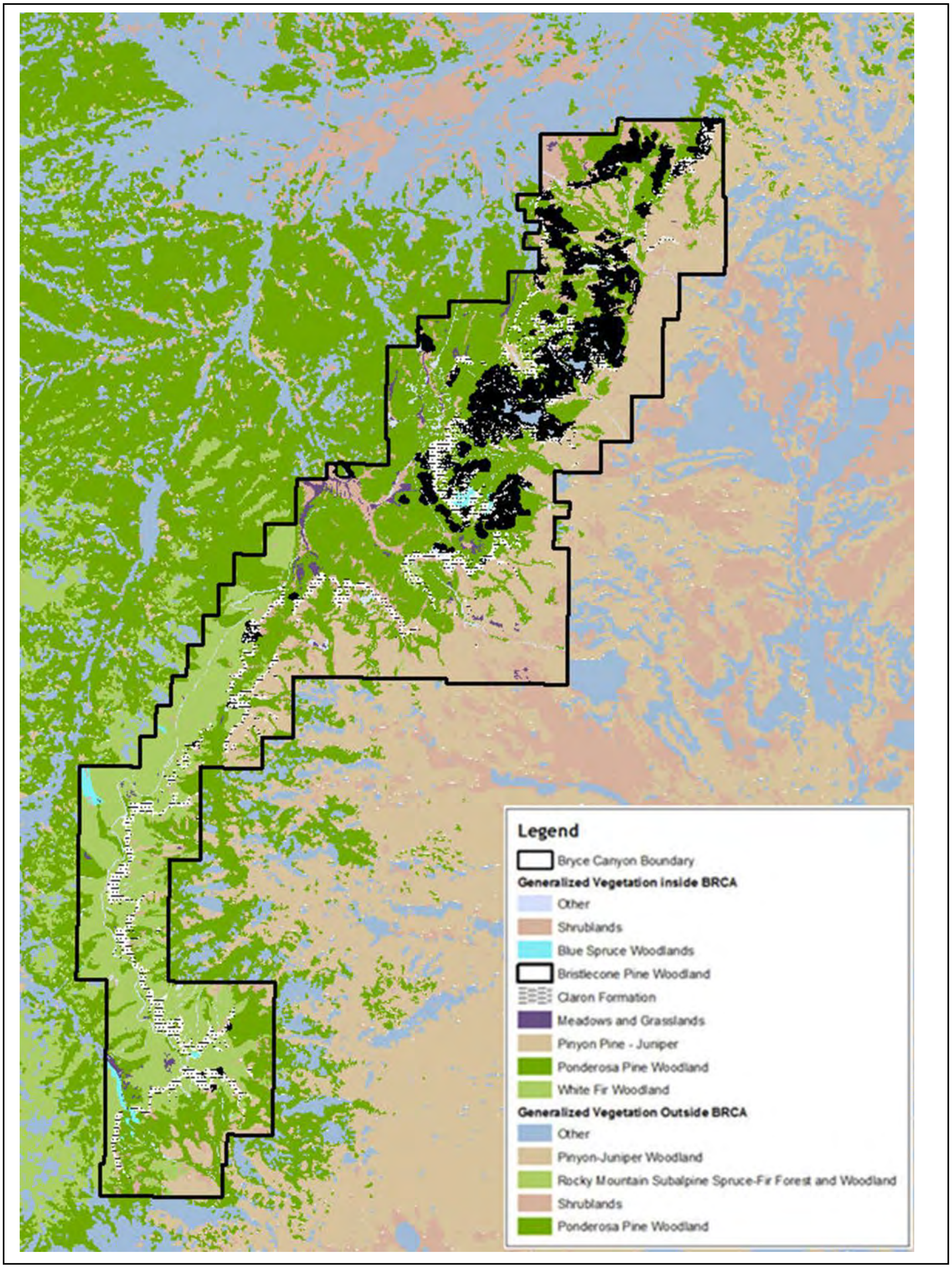


Figure 50. Generalized Vegetation inside and outside of BRCA.

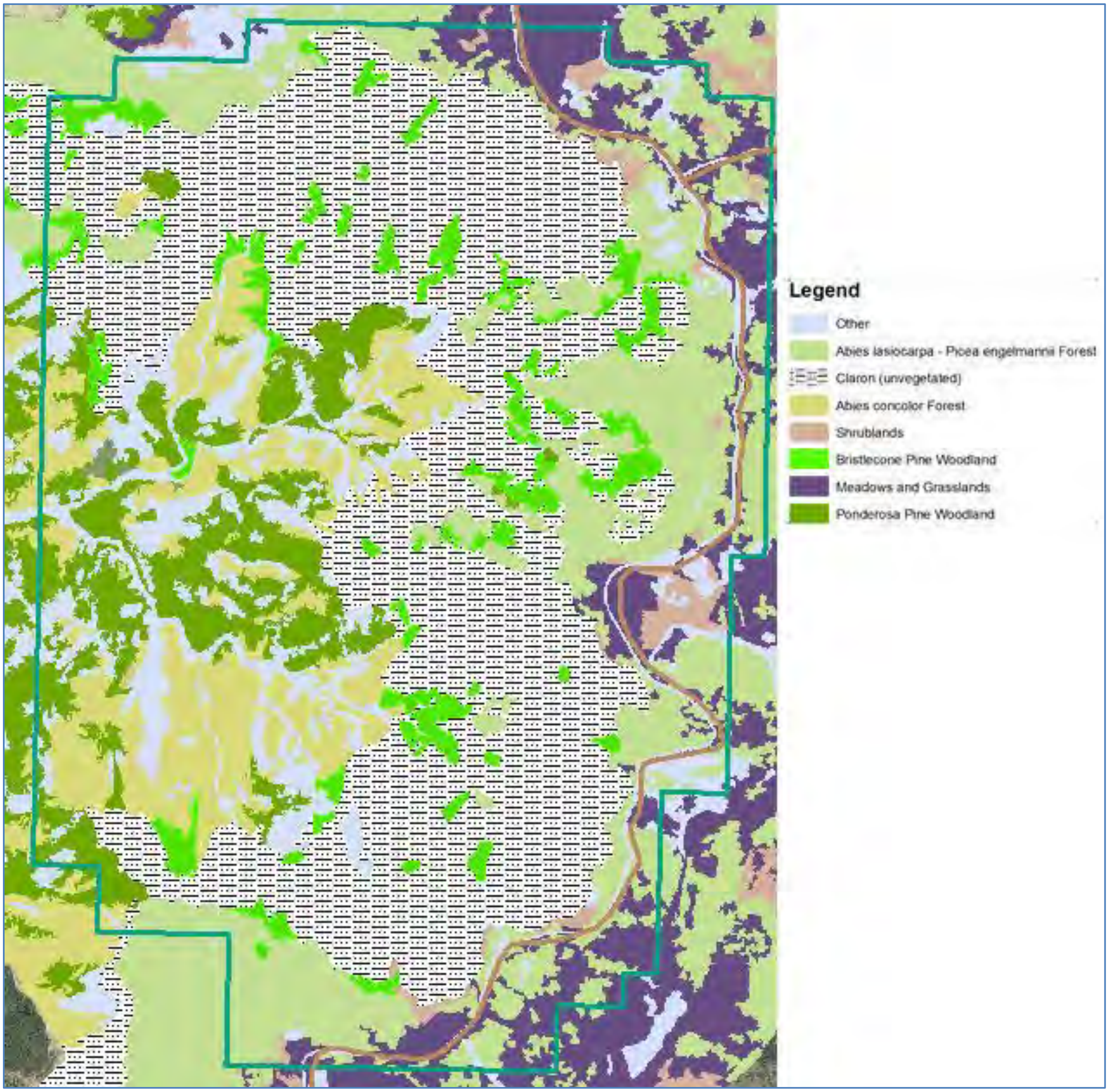


Figure 51. Generalized Vegetation inside and around CEBR

Model Development and Application

Because of the above, the highest PILO stands in the harshest conditions (ibid) are probably the ones that have the best prognosis. However, this may not apply in BRCA or CEBR, as in both Units PILO occurs well below treeline and in warmer environments. It is likely BRCA and CEBR PILO populations are controlled by factors other than treeline environmental ones, and are likely part of a "topo-edaphic" system, or one dominated by the local environmental conditions created by elevation, landform, and soils. Summing all the environmental threats probably indicates lower, mixed stands are at greater risk as mountain pine beetles and wildfire are more common there, as is the case in CEBR and BRCA. No PILO was inventoried in ZION.

Though climatic threats to PILO have been articulated in general terms above, and probably generally apply to PILO in BRCA, no existing species distribution model has been discovered. In fact, the literature generally does not even address the specific environments of PILO in BRCA. Almost all research is located where PILO inhabits harsh tree-line environments at relatively cold sites, and in BRCA this is not the case. BRCA has a relatively warm climate, and almost all habitat is well below tree line in some of the warmest environments in the Park (Figure 50 above). BRCA, like many NPS Units is relatively unique with its badland topography and vegetation, forming a transitional area between drier, warmer shrublands and pinyon-juniper woodlands and through cooler white fir forests, then to warmer ponderosa pine forest (ibid). PILO in CEBR also inhabits environments well below treeline, even with the relatively harsh climate there (Figure 51 above). This may help explain why relatively-extensive PILO stands occur here.

Model Development for PILO in BRCA

Because of the rather unique character of PILO in BRCA and CEBR, and the lack of a readily-available species distribution model, the development of a local distribution model was explored using physical parameters associated with its occurrence with the objective of extrapolating to a warming environment. The following discussion addresses this model development. The landscape factors of parent material (soil), slope, elevation, landform, aspect, and relative position with respect to other vegetation types were explored individually and in total.

The BRCA analytical spatial database was created by unioning polygons from the10 m resolution elevation, slope, and aspect grids; National Park Service (NPS) vegetation mapping; USGS geologic mapping; NRCS soils mapping; and intersecting the BRCA boundary. This process resulted in a finely detailed, yet completely-attributed spatial layer of 1,590,000 polygons. Raw results were summarized in ACCESS, and charted and formatted in EXCEL. All the following results come from this database.

To facilitate analysis of PILO in BRCA, the Park was separated into general ecological types (Areas) based on latitude and elevation (Figure 52). Within these types, BRCA has two distinct landforms (plateaus and badlands) and these were delineated (Figure 53). Slope differentiates between these, with plateaus averaging 10% and badlands at 20% (Figure 55).

Elevation generally increases as one moves southward (Figure 54), but when averaged by Area, the differences between units are relatively small (on the order of 300 m between lowest and highest) for the steep, eroded badland areas (Areas 10, 20, 30, 40, and 50) (Table 13).

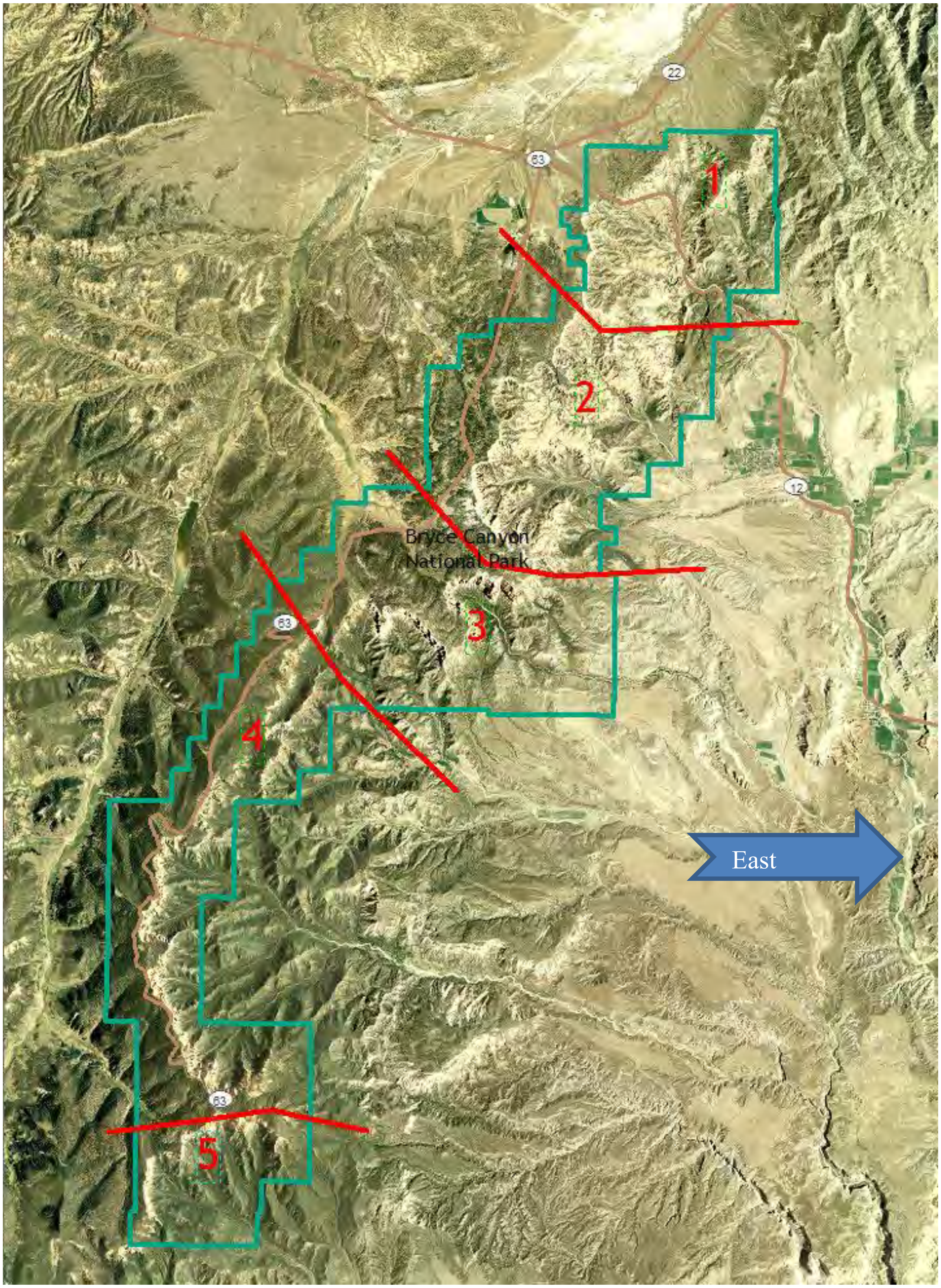


Figure 52. Ecological types (Areas) Preliminary Divisions in BRCA and imagery. The general aspect of steeper slopes is eastward.

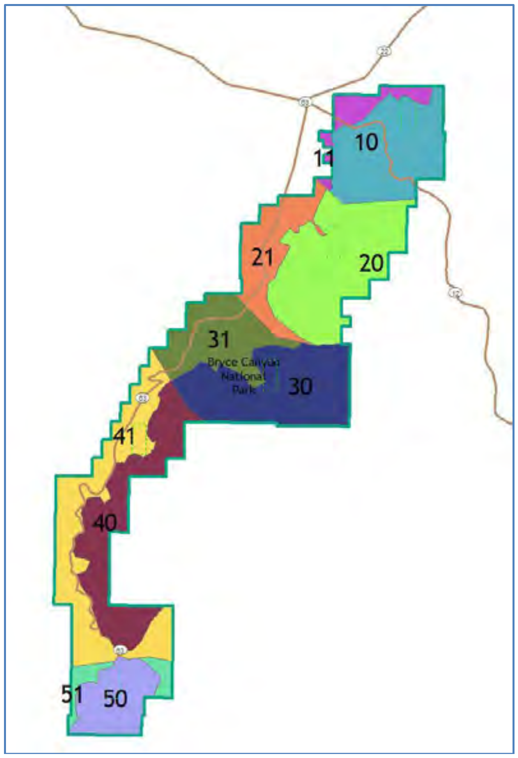


Figure 53. Ecological Areas in BRCA. Suffix of "0" = steep basins; "1" = gently sloping plateaus

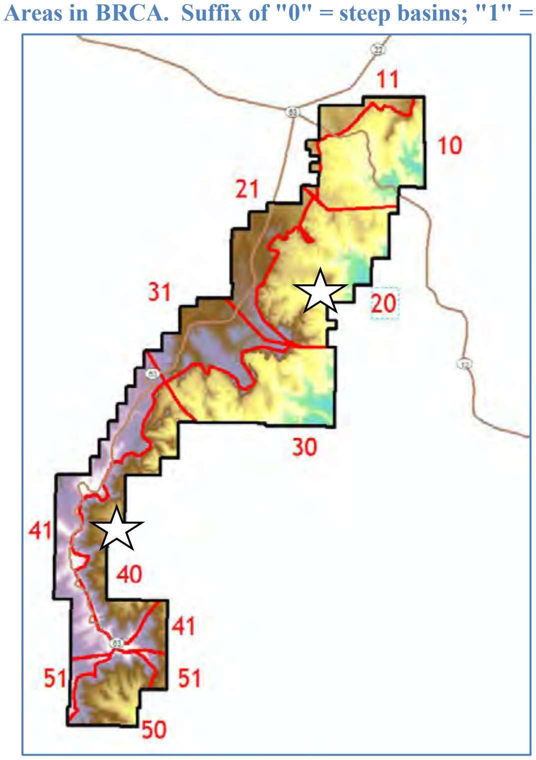


Figure 54. Elevation and Ecological Divisions (Areas) in BRCA. Stars are closeup locations. Graduation is from green (lowest) to purple (highest).

Table 13. Elevation Characteristics by Area in BRCA

Area	Avg Elevation (m)	Min Elevation (m)	Max Elevation (m)	StDev Elevation
10	2,198	2,011	2,407	81
11	2,339	2,266	2,395	20
20	2,258	2,009	2,544	94
21	2,435	2,290	2,555	41
30	2,236	2,006	2,565	113
31	2,475	2,354	2,584	42
40	2,446	2,182	2,777	115
41	2,596	2,320	2,778	83
50	2,435	2,219	2,779	110
51	2,547	2,341	2,779	107

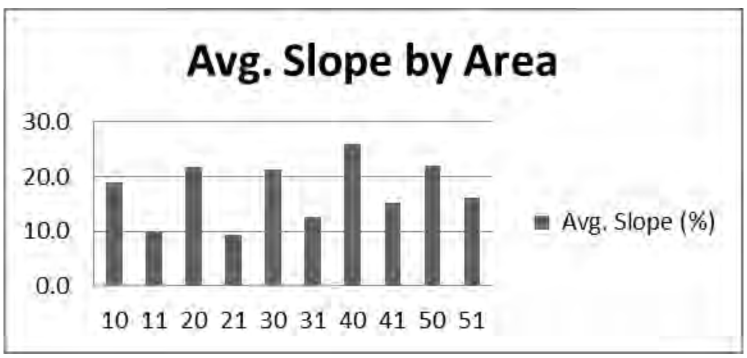


Figure 55. Average Slope by Area for BRCA

PILO occurs primarily in very open stands almost devoid of vegetation (Figure 56 upper image) in the northern part of BRCA (Figure 57). Those stands make up 694.3 ha (Table 14) or 4.8% of the total Park area. Almost all PILO stands occur in Areas 10 and 20 (Table 14) which are on steeper slopes (Figure 55). Stands occur from 2,085 to 2,763 m in elevation (Table 15). PILO stands actually occur in habitats having the lower average elevations in the Park (2,085 to 2,121 m (Table 15) in Areas 10 and 20 vs. a range of 2,004 - 2,777 m for the whole Park (Table 1)), and the majority of PILO stands themselves occur at lower elevations (Table 15) when compared to the forested plateaus (Areas 11, 21, 31, 41, and 51 in the Park (Table 13)), and range from the base to the highest elevations in the badlands (Areas 10, 20, 30, 40, and 50) (ibid).

PILO also occurs in other community types. Analysis of plots used in the NPS vegetation mapping indicates PILO individuals occur at 56 total sites, with 36 in PILO stands, and the remainder in shrublands (6 plots), in pinyon/juniper (2), ponderosa pine (5), and white fir (7) (Figure 57). These appear to occur mostly on the forested plateau Ecological Areas.

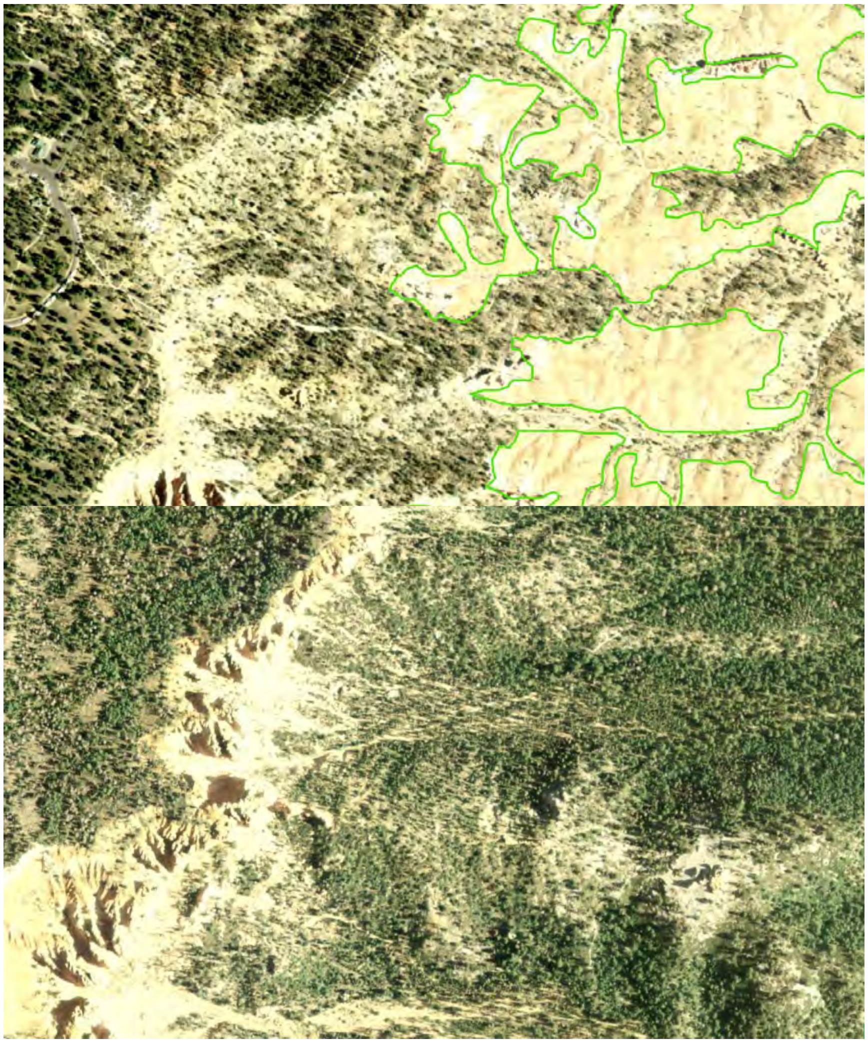


Figure 56. Closeups of Occupied PILO habitat (upper) in northern BRCA and similar physical habitat at the southern end of BRCA (See Figure 54 for location).

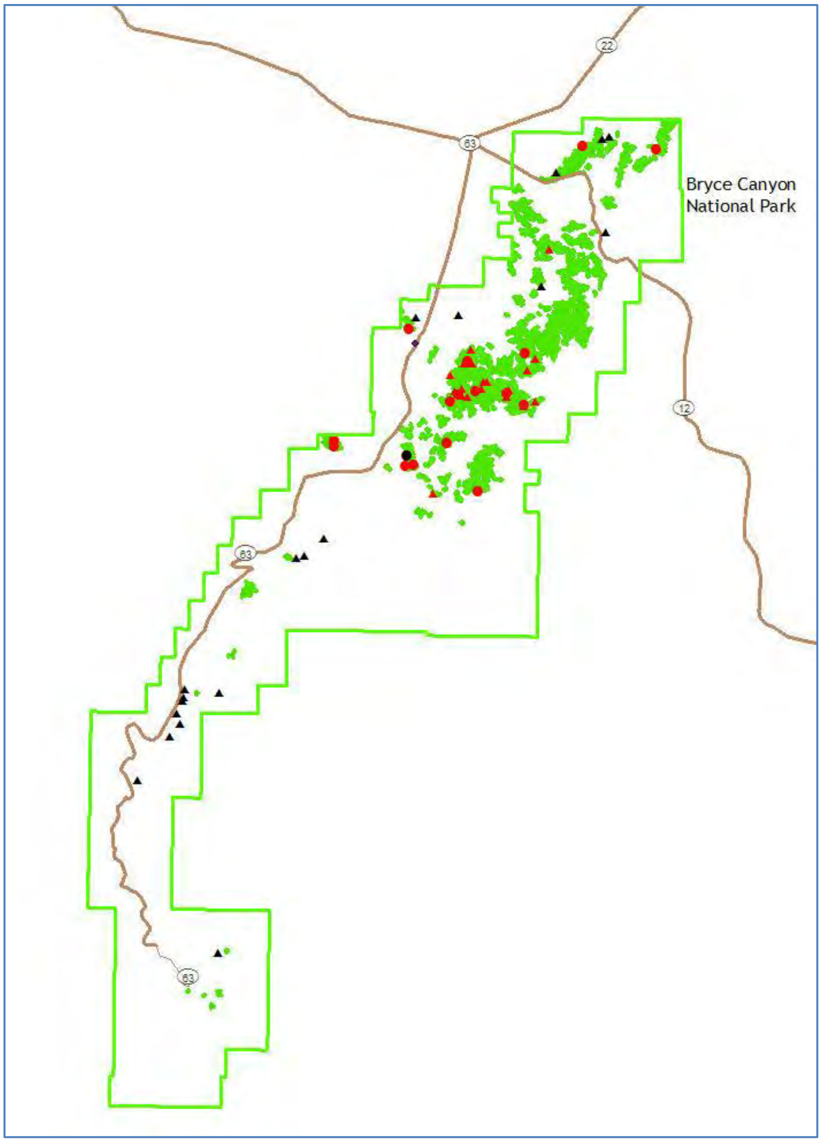


Figure 57. PILO Occurrence and Observation sites in BRCA (Red symbols are observations in PILO stands. Black symbols are observations of PILO in other vegetation types. PILO stands are in green.

Table 14. Extent of PILO by Area in BRCA

Area	Areal Extent (ha)	Percentage of Total PILO
10	206.9	29.7
11	4.7	0.6
20	424.7	61.1
21	27.6	3.9
30	3.4	0.5
31	17.1	2.4
40	4.6	0.6
41	3.2	0.4
50	1.9	0.2
51	0 .2	0.0

Total PILO	694.3	100.00
Total PILO on Areas 10, 20, 30, 40, 50	641.5	92.3
Total PILO on Areas 11, 21, 31, 41, 51	52.8	7.7

Table 15. Elevation Characteristics by Area for PILO only in BRCA

Area	Avg Elevation (m)	Min Elevation (m)	Max Elevation (m)	StDev Elevation
10	2,248	2,085	2,407	61
11	2,347	2,273	2,394	28
20	2,289	2,121	2,540	60
21	2,480	2,391	2,541	38
30	2,463	2,365	2,529	51
31	2,436	2,388	2,526	34
40	2,495	2,349	2,643	70
41	2,543	2,384	2,643	57
50	2,651	2,478	2,763	91
51	2,725	2,707	2,746	12

Almost all stands occur on soils that are mapped as very rocky or bare rock (Figure 58). The converse is not true. Although these kinds of soils occur throughout BRCA on eroded slopes (Areas 10, 20, 30, 40, and 50 in Figure 59), only two areas (10 and 20) harbor PILO stands, so most rocky soils have other vegetation types or are barren. See Figure 64 for the distribution of soils.

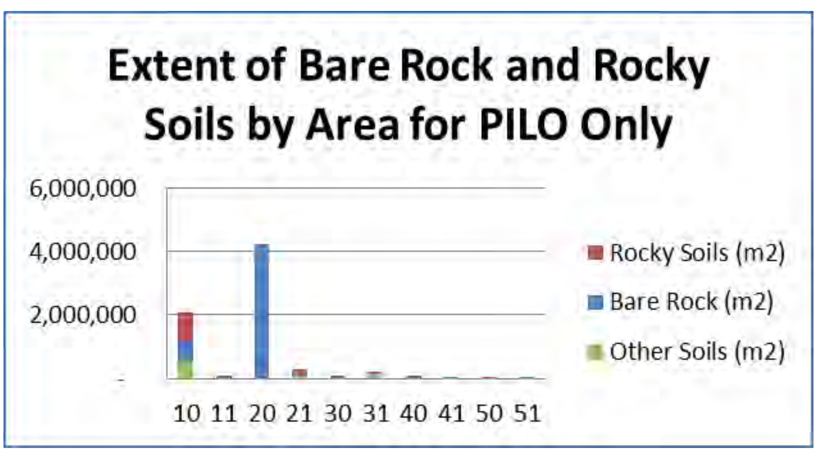


Figure 58. Extent for Bare Rock and Rocky Soils for PILO only by Area in BRCA

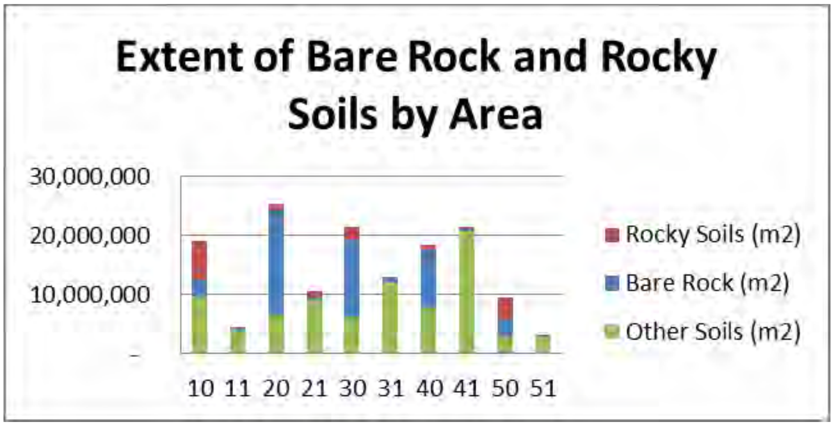


Figure 59. Extent for Bare Rock and Rocky Soils by Area in BRCA

Rocks of the Claron, Wahweap, and Straight Cliffs formations underlie most of BRCA (Figure 60). The Claron is composed of limy mud sediment interspersed with white limestone bands and sandy sediment. Layers have significant differences in resistance to weathering and erosion, but as a whole are quite erosive when exposed (Kiver and Harris, 1999). Steep, eroded slopes (Areas 30, 40, and 50) in the mid and southern part of BRCA are underlain primarily by the Wahweap and Straight Cliffs formations. These are dis-similar to the limy Claron formation, being sandstones with interbedded coal (Allen and Johnson, 2010). They are vegetated and do not underly the unvegetated badlands in the BRCA area (Figure 52, area 2 in Claron vs. Area 5 in Wahweap). A closeup of the differences is in Figure 56.

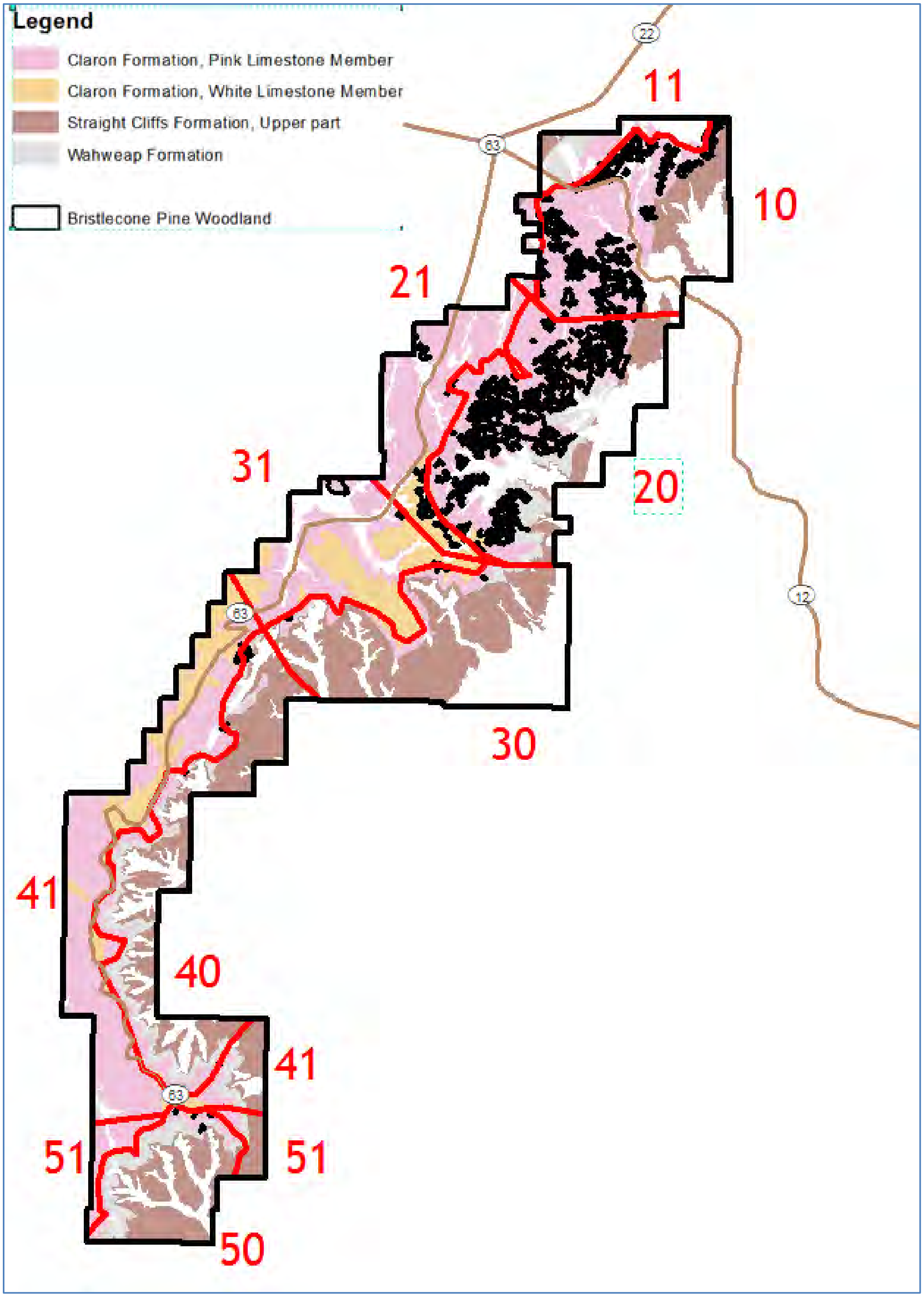


Figure 60. PILO Occurrence (black) and Geology in BRCA. Red Polygons are Ecological Areas

Though BRCA contains a variety of geologic units, almost all PILO occurs on material weathered from eroded exposures of the Claron formation (Figure 61). However, the reverse is not true, as it appears there is significant extent in each Area with Claron formation exposed not in PILO stands (Figure 60 and Figure 62). Comparing Figure 60 with Figure 64 suggests that though most PILO occurs on rocky soils or rock rubble weathered from the Claron Formation in Areas 10 and 20, again the reverse is not true. Those soils occur throughout the steeper Areas in other vegetation types. Comparing Figure 60 and Figure 54 above, the upper elevation range of the Claron formation in Areas 10 and 20 appears to exceed that of PILO stands and the lowest edge of the Claron coincides closely with the lowest range of PILO.

Completely barren areas in the eroded Claron Formation are only a small part of the Unit's total area (984 ha or 6.8%, Table 26 in Appendix), are at the highest edge of the badlands ("Claron Formation" in Figure 64) and have very steep average slopes (38% from Table 26 in Appendix). The remainder has at least some vegetative cover (Figure 63). The uneroded plateau areas (11, 21, 31, 41, and 51) underlain by the Claron do not have significant PILO (Table 14), other than that which occurs in other community types.

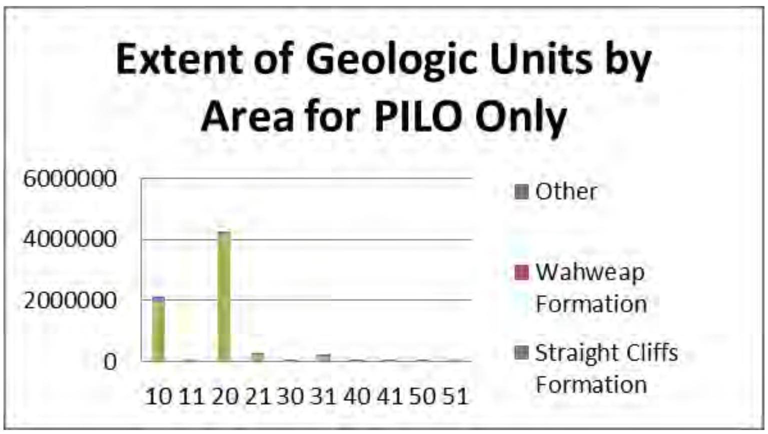


Figure 61. Extent of Geologic Units for PILO only by Area in BRCA (sq. m.)

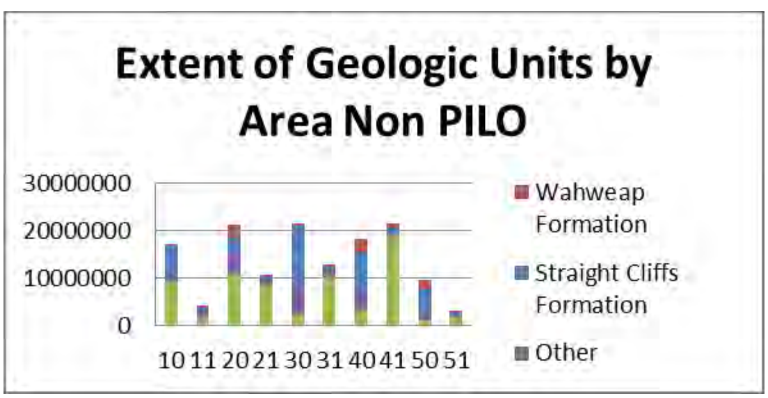


Figure 62. Extent of geologic Units by Area in BRCA not in PILO Stands (sq. m.)

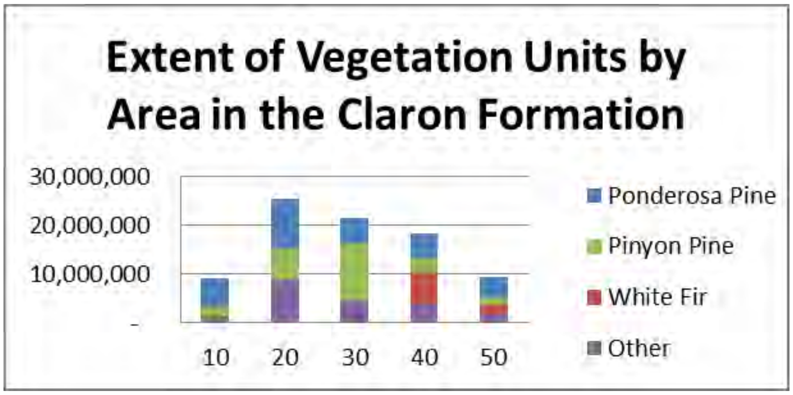


Figure 63. Area Extent of Vegetation units in Potential Physical Habitat for BRCA (m^2)

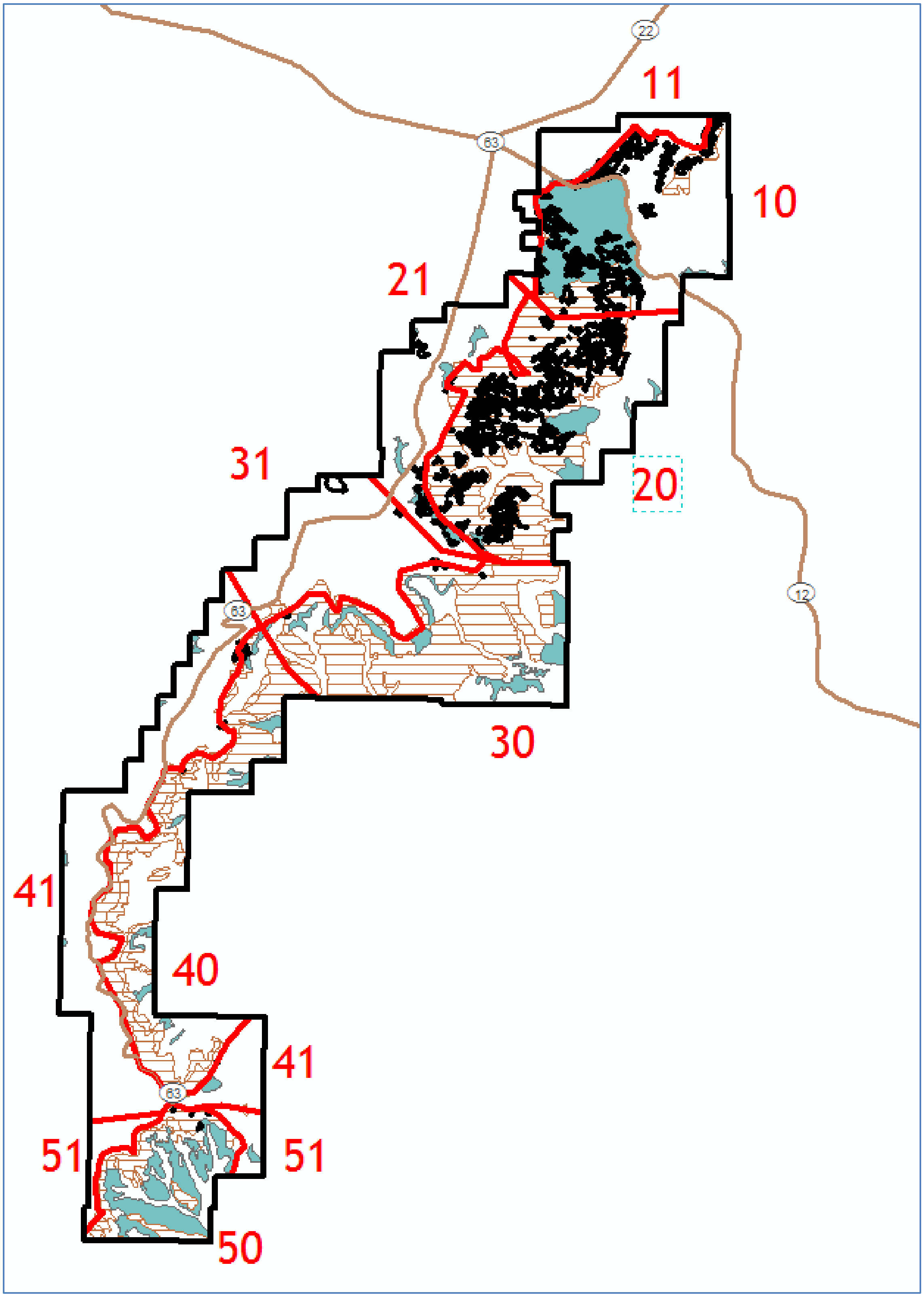


Figure 64. Soils and BRCA. Black is PILO. Blue are rocky soils, Brown hatch are rock rubble and bare rock. Red lines are Ecological Divisions (Areas).

In terms of aspect, Areas where PILO occur generally face eastward (Area 10) and east-south-eastward (Area 20) (Figure 52). Aspect is actually complex and widely-distributed for PILO stands (Figure 65), as well as for the Areas in general (Figure 66). Other than both being complex, no other pattern is apparent, between PILO stands between Areas or between Areas in general.

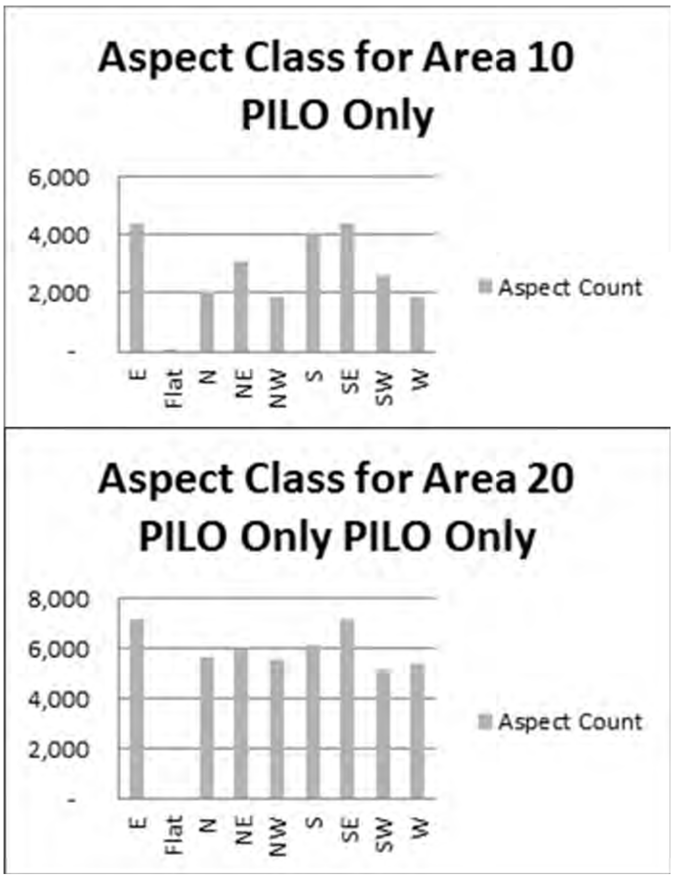


Figure 65. Aspect Class for PILO only for Areas 10 and 20 for BRCA (m^2)

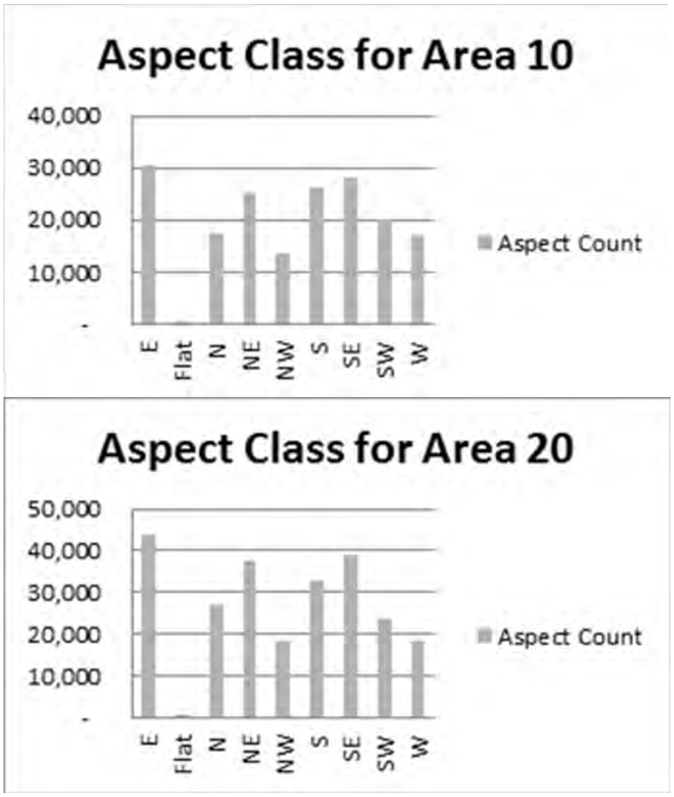


Figure 66. Aspect Class for Areas 10 and 20 for BRCA (m^2)

Slope distributions within Area 10 and 20 and for PILO within these Areas are almost identical (Table 16 and Table 17). Apparently there is no strong slope relationship for PILO stands grouped by Area other than that they occur throughout the slope range for an Area, and have an average slope similar to the Area landscape.

Table 16. Slope Characteristics by Area in BRCA

Area	Avg Slope (%)	Min Slope (%)	Max Slope (%)	StDev Slope
10	19.0	0.0	66.0	10.3
11	9.7	0.0	45.0	8.5
20	21.8	0.0	73.0	11.8
21	9.4	0.0	70.0	8.5
30	21.2	0.0	78.0	13.1
31	12.6	0.0	72.0	8.8
40	26.0	0.0	78.0	13.9
41	15.1	0.0	74.0	7.6
50	21.9	0.0	79.0	11.6
51	16.1	0.0	60.0	8.3

Table 17. Slope Characteristics by Area for PILO only in BRCA

Area	Avg Slope (%)	Min Slope (%)	Max Slope (%)	StDev Slope
10	21.7	0.0	66.0	10.2
11	22.6	0.0	44.0	9.6
20	22.3	0.0	68.0	10.6
21	13.4	0.0	46.0	7.6
30	25.6	0.0	66.0	14.0
31	9.8	0.0	52.0	7.2
40	36.8	3.0	76.0	14.5
41	36.8	5.0	69.0	11.2
50	31.7	2.0	75.0	12.3
51	24.9	17.0	36.0	4.6

Of the above-analyzed habitat factors (aspect, elevation, soils and geological materials, slope, and landform), the dominant features appear to be geology and landform. Rocky or rubble soil material weathered from the Claron formation seems to be a necessary but not sufficient factor for a PILO-dominated stand, at least in the BRCA environment. This is consistent with literature (Fryer, 2004). The badlands landforms (specifically Areas 10 and 20) in the northern part of the Park also contain almost all PILO stands. Therefore, the Claron formation in the badlands landform (Areas 10, 20, 30, 40, and 50) is considered the base physical habitat for PILO (Figure 60 above). The other steeply-sloping areas, though similar in landform and higher in elevation are probably not potential habitat under any climate-warming alternatives, since they have different soil materials.

Aspect relationships are complex, and there is no obvious trend, though a mix of eastern aspects is likely based on a visual review of the area (Figure 52 above). In terms of elevation PILO occurs at the base elevation of the Claron badlands habitat in Areas 10 and 20, but does not range to its highest elevation within the Claron-dominated part of those Areas.

Model Development for PILO in CEBR

The same steps were followed as in the model developed for BRCA, but because of its smaller size (only 2,483 ha), a union of spatial data was not created. However, individual spatial layers were used in the following discussion.

As in BRCA, the species is again a very small part of the Unit's surface cover (106 ha or 4.3%, Table 24 in Appendix). Its average elevation is much higher than in BRCA (2888 m vs. 2292m, Table 24 and Table 27 in Appendix), and aspects are generally western (Figure 67), as opposed to the easterly trending aspects of PILO in BRCA. Though they also occur almost entirely on the Claron Formation (Figure 68), average slope is much higher (30.7% vs. 21.4%, Table 25 and Table 26 in Appendix). Barren Claron is also a much higher proportion of CEBR (38.9% vs. 6.8%, Table 25 and Table 26 in Appendix).

Landforms occupied by PILO are much more variable (Figure 69) than in BRCA. They range from steep eroded slopes to ridgetops and benches. These kinds of landforms occur throughout the barren Claron landscape in CEBR at elevations similar to existing PILO stands.

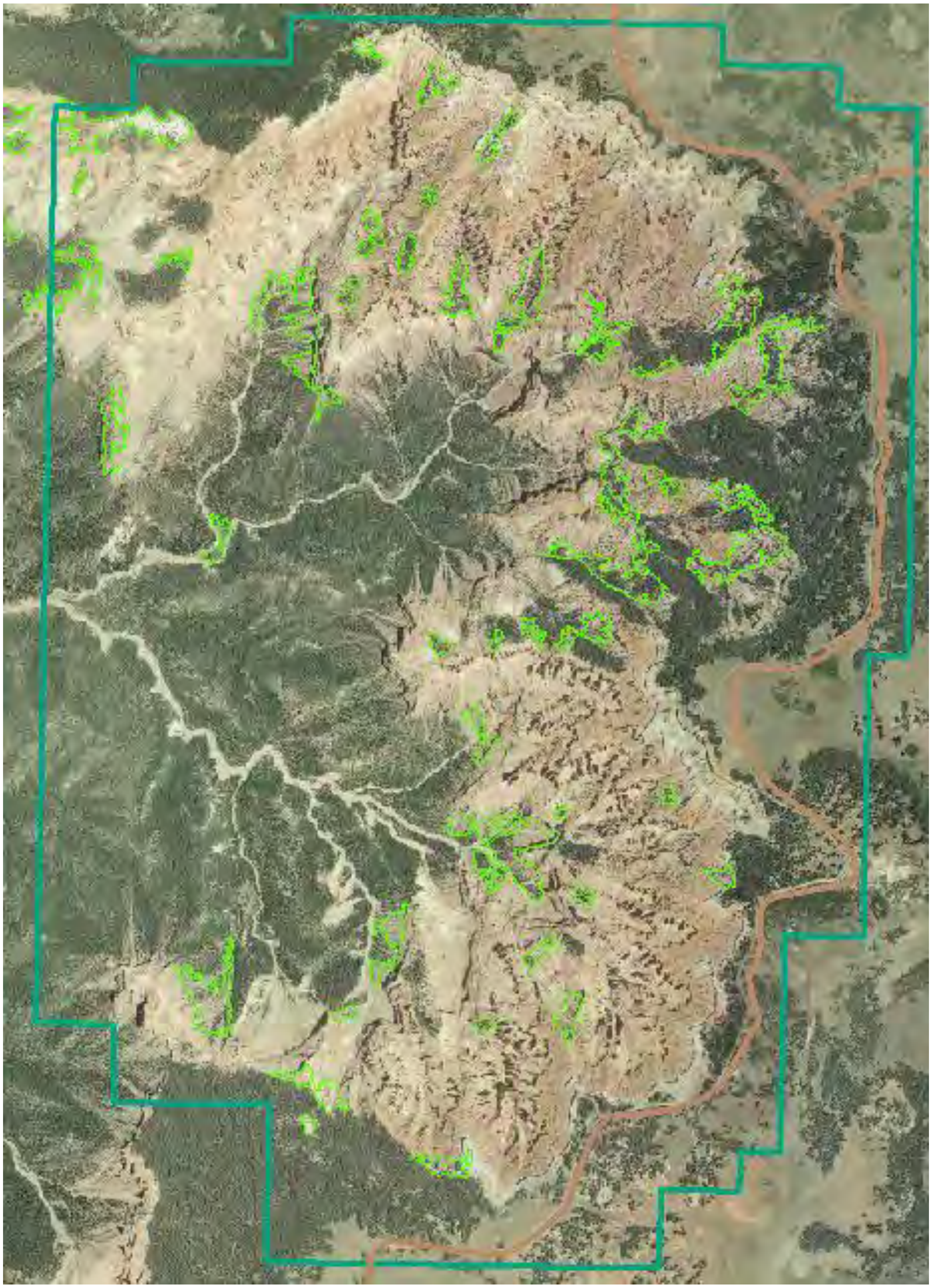


Figure 67. PILO in green and imagery of CEBR. North is Up.

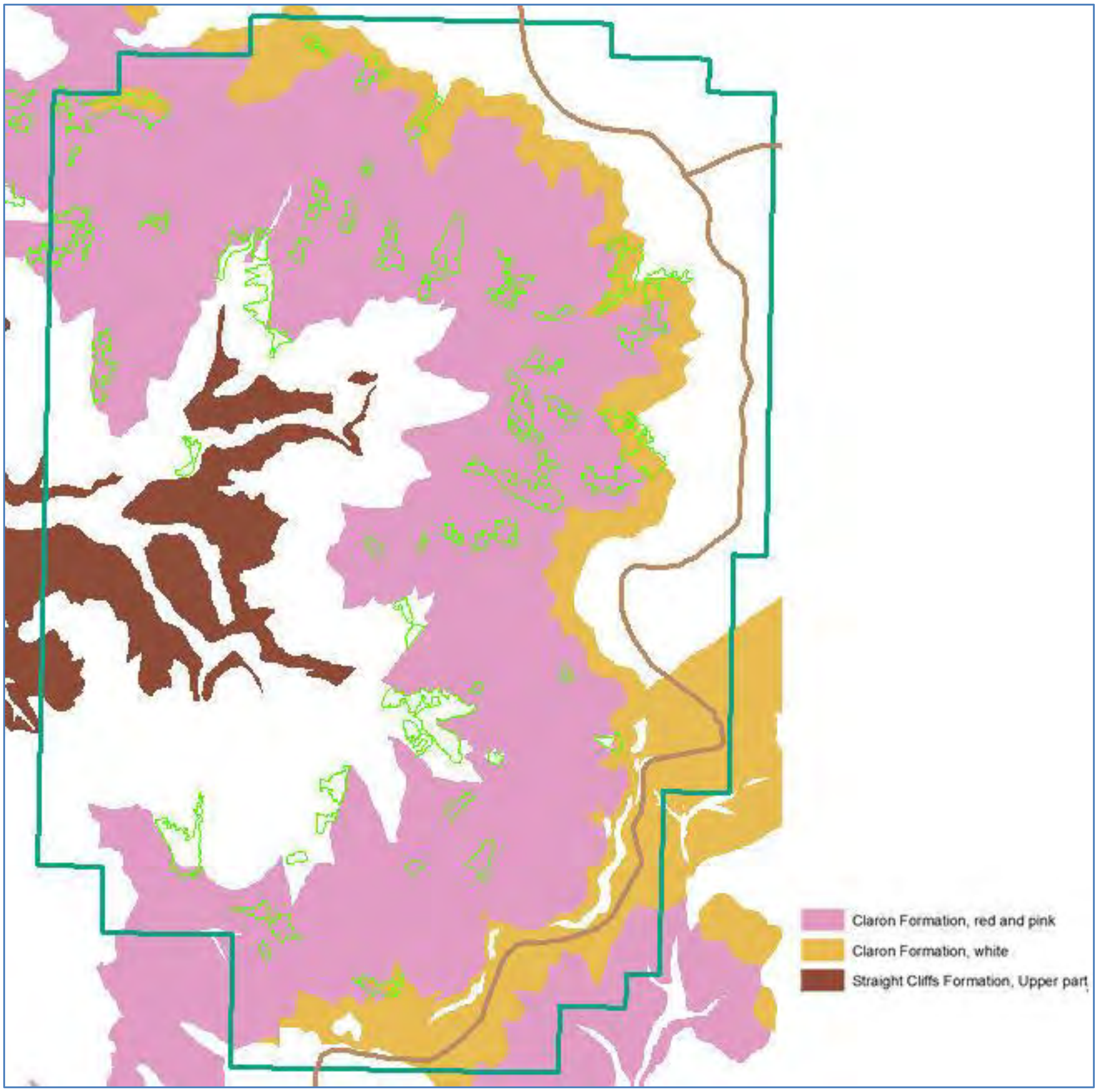


Figure 68. PILO Occurrence in green and Geology in CEBR. White are other formations, primarily sandstone and volcanics.

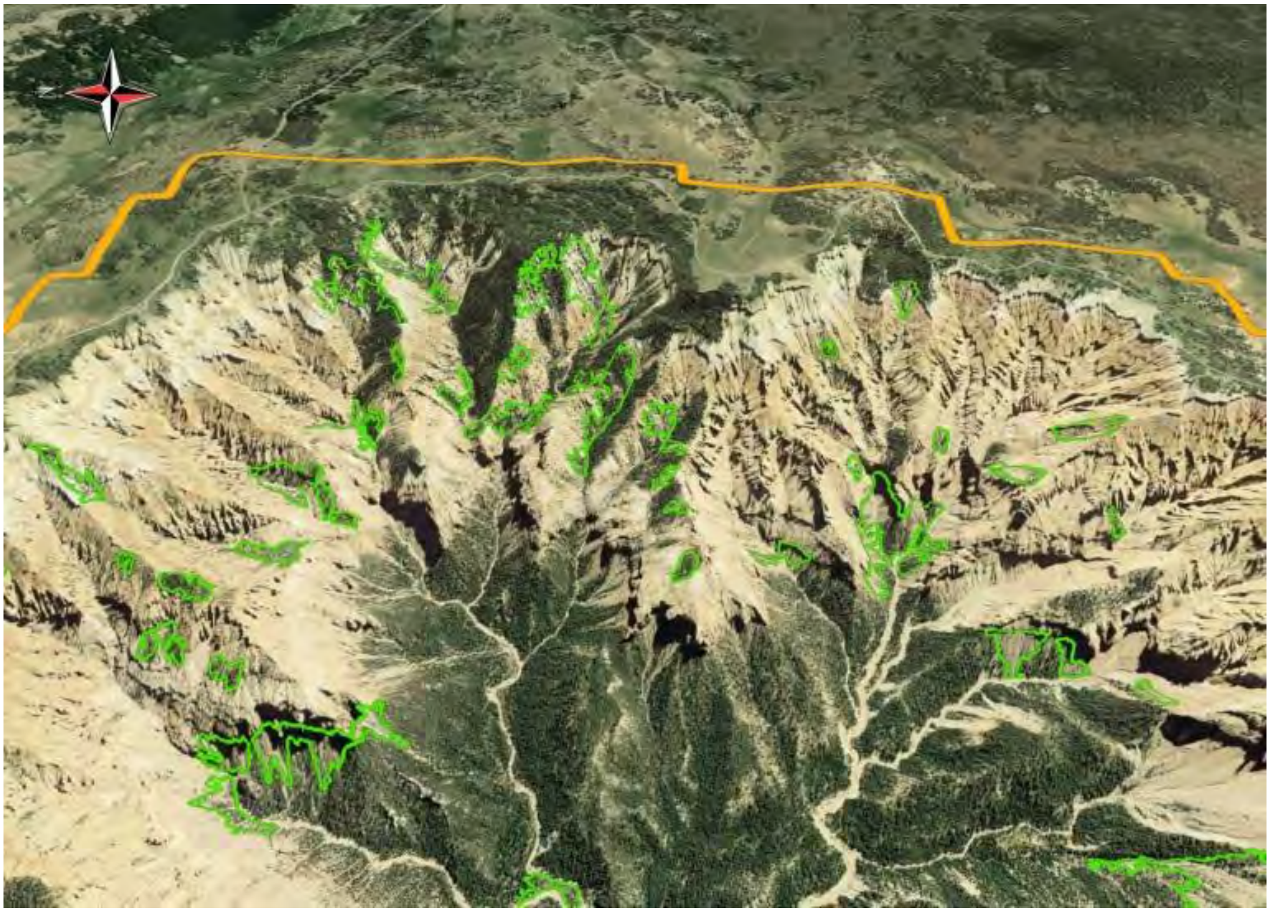


Figure 69. CEBR landscape looking towards the east, with PILO in green on both steep slopes and benches. CEBR boundary in yellowish red.

Stands consistently occur below spruce and fir forests and above Ponderosa pine woodlands (Figure 51 above). The elevation range of spruce and fir forests is 2715 m to 3247 m (Table 24 in Appendix), and that of Ponderosa pine woodlands is 2463 to 2955 m (ibid). PILO's range is consistently in between these ranges (2512 m to 3176 m; ibid), and occurs in between their habitats (Figure 51 above). The barren Claron formation has a range of 2645 to 3208 m (ibid.) and surrounds the PILO stands (Figure 70). PILO occurs below the highest elevation of the Claron.

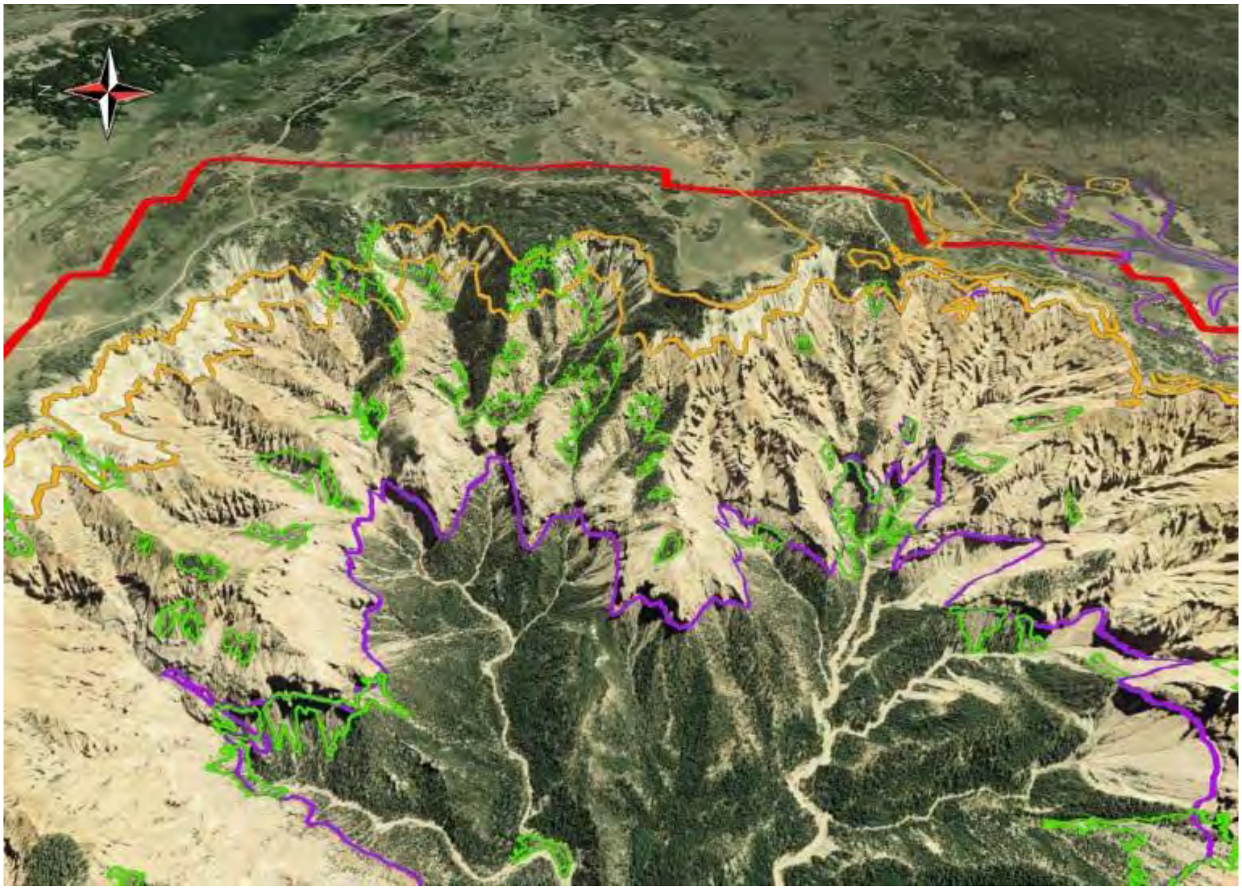


Figure 70. CEBR landscapes with Geology. Pink Claron above purple line, White Claron below top yellow line. CEBR boundary in Red.

Results

In BRCA It appears that habitat characteristics are more complex than can be characterized by the above parameters. BRCA apparently does not have suitable unoccupied potential habitat outside of Areas 10 and 20. However, there may still be within-Area potential. Area 20 in particular has the most PILO (Figure 60 above) and the lowest quality soils in the Claron Formation (Figure 60 and Figure 64). A further qualitative analysis in Area 20 habitat using contour lines indicates they prefer a convex, rounded landform within soil, slope, and aspect constraints. Example mapping of these landforms in Area 20 shows there is some potential habitat at higher elevations (green stars in Figure 111). They are almost all presently occupied by sparse ponderosa pine stands. Therefore, elevation range appears to be an overlay on physical habitat characteristics, since there are areas meeting all the previous requirements but are presently unoccupied by PILO.

These areas may be suitable as PILO habitat if climate warming either eliminates other vegetation types or encourages the kinds of harsh environmental conditions PILO prefers, since PILO occupies physical habitat to its base elevation to its upper limit. Since PILO is adapted for harsh environments, we conclude that it is not likely to rise from that base even if conditions become harsher as climate warms. However, it may utilize additional habitat if it becomes available within its range. Taking the example habitat locations from Figure 111 as points and comparing to a 10 resolution DEM, elevation range is from 2,223 to 2,313 m. With a maximum elevation change of 626 m from Table 3 above and the maximum existing stand at 2,540 m in Area 20, it appears these new locations could eventually be in the range of PILO, given the occupying Ponderosa pine vegetation types are removed through mountain pine beetle-caused mortality or wildfire, all of which are predicted to increase under climate warming. These same factors could also eliminate the significant number of PILO individuals in other plant communities, further restricting future habitat to that in Areas 10 and 20.

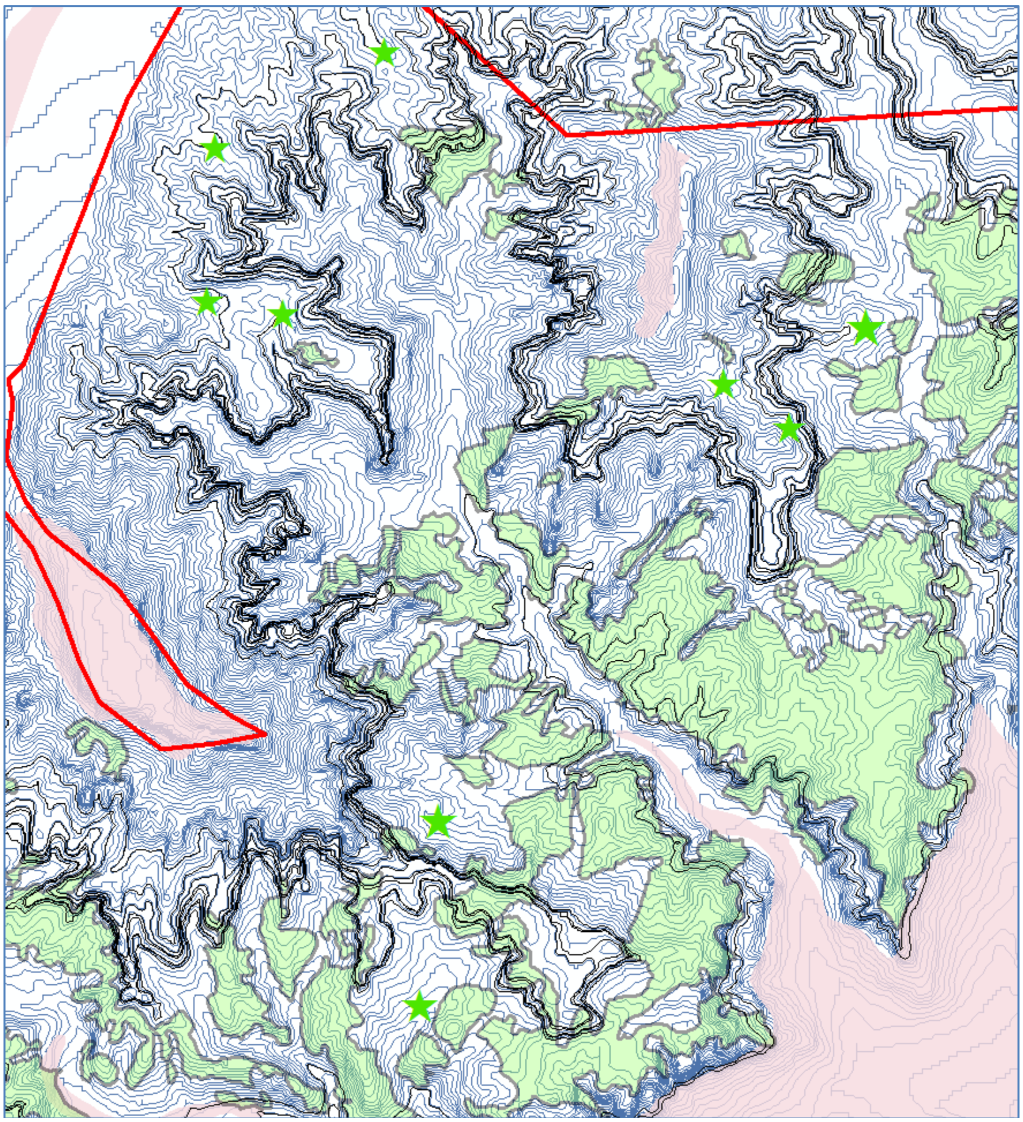


Figure 71. Potential Habitat in Area 20. Red polyline is an Area boundary. Green stars are potential landforms for PILO. Green is existing PILO. Pink is non-Claron rock.

In CEBR, it appears that as in BRCA, the eroded Claron Formation is a physical habitat base, and presence of PILO is dependent upon complex aspect-elevation relationships. However, in CEBR there is a much larger area of unoccupied potential habitat. Because of their distribution over a variety of landforms in the extensive Claron badlands, and the preponderance of those landforms in the PILO elevation range, it is likely that with climate-warming there is a potential habitat for PILO migration. Since the CEBR environment may be cold-limited (due to its high elevation), warming of lower slopes may allow other vegetation types to replace PILO, and allow PILO to occupy sites that are now too cold. The elevation of the rim above the badlands is 3,181 m, with PILO's minimum at 2,512 m. This gives a potential habitat range of 669 m. If climate warming drives PILO up the elevation gradient, it would still have potential physical habitat at the longest period and maximum MAT increase (an elevation increase of 626 m (Table 3 above)).

For both CEBR and BRCA the above analysis is exploratory. It does not directly account for factor inter-relationships, other than in the concept of Ecological Areas, which composite generalized aspect and slope. Analysis of other interactions would be useful, but is beyond the scope of this project.

Further analysis using just these data is also problematic. Mapping of all factors is subject to some degree of spatial correlation (e. g. where PILO could be mapped using landform as a dominant criterion, and landform is subsequently erroneously observed as a dominant factor in habitat determination). The density of field data points used in the NPS model (Figure 57 above) and the NPS standards used in their vegetation mapping program appear sufficient to preclude a large negative effect, and geological analysis used independent data generated by the USGS.

Finally, the distributions of elevation, slope, aspect, and geological types are based on mapped PILO stands, which are very open and generally include few individuals (Figure 56 above). Further exploration may require measuring those landscape parameters by individual, rather than by the more general delineation of low density habitat.

Shivwits Milk-Vetch

Additional Base Data

Note: Unless otherwise cited or observed in field review, this information was excerpted, quoted, and paraphrased from an unpublished summary provided by Cheryl Decker, Zion National Park Botanist in January, 2011.

Physiology and Ecology

The Shivwits Milk-vetch was discovered in 1976, but there was taxonomic confusion due to its close resemblance to both *Astragalus ampullarius* and *A. eremiticus*. It was not identified as a separate species until genetic testing was completed in 1997. Because historical distribution data are not available for the Shivwits Milk-vetch it is uncertain whether or not these populations have been reduced in size, nor whether some populations have been extirpated. It has been theorized, but not yet researched, that the species is a relatively new endemic which may have speciated relatively recently.

Because of its relatively new identification and even newer status as an endangered plant, Shivwits Milk-vetch does not have a complete life history assessment, although tracking of seedlings from 1995 indicates a lifespan of at least 9 years. Depending on temperatures and precipitation, emergence and flowering occurs between April and late May, and plants senesce by mid-June. The perennial rootstock allows Shivwits milk-vetch to survive dry years, and in a drought year plants may not emerge. This is a form of adaptation to desert conditions and allows the plant to conserve energy for reproductive effort when resources are available. Each *A. ampullarioides* plant is capable of bearing up to 45 flowers per flower stalk. Seeds are produced in small pods, and the plant dies back to its root crown after the flowering season. The fruit is a short, broad pod between 0.8 and 1.5 cm in length and 0.6 to 1.2 cm in width (U. S. Fish and Wildlife Service, 2001).

The species reproduces only via seed production and, therefore, pollination is critical to survival of the species. Primary pollinators of *A. ampullarioides* include the native bees *Anthophora coptognatha, A. dammersi, Anthophora* spp., *Eucera quadricincta, Bombus morrisoni, Hoplitis grnnellei, Osmia clarescens, O. marginata,* and *O. titusi,* as well as the nonnative honeybee *Apis mellifera*. Shivwits Milk-vetch relies solely on the production of seeds for reproduction, and pollination is thus highly linked to the survival of the species. Although flowers on plants can produce fruits through self-pollination, this strategy produces significantly fewer seeds per fruit than cross-pollination by insect visitors. Overall, pollinator visitation increases the total number of fruit and seed produced, resulting in more genetically diverse offspring.

Methods of seed dispersal have not been researched. Because of its size, it is unlikely that wind-dispersal is the primary method, though the fruit may be carried by birds. Water flow patterns, landscape erosion, and soil slumping likely contribute to the development of appropriate habitat sites and may transport seeds within sites.

The distribution of disjunct populations of (Figure 13 above) implies they are members of a metapopulation (a population of populations), but the gene flow between populations is not yet known. Successful species conservation and restoration requires adequate genetic variability to enable species to respond to changing environmental circumstances. Inbreeding depression is a primary concern. It is especially relevant to the conservation of rare species since individuals in small populations tend to be more inbred than those from larger populations.

Herbivory by native vertebrates have statistically significant effects on numbers of reproductive shoots and fruits produced by milk-vetch plants. The data suggest a 90 percent reduction in fruit production due to herbivory, and demonstrates the capacity of native herbivores to severely limit reproductive output in small, geographically constrained populations – particularly in dry years when reproductive output is already limited by resource availability. Based on field observations, the most likely herbivores responsible for milk-vetch herbivory were rabbits.

Habitat

Habitat is sparsely vegetated with an average 12% cover. Native forbs and grasses include *Calochortus flexuosus* (sego lily), *Dichelostemma pulchellum* (bluedicks), *Hilaria rigida* (galleta), and *Lotus humistratus* (hill lotus). Other native species occurring nearby include trees and perennial shrubs such as *Pinus edulis* (pinyon pine), *Gutierrezia microcephala* (broom snakeweed), *Colegyne ramosissima* (blackbrush), and *Atriplex canescens* (fourwing saltbush). A study in 2007 showed that red brome and cheatgrass are the two most abundant exotic species, as well as the two most abundant plants overall. Average relative cover of exotic plants (i.e., the exotic proportion of total live cover) was 58.6 percent--a considerably larger value than was sampled in 2003. The spread of aggressive non-native annuals is a concern not only because they seize limited resources from native plants at the same time that the Milk-vetch must utilize them, but also for their potential to create continuous dense fine fuels thereby increasing wild fire threats. This plant occurs in areas that, before brome species filled in available niches had many open spaces and did not carry fire well. It is unknown how this species will respond to the increased fire-cycle caused by cheatgrass invasion.

Small population sizes and limited geographic distributions threaten the species as does urban and suburban development, livestock grazing, off-road vehicle use, herbivory, and invasive exotic plants, especially those that produce fine fuels that promote burning in areas that historically have rarely burned.

Model Development and Application

Implications for the species' future have been extensively reviewed (Miller et. al., 2007). One of the objectives of that publication was to "use Geographic Information Systems (GIS) tools to prepare a predictive habitat model that can be used to guide future surveys and efforts to evaluate sites for reintroduction efforts". The recommended modeling method was the development of a set of spatial intersections, rather than a statistical analysis. This was partly due to the small number of milk-vetch occurrences, lack of site-specific plant-environmental data, and lack of site-specific climatological data, but also the relatively-strong association with spatially-well defined geological and landscape characteristics.

Recently, an effort has begun to model the distribution of milk-vetch. Miller and Mann (draft 2010) have made a preliminary effort to make a spatial model of its habitat. Field data were used to establish draft criteria for habitat, including geologic substrate, elevation, slope, distance from roads, land ownership, and distance from known populations. Field data were collected in 2006 with one additional point in 2009. A spatial model was recommended and trials run. An additional point was collected in April of 2011. Though this was west of ZION, it was on the Chinle Formation at an elevation of 1392 m (based on the GPS point and the 5 m DEM), and at a slope of less than 5% (from the USGS Topographic map).

Miller and Mann (draft 2010) recommended a spatial model using the intersection of six habitat variables to spatially define milk-vetch occurrence. The low population and low sample numbers made it impractical to create a more robust, statistical model. It appears the three physical habitat variables (geology, elevation, and slope) are relatively strong in their individual relationships to milk-vetch site data. The three conservation variables (land ownership, distance from roads, and distance from other populations) are not directly tied to the habitat, but were used to better understand potential relationships to conservation efforts.

These last three variables are not used as criteria in the present application. Land ownership is important to the larger population of milk-vetch, but since only National Park Service lands are considered in the present research, it is considered not relevant to the model. Distance from roads is also undoubtedly a factor in the larger population, but again is not so important in the context of ZION. However, since this variable is important to long term viability, because of potential for anthropogenic disturbance, it is included only as a model output. Predicted habitat under climatic scenarios may have more or less quality, depending on that potential. Distance from other milk-vetch populations may also influence species distribution, but since this model's purpose is to predict potential, not actual habitat, it is not considered here.

The three physical habitat variables are slightly modified from Miller and Mann (draft 2010). Since they indicate geology has the strongest relationship, a buffered version of the Chinle formation (Petrified Forest Member) is mapped in their publication, and as the blue polygons in Figure 72. However, subsequent to their draft report, additional geologic map data have been obtained for the Kanab and Cedar City Quadrangles (Rowley et. al., 2008 and Biek et. al, 2010), and additional Chinle exposures indicated in those recent efforts are mapped here, shown in red. These new buffered data were clipped to ZION boundaries, and include only a small additional area near the northern and southern boundaries (Figure 73).

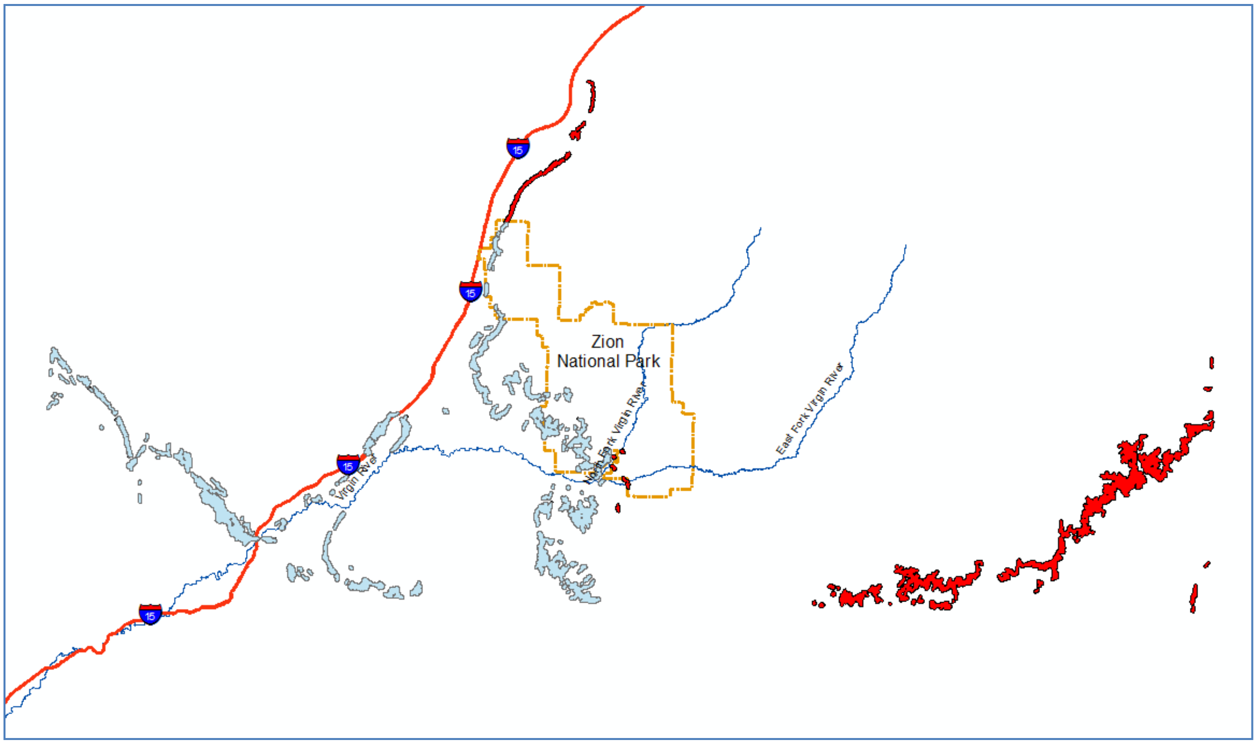


Figure 72. Extent and Distribution of the Chinle Formation (Petrified Forest Member) in the study area in ZION. Blue polygons used in Miller (draft 2010). Red polygons are from additional subsequent mapping (Rowley et. al., 2008 and Biek et. al, 2010)

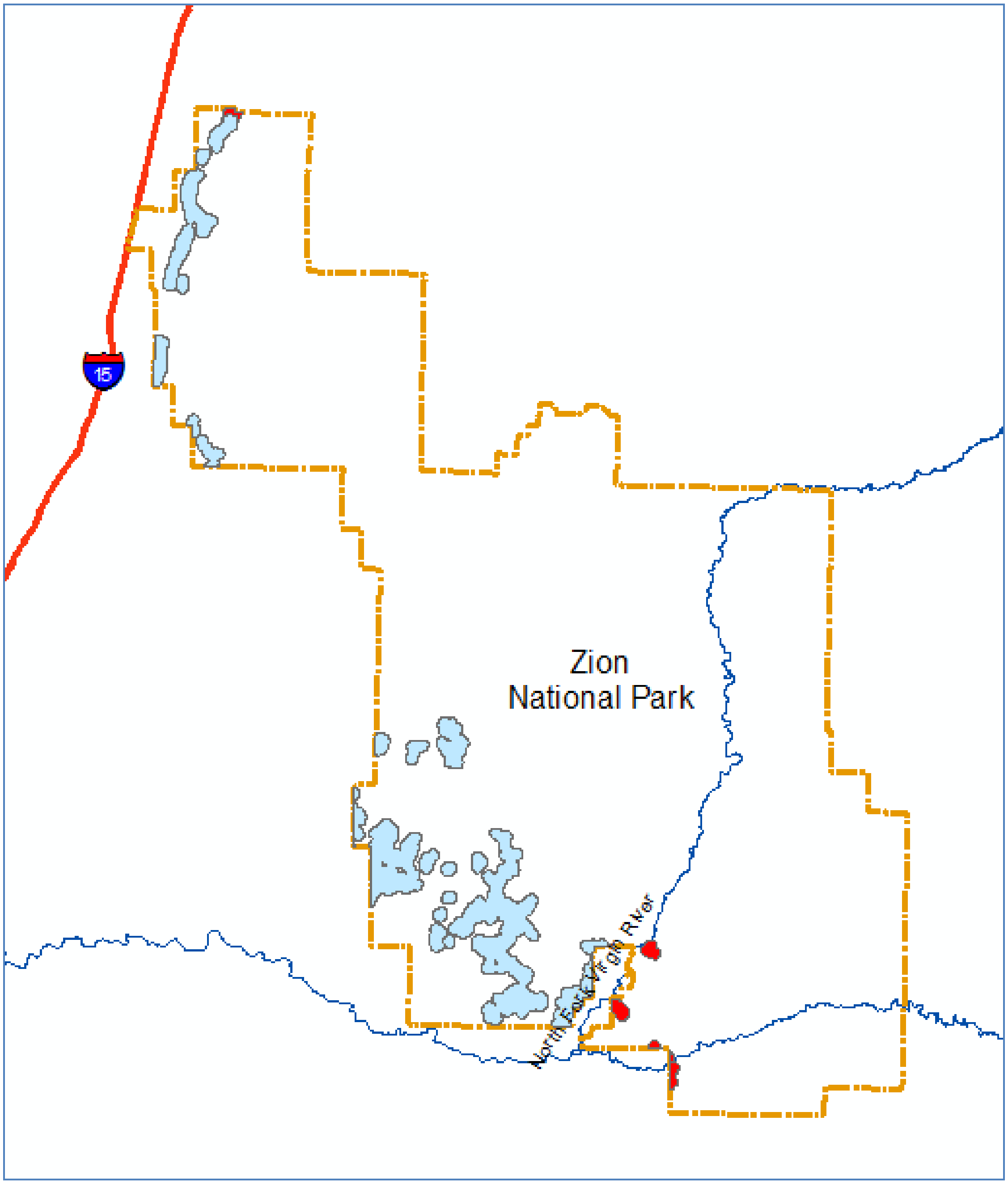


Figure 73. The Chinle Formation Clipped to ZION boundary

Elevation is the second important variable. The Miller and Mann range for existing populations is 600 to 1700 m, which is used in the present model without modification. However since elevation is used as a proxy for climate change in our model, and their 100 m elevation bands used are not of fine enough detail for this project, the DEM (digital elevation model) used in their study was re-processed for a 1 m vertical increment, which being smaller than the normal vertical resolution, avoids loss of precision. This increases the complexity of the model, but is limited to the spatial extent of the intersection of the three variables so is computationally reasonable.

Slope is another important factor discussed in Miller's draft. Only three slope classes were used (0-10, 10-45, and >45%). However Miller’s field data and a field review in 2011 indicated slopes less than 30% are dominant. Therefore only slopes less than 30% are used for this model. Because some additional potential habitat was added via the geology layers, the 10 m DEM was used to create a new slope grid clipped to the geology layer. The polygon version of this raster was queried for slopes less than 30%.

The conservation variable "Distance to Roads" was modified to include the entire Chinle geology layer. The data from which the variable was calculated in Miller and Mann was at least 10 years old, so a version from 2009 was used, provided by ZION staff. This was clipped to the geology layer and processed with a Euclidian distance function, then reclassified and converted to polygons.

The resulting four spatial layers (Geology, Elevation, Slope, and Distance to Roads) were intersected to form the base spatial model for present potential habitat. This final feature class (spatial layer) is similar to creating a query for the parameters of elevation (600-1700 m), slope (less than or equal to 30%) on the clipped geology layer (similar to Miller and Mann). This results in the present potential habitat for Milk-vetch in ZION. Distance from roads is an attribute of the resulting feature class.

Results

Under present conditions, total potential Milk-vetch habitat equals 1,669 ha (Figure 74), or 47% of a total of 3,487 ha of the buffered Chinle formation in ZION (Figure 73). Present habitat is 87% of the 1,913 ha of physiographic habitat (composed of buffered Chinle and slope constraints without elevation). Comparing this figure to Figure 73 (the base geological habitat), most of the excluded area is in the northern portion of ZION where elevation is higher than allowed by model criteria. Exclusions for slope were well distributed throughout the area. For context, this is approximately 81% of the entire 2,055 ha predicted by querying Miller’s original model and criteria for ZION (Miller, draft 2010) mostly due to the reduction of maximum allowed slope and possibly the finer resolution of elevation.

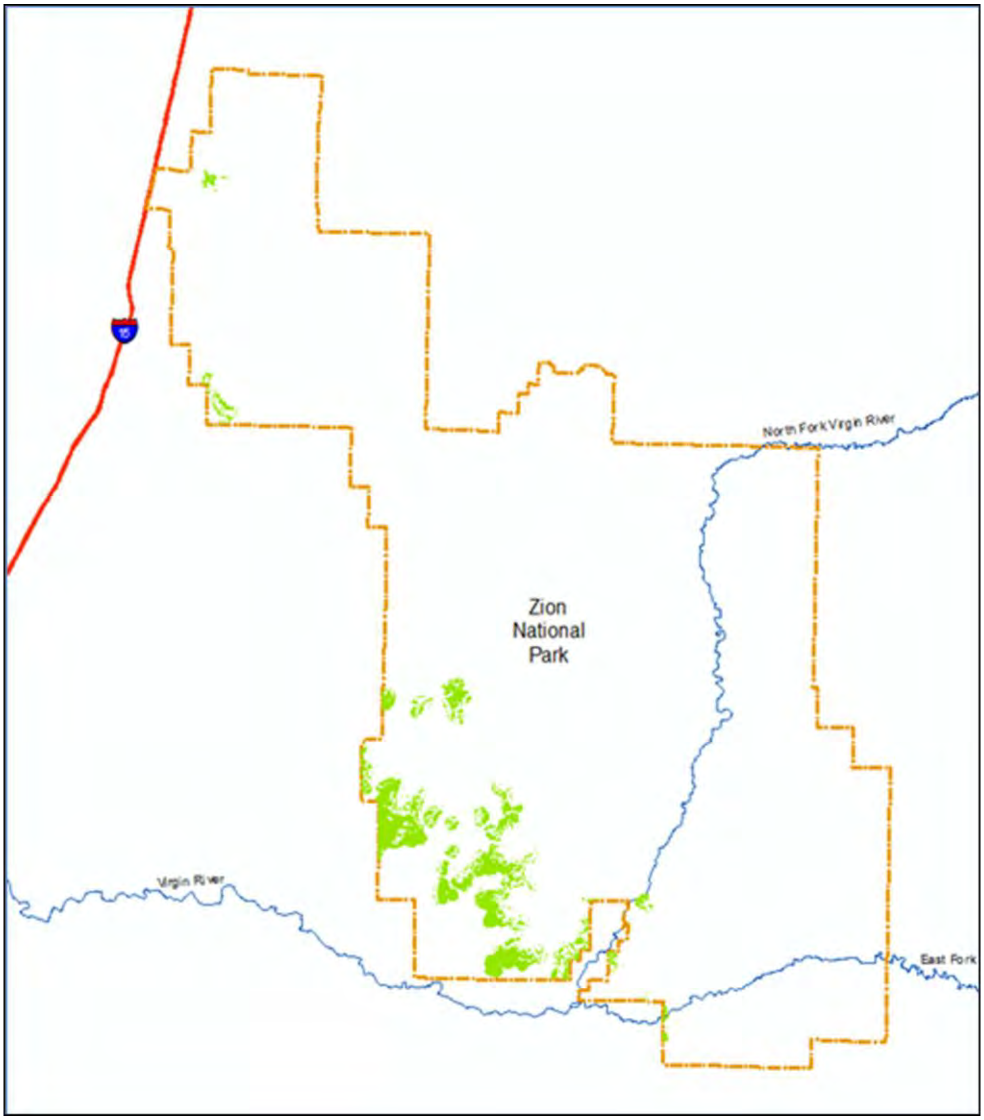


Figure 74. Potential Milk-vetch Habitat under Present Conditions in ZION

As in all four models in this study, elevation is used as a proxy for climatic change effects. In this analysis, climate warming is expected to raise the upper boundary of habitat in ZION. The lower boundary may also shift upward as climate becomes too warm for the species. This is based on the assumption that elevation is the most important factor in determining species range. This may not be the case, but is used here.

Based on sampling, the elevation range of Shivwits Milk-vetch throughout its geographic range is 962 m to 1,422 m (Miller, 2010 draft). In ZION, its observed range is 1,255 m to 1,422 m, the upper limits of its range. Using elevation as a proxy for annual mean temperatures, it follows that if the physiographic habitat (based on geology and slope) occurs in areas now too cool for inclusion in potential habitat, then this habitat may become available if temperatures increase. The opposite is not true in all cases. As long as the lower edge of the observed elevation range is below ZION's lower elevation limits (1,115 m, Table 1 above) and also below the lowest elevation (1,175 m) in the physiographic habitat feature class, as well as the present potential habitat (1,175 m) (Table 18), no upward shift in the lower habitat boundary will occur in ZION.

Four alternative spatial layers were created via a query of the physiographic habitat feature class with an elevation range determined by Table 3 above. Both lower and upper elevation limits for each alternative were raised. The rise in effective elevation is for 50 and 100 year periods and for the range of predicted mean annual temperature increases.

In Table 18, Predicted Elevation Range for the Entire Population refers to the entire range of the species known to date. Predicted Elevation Range in ZION refers to model results clipped to ZION boundaries. Mean Elevation and Habitat Quality are averages for the feature class.

In terms of physiographic habitat, a wide elevation range is available to the species in ZION (Alternative 0 in Table 18). For actual potential habitat, as climate warms over longer periods, potential habitat increases with both extremes of predicted MAT increase (up to 15% over present habitat in Alternative D). However, at the highest predicted temperatures, habitat decreases (Alternative E). This is because in Alternatives A-D both the lower and upper limits are within the maximum physiographic habitat (from Alternative 0) and in Alternative E warming exceeds the highest elevation available, as well as reducing habitat at lower elevations.

Table 18. Habitat Extent for Climate Alternatives for Shivwits Milk-vetch in ZION

Alternative Label	Alternative	Predicted Elevation Range (m) for Entire Population	Predicted Elevation Range (m)in ZION	Extent (ha)	Change in Extent over Present (ha) (%)	Habitat Quality (Index of Average Distance from roads)	Minimum Elevation (m)	Maximum Elevation (m)	Mean Elevation (m)
0	Physiographic Habitat only	N/A	1175-2096	1913	N/A	5.07	1175	2096	1421
A	Present Potential Habitat	600 - 1700	1175 - 1700 (no change)	1669	0 (0)	5.07	1175	1700	1347
B	Minimum Temp. Change, 50 years, Increase Upper Bound Only	845 - 1945	1175 - 1945	1872	203 (12)	5.10	1175	1945	1407
C	Maximum Temp. Change, 50 years, Increase Upper Bound Only	981 - 2081	1175 - 2081	1913	244 (15)	5.07	1175	2081	1421
D	Minimum Temp. Change, 100 years, Increase Upper Bound Only	1008 - 2108	1175 - 2096	1914	245 (15)	5.07	1175	2096	1421

E	Maximum Temp. Change, 100 years, Increase Both Lower and Upper Bound	1226 - 2636	1226 - 2096	1840	171 (10)	5.18	1226	2096	1429

Figure 75 shows the present potential habitat (Alternative A in Table 18) as predicted by this model. ZION staff provided a current a Fish and Wildlife Service (FWS) designated "critical habitat" that overlays in the southwestern part of the Unit. The Critical Area includes the current ZION field-verified populations (Figure 13), and includes with the FWS Critical Area (Figure 75). It appears, however, that there is considerably more potential habitat in ZION than previously thought. Local ZION biologists are planning further field surveys in other potential habitat areas.

Changes in potential habitat under different Alternatives are shown in Figure 76 for northern ZION, and Figure 77 for the southern portion. Under climate alternatives, northern ZION is likely to be a more favorable habitat for milk-vetch, while southern ZION (with the FWS "critical habitat" and most of the field study plots) may become less desirable.

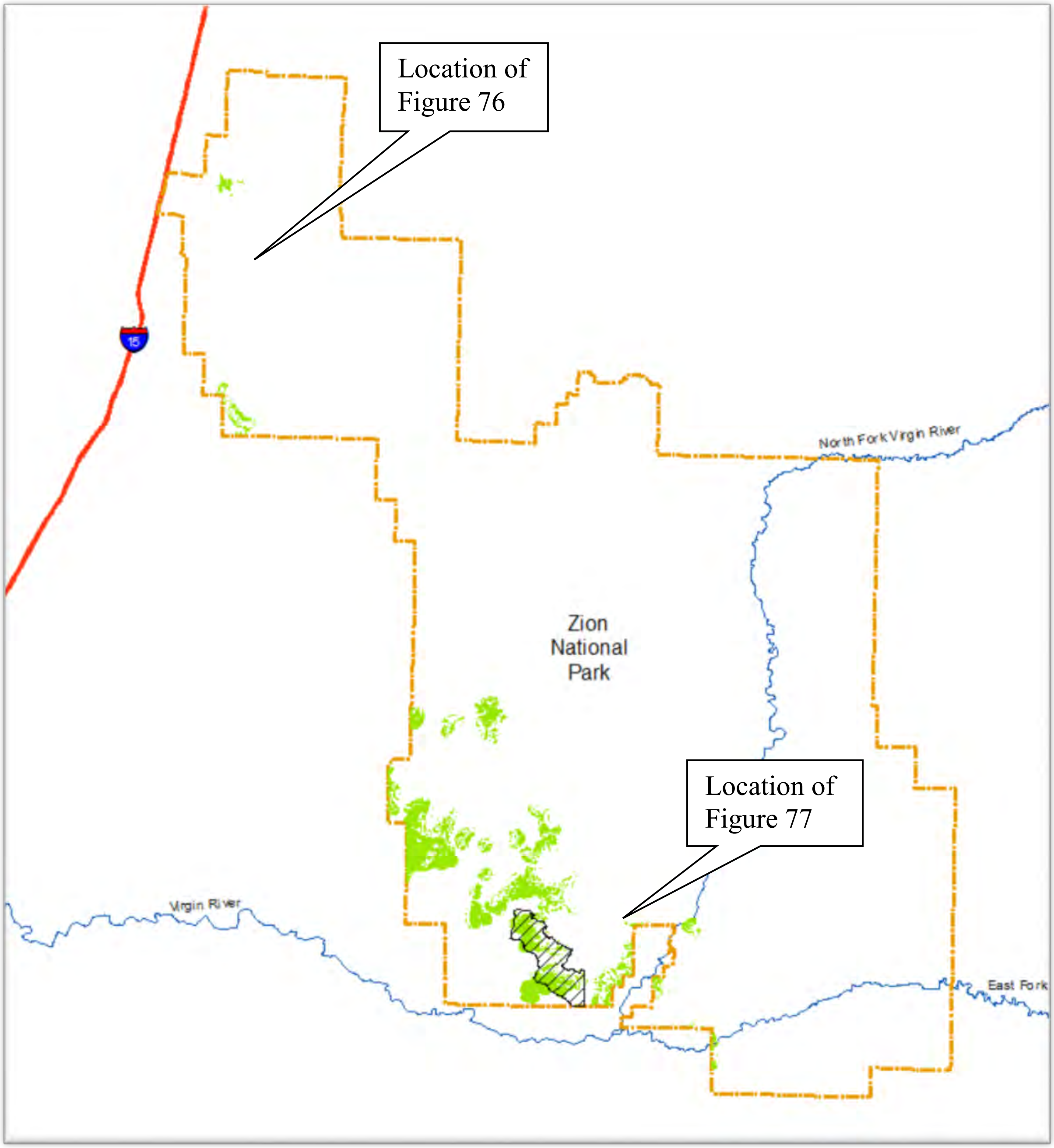


Figure 75. Potential Milk-vetch Habitat under Present Conditions in ZION (in green). Location of Fish and Wildlife Service Critical Habitat is cross-hatched.

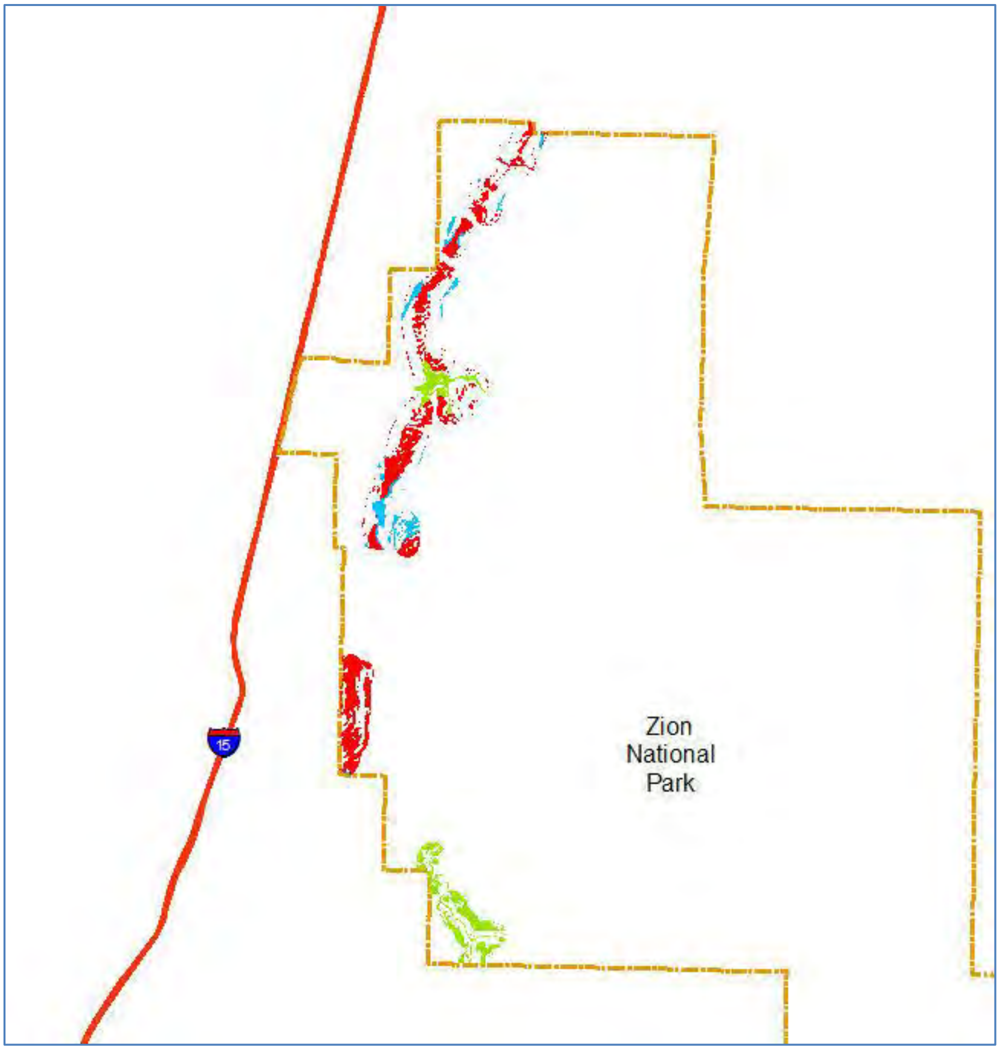


Figure 76. Predicted Change in Milk-vetch Habitat - Northern Limit (Green is present predicted habitat, red is increase in Alternative B, and blue is additional increase in Alternative C, D, and E.)

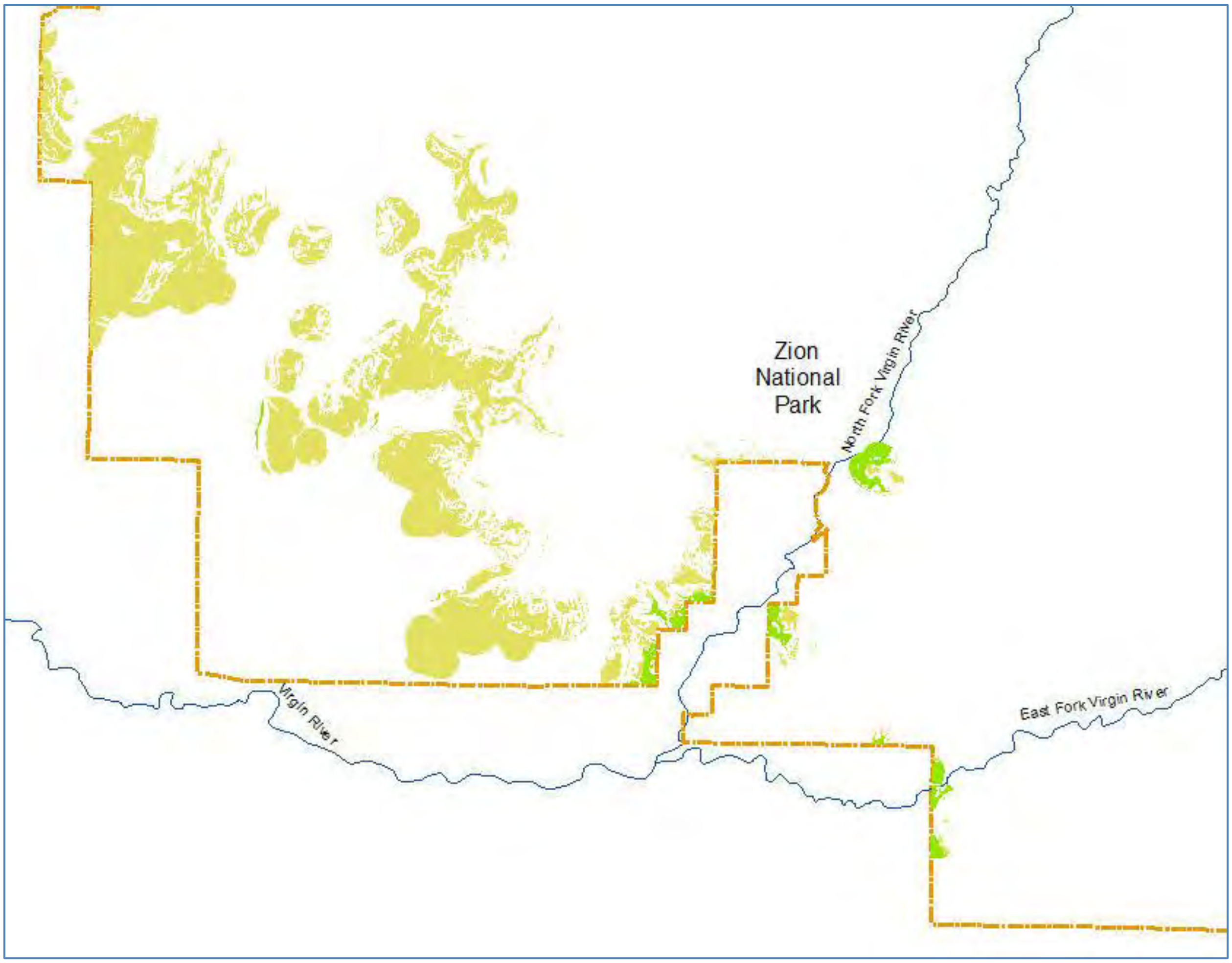


Figure 77. Predicted Change in Milk-vetch Habitat - Southern Limit (Green is present predicted habitat lost in Alternative E (yellow))

Summary and Conclusions

Validity of Models

The climate models were verified by literature, expert consultation, and use of localized data. The species distribution models (SDM's) were validated primarily by local field review and for published models, statistics generated in their development.

Climate Change Proxies

The climate change model consists of three steps. The first develops the use of Mean Annual Temperature (MAT) changes as a proxy for the environmental change associated with global warming. The future MAT was modeled using IPCC scenarios for CO2 emissions in Gonzalez, et. al. (2010)

The second step consists of associating temperature change with an "effective" elevation change. This was accomplished through the use of lapse rates. The model was derived using weather station data to develop a local application. It was validated by comparison with other published lapse rates. Though the locally derived lapse rates appear reasonable they are higher than most and perhaps more importantly, there are many assumptions in its application. For example, see the sensitivity analyses of the summer vs. annual lapse rates.

The third step uses elevation change as MAT change in the habitat models. All the species response models incorporate elevation as a variable. Though there are significant problems in its direct application, it was used because of its consistent and measurable nature.

Summary of Species Distribution Models and Validation

Model characteristics for each species are summarized in Table 19. For the American pika, the mapping of physical habitat was critical to apply the chosen SDM model to the Units. Remote sensing and existing spatial data were used for this, and required ground truth for validation. This was accomplished through field review. Unit-generated field data support the model results. The model itself was used without modification since its application required very minor extrapolation from its spatial and elevational limits. The model has an associated statistical reliability, and this was used in judging the reliability of results. Climate effects were validated by comparing habitat locations with climate change-related predictions.

Validation for the desert tortoise model was based on the published model which incorporates statistical validation. The model itself was used without modification since its application required no extrapolation from its geographical and elevational limits. Field review data and Unit-generated data confirmed presence of populations within predicted habitat. Climate change effects were validated by Unit-generated monitoring, which suggest increasing use in areas predicted as important future habitat. Finally, the use of annual vegetation productivity in the model was validated using an alternate method.

The Great Basin bristlecone pine model was generated specifically for this report from an analysis of geographic and physiologic data. It was validated by field review to verify geographic accuracy. Only Unit-approved base spatial data were used. The Shivwits milk-vetch model was generated specifically for this project using a GIS-based analysis as recommended by literature from research professionals in the field. Spatial habitat parameters were inferred from published habitat parameters. This, additional spatial data, and additional observations both by the Unit monitoring programs and field review were used to establish spatial habitat limits.

Table 19. Summary of Characteristics for Each Species Distribution Model

Species Distribution Models					
Species	Presence in Study Units	Range	Status	Model	Relative Model Uncertainty
American pika	ZION, CEBR	Western U.S.	Under review for listing under Endangered Species Act	Published statistical model; Spatial model developed locally; lower boundary shifts up.	Low: Only limited extrapolation needed
Desert tortoise	ZION	Southwestern U.S	Listed as Threatened under Endangered Species Act	Local application of a published, statistical, probability-based spatial model; boundary does not shift	Low: Relatively coarse resolution; no extrapolation needed
Great Basin bristlecone pine	CEBR, BRCA	Southwestern U.S.	Considered at risk	Physiology extrapolated to analysis of local spatial features; upper boundary shifts up.	High: Exploratory study
Shivwits milk-vetch	ZION	Southwestern Utah	Listed as Endangered under Endangered Species Act	Spatial Intersection using existing data; rule-based; both lower and upper boundary shift up.	High: No formal statistical measures

Application in Vulnerability Analysis

The publication "Scanning the Conservation Horizon" discusses at some length the terms Sensitivity, Exposure, and Adaptive Capacity. They are used to define components of vulnerability analysis. The term "Potential Impact" is an additional component, only indirectly addressed in that publication. But this is where the "rubber meets the road". It refers to the application of models to "peer" into the future. In our study, we emphasize those impacts. Sensitivity and Adaptive Capacity for all our candidate species were pre-defined using life history characteristics from the literature. Exposure is constant, set for all species by the climate alternatives. It is rated "Moderate" because the estimates of change are conservative when compared to recent climatic data and our use of conservative lapse rates.

Potential impacts incorporate the modeled response to climate warming. Those impacts have multiple causes that may relate to local Park habitat or to the species itself. Park management decisions depend on both internal and external pressures, Park resources, and NPS priorities, but the listed impacts should be considered by managers involved with managing the species. The following ratings use the results of this project to estimate the impacts to the local Park habitat, the species, and Park management. The results of this modeling project (including Table 19 above) and general knowledge of NPS management concerns are used to estimate these impacts. They do not include management responses, since those are in the realm of Scenario Planning.

American Pika

Local data shows American pika are likely present in CEBR, and at least recently in ZION. However, the local application of Dr. Beever's research indicates that, though there is probably physical habitat widely available in ZION, the only area likely to have long-term potential is the limited habitat in CEBR. Though physically the Lava Point habitats appear to have mitigative landscape features, they appear to have high potential for extirpation

Because of its low tolerance to temperature change and specific talus habitat requirements pika is rated "High" in Sensitivity (Table 20). Its adaptive capacity is rated "Low" because of its low migratory potential. Though there is significant physical habitat (talus) within Park boundaries, potential impacts to its habitat in ZION and CEBR are "High" and negative because of its high extirpation potential and uncertain presence in some habitats.

Potential impacts to the species are rated "Low" because of its wide distribution and unlisted status. However potential impacts to Park management are "Moderate". All present species are important to the preservation of Park ecosystems, and this species appears at great risk. However, its loss would not highly impact the species distribution as a whole, unless there is some unique genetic characteristics. The population in CEBR in particular may require more intensive management and research on its stability.

Table 20. Summary of Species Vulnerability

Vulnerability using Annual Lapse Rates						
Components				Potential Impacts		
Species	Sensitivity	Exposure	Adaptive Capacity	To Park Habitat	To the Species	To Park Management
American pika	High	Moderate	Low	High (-)	Low	Moderate
Desert tortoise	Moderate	Moderate	Moderate	High (+)	Moderate	High
Great Basin bristlecone pine	Moderate	Moderate	Low	Low (0)	Moderate	Moderate to High
Shivwits milk-vetch	High	Moderate	Low	Low (+)	High (+)	High

Desert Tortoise

Local data show desert tortoise are present in southwestern ZION and are probably a reproducing population. Application of Dr. Nussear's model shows a significant increase in habitat quality under climate warming, both inside and near ZION. This occurs primarily in the first 20 years, and then levels off. Within that habitat, the southern corner near Springdale appears to have the largest increase. Other parts of ZION having physical habitat have little future potential in the next 100 years.

The species' is dependent on certain vegetation types, but because of its physiology and behavioral adaptations to high temperatures it is rated "Moderate" in Sensitivity. Though slow moving and slow growing, the species is capable of migration, and is therefore rated "Moderate" in its ability to adapt to warming temperatures.

Potential impacts are rated "High" and positive in terms of Park habitat. Not only is there significant potential physical habitat (in terms of available landscapes), but its quality is significantly improving. Impacts to the species are "Moderate", because though the Park is only a small part of its existing range, its environment is protected from threats common on other private and public lands. Potential impacts to Park management are "High" because of the species listing as "Threatened" and high public profile. Also ZION monitoring data, though relatively short-term, validates its presence, and modeling results show a growing habitat potential.

Great Basin bristlecone pine

This species, *Pinus longevia* (PILO),is widespread in both CEBR and BRCA, though it often occurs in very low densities in mapped areas. PILO appears to have a different kind of ecological niche in each Unit.

In BRCA there are strong spatial relationships to geological type, soils, and landform. The poor relationship to aspect or slope is probably a result of low spatial data resolution. It appears PILO occupies some of the warmest and driest areas starting at the base elevation of the physical habitat. Within this habitat local landforms also occur at higher elevations, but are presently populated by other species. These areas may have potential for PILO influx if the occupying species are eliminated through climate warming effects (primarily wildfire and insect outbreaks) and conditions become harsher.

CEBR populations have the same physical habitat parameters, but occupy a variety of local landforms scattered throughout the elevation range. Because of its higher elevation and aspect these stands are probably colder and drier than other sites in CEBR. Similar landforms within the elevation range are presently barren and may be candidates for colonization under warming alternatives, since conditions will probably moderate. However, model uncertainty for both Units is high (Table 19 above), so these results are cautionary.

Potential impacts to Park habitat are rated "Low". Though climate warming may affect the species viability in present environments there appears to be adequate "refugia" that are either presently occupied by other vulnerable species or are barren now. Impacts to the species are rated as "Moderate". The species has a wide range and is present locally outside of Unit boundaries, so populations in CEBR and BRCA are probably not critical to its survival. However, though recent research shows PILO in mountainous treeline environments as actually benefiting from climate change, the unique environments in CEBR and BRCA may represent an important niche that is not well represented by those results. Hence the rating was increased from "Low" regionally to "Moderate" locally.

Impacts to Park management are rated "Moderate to High". It is a signature species in both Units and its longevity and tolerance for harsh conditions are well known. As opposed to the mountain top environments usually associated with bristlecone pine, these Units are easily accessible by the public.

Shivwits Milk-Vetch

This species habitat exhibits moderate increase over most climate warming alternatives. However, at the highest MAT increase it begins a decrease within Park boundaries. If MAT estimates are too low, habitat may significantly decrease within the Park. Occupied habitats outside the Park are at lower elevations, and may become too warm for a viable population, raising the importance of the ZION habitats. Though the species response model is based on literature and field data, it is not statistically based, so caution should be used in its interpretation (Table 19 above).

Sensitivity is rated "High" (Table 20 above) because of its strong relationship to elevation and small spatial extent. Adaptive capacity is rated as "Low" because of its strong tie to a specific geologic type, limiting its migratory opportunities. Also, though its potential habitat is relatively wide-spread in ZION, its presence has not been verified in most of that area.

Potential impacts to the Park habitat are rated "Low" and positive. The modeled habitat exhibits a moderate increase in extent over present conditions. Impacts to the species are "High" and positive. This is because most of the present and projected habitat is within the Park, a protected area. Because of this impacts to Park management are probably also "High". Even with high model uncertainty, the data was of adequate quality to result in the species listing as "Endangered".

And What if?

Since the habitat response models were selected and modified to use an elevation parameter to simulate climate change, they can be used to simulate other alternatives. For example, what if seasonal lapse rates rather than annual lapse rates are used to model habitat range shifts? The effect of that change is to increase the elevation shift to 2090 m. This results in an additional 1464 m of elevation shift in each model. Though we did not formally run our models on this basis, the following paragraphs estimate this impact. "Exposure" as defined above, would now be rated "High", rather than "Moderate". Table 21 shows estimated results.

Table 21. Summary of Species Vulnerability under lowered lapse rates

Vulnerability using Summer Lapse Rates						
Components				Potential Impacts		
Species	Sensitivity	Exposure	Adaptive Capacity	To Park Habitat	To the Species	To Park Management
American pika	High	Moderate	Low	High (-)	Low	Moderate
Desert tortoise	Moderate	Moderate	Moderate	High (-)	High	High
Great Basin bristlecone pine	Moderate	Moderate	Low	High (?)	Moderate	High
Shivwits milk-vetch	High	Moderate	Low	High (-)	High (-)	High

American pika: This elevation shift is not directly used in the pika *potential* habitat evaluation. However, under this shift both the CEBR and ZION populations fall far below the minimum elevations *for existing* populations in the Great Basin. It is unlikely these populations are viable under this alternative. Potential impacts to Park management may be only "Moderate" since the species is possibly viable elsewhere, but the loss of species should still be considered in decisions.

Desert tortoise: The Maxent model is complex, making an estimate of habitat quality difficult without actual model runs. However, it appears that this large decrease in effective elevation would probably result in a dramatic decrease in habitat quality over the present situation. This would probably result in a total loss of tortoise in ZION, as most of the existing habitat is at the southwest edge of the Park and at the lowest elevations. Higher elevations with appropriate vegetation and slope may open up as viable habitat, but they may be too distant and vertically isolated from existing populations for potential natural migration. Potential to Park management is “High” because of the possibility of migration assistance, and the tortoise importance to the region.

Bristlecone Pine: In BRCA, a dramatic shift upward in PILO is likely, as other species are probably eliminated by indirect climatic effects such as wildfire or insect infestations. It will probably occupy all the potential physical habitat available. In CEBR, as conditions moderate on the barren slopes, PILO should also be viable in that entire habitat. In this case, potential impacts on management may be “High”, since this would represent a radical vegetation change with probable associated impacts.

Shivwits milk-vetch: This elevation shift is applied to both lower and upper limits of the potential physical habitat. It is likely there will be no viable habitat remaining in ZION. The potential impact to the species is also “High” since there is little verified physical habitat outside of ZION at higher elevations, so the species is likely to be severely at risk.

The situation for all species has radically shifted under this alternative *which is within a reasonable future*. Without radical management policies, three of the four species could face extirpation from the three Units. Only bristlecone pine benefits from this degree of warming, and this comes at the probable expense of other vegetation types, particularly in BRCA.

The above discussion of the use of summer lapse rates may make the lapse rate/elevation association used in our modeling too conservative. Local data show the historical temperature increase is higher than our models present. Our “reasonable” futures may be too reasonable.

Change is indeed coming to our National Parks. Though the models predicting that change are imperfect, and resolution could always be improved, they unequivocally show the direction and magnitude of change. Yes, they predict radical change, especially in the light of new information. This degree of change is hard to accept, but even under “reasonable” climate change conditions, this may be just the beginning.

Wayne Gretkze (of hockey fame) said “A good hockey player plays where the puck is. A great hockey player plays where the puck is going to be.” The puck is moving. It’s up to us to play it not where it is, but where it may be if our National Parks are to survive in any recognizable form.

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Appendices

Appendix A: Supplementary Tables

Table 22. Talus Polygon Attributes in ZION and CEBR

Polygon ID	Area (m^2)	MAXELEV	Longitude of Centroid	Latitude of Centroid	Mean Elevation of Polygon (m)	Mean Slope (%)	Mean Insolation (watthours/m^2)	Maximum Elevation of Polygon (m)
1	1,078	2,414	-113.036586	37.39791086	2,335	19	824,235	2,338
2	1,187	2,414	-113.035882	37.39764508	2,324	27	823,371	2,327
3	647	2,414	-113.036722	37.39716412	2,345	23	831,718	2,346
4	36,224	2,414	-113.036069	37.39436333	2,352	24	827,893	2,378
6	6,045	2,414	-113.035438	37.39057618	2,340	15	867,043	2,352
7	7,821	2,414	-113.037873	37.39065886	2,375	30	841,681	2,400
8	7,961	2,414	-113.0381	37.38971695	2,380	34	813,487	2,402
9	5,835	2,414	-113.036233	37.38957433	2,349	14	859,236	2,362
10	1,572	2,414	-113.04133	37.38898376	2,405	31	819,542	2,415
11	15,624	2,414	-113.041659	37.38676754	2,397	38	803,620	2,414
12	1,020	2,414	-113.040947	37.38729479	2,394	67	783,946	2,402
13	11,336	2,414	-113.032516	37.38671458	2,386	31	780,591	2,400
14	105,622	2,414	-113.037125	37.3824024	2,344	55	804,762	2,405
15	4,222	2,414	-113.036596	37.38566471	2,404	13	842,891	2,407
16	192,216	2,414	-113.038664	37.37851695	2,296	46	770,272	2,403
17	17,261	2,414	-113.028454	37.38452996	2,350	35	753,327	2,378
18	595	2,414	-113.040779	37.38352268	2,389	58	729,271	2,395
19	1,667	2,414	-113.030433	37.38252042	2,377	79	791,104	2,393
20	1,688	2,414	-113.040498	37.38214004	2,383	53	752,229	2,390
21	5,540	2,414	-113.031069	37.38175383	2,370	48	826,742	2,403
22	1,804	2,414	-113.039596	37.38030323	2,356	72	723,933	2,374
23	26,393	2,414	-113.040031	37.37313436	2,315	53	787,262	2,391
24	171,595	2,414	-113.042054	37.36884819	2,290	37	821,238	2,392
25	2,190	2,414	-113.037726	37.37151097	2,194	48	827,892	2,220
26	7,254	2,414	-113.037372	37.37102707	2,170	45	810,480	2,248
27	1,613	2,414	-113.037327	37.36867483	2,134	41	785,430	2,143
28	1,082	2,414	-113.042591	37.36583736	2,287	32	821,523	2,293
29	973	2,524	-113.070797	37.35614166	2,248	28	776,897	2,253

30	943	2,524	-113.076371	37.35909556	2,379	56	675,879	2,386
31	987	2,524	-113.077035	37.35887333	2,385	36	770,671	2,389
32	2,551	2,524	-113.07219	37.35831456	2,273	36	802,789	2,280
33	630	2,524	-113.077171	37.35825468	2,383	49	854,003	2,389
34	2,529	2,524	-113.075487	37.35763356	2,379	54	851,152	2,399
35	1,266	2,524	-113.075731	37.35747518	2,357	68	828,423	2,362
37	3,256	2,524	-113.072715	37.35663751	2,318	69	644,564	2,341
38	2,708	2,524	-113.074665	37.3562347	2,341	74	796,211	2,356
39	3,651	2,524	-113.086599	37.37299298	2,410	40	845,393	2,420
40	1,504	2,524	-113.085928	37.37313349	2,423	7	869,982	2,424
41	1,448	2,524	-113.082679	37.37197222	2,441	12	857,682	2,443
42	3,215	2,524	-113.084111	37.36400159	2,187	67	628,651	2,230
43	17,437	2,524	-113.08508	37.36225915	2,201	54	725,237	2,241
44	5,879	2,524	-113.084445	37.36029382	2,188	66	788,614	2,223
56	4,507	1,965	-113.214335	37.40256879	1,950	37	716,578	1,965
66	3,565	2,002	-113.068834	37.32295571	1,987	58	772,619	2,002
67	684	2,002	-113.083369	37.30810434	1,703	43	675,960	1,707
68	542	2,002	-113.086665	37.30671167	1,673	27	718,666	1,676
69	3,617	2,002	-113.086033	37.30645631	1,691	40	699,346	1,705
70	5,090	2,002	-113.087043	37.30626902	1,665	29	715,383	1,675
71	2,552	2,002	-113.078199	37.3020389	1,666	69	674,273	1,685
72	3,709	2,002	-113.079402	37.30171203	1,690	62	719,484	1,707
73	1,856	2,002	-113.079835	37.30060088	1,686	53	731,544	1,698
74	1,645	2,002	-113.077965	37.30007251	1,638	81	658,244	1,653
75	367	2,002	-113.07455	37.30012261	1,636	68	706,881	1,647
76	2,598	2,002	-113.075047	37.29924921	1,613	65	719,611	1,651
77	2,481	1,707	-113.082709	37.29591454	1,531	54	683,250	1,548
79	2,675	1,707	-113.091567	37.28377394	1,417	83	644,303	1,446
100	6,175	1,339	-113.080192	37.21242869	1,286	42	699,167	1,302
101	10,798	1,339	-113.080612	37.21106489	1,288	19	758,984	1,300

102	7,572	1,339	-113.080532	37.19629099	1,201	49	590,030	1,229
103	3,172	1,339	-113.090291	37.19595565	1,324	20	782,903	1,339
104	2,319	1,339	-113.082571	37.1964759	1,272	90	455,694	1,293
105	2,319	1,339	-113.083928	37.19628441	1,293	32	670,433	1,298
106	3,086	1,339	-113.08626	37.19588372	1,303	14	738,328	1,305
107	5,184	1,339	-113.079338	37.19535465	1,223	54	571,489	1,256
108	2,940	1,339	-113.087489	37.19505223	1,305	3	763,566	1,309
109	21,005	1,339	-113.079361	37.19427065	1,241	53	705,745	1,291
110	3,325	1,339	-113.088225	37.19498161	1,308	23	719,495	1,317
113	1,433	1,339	-113.077976	37.1938776	1,201	60	702,530	1,213
114	797	1,339	-113.079864	37.19348162	1,232	67	741,856	1,238
115	3,215	1,339	-113.088348	37.1916045	1,316	6	766,366	1,317
116	1,916	1,339	-113.089028	37.1912027	1,316	4	770,406	1,317
117	5,407	1,339	-113.086311	37.18498219	1,198	45	615,740	1,216
118	7,982	1,339	-113.085061	37.18465554	1,187	50	665,389	1,209
119	2,866	1,339	-113.087655	37.18390735	1,211	41	635,522	1,220
120	1,560	1,339	-113.085264	37.1837656	1,198	58	668,815	1,216
121	4,188	1,339	-113.085289	37.1829326	1,198	68	644,617	1,216
122	7,788	1,339	-113.090291	37.18247758	1,247	49	606,126	1,262
123	7,376	1,339	-113.08721	37.18244581	1,250	48	619,660	1,268
124	3,646	1,339	-113.089206	37.18226936	1,252	28	694,099	1,262
125	3,444	1,339	-113.088689	37.17941853	1,249	35	772,211	1,257
126	3,779	1,339	-113.084217	37.17870302	1,182	63	583,949	1,200
127	2,671	1,339	-113.083226	37.17805547	1,175	55	597,177	1,194
128	1,212	1,339	-113.082693	37.17765467	1,171	61	596,041	1,185
129	2,761	1,339	-113.090657	37.17584252	1,182	63	677,610	1,199
130	1,482	1,339	-113.087758	37.17487259	1,166	57	728,879	1,200
131	1,148	1,339	-113.087484	37.17460796	1,160	56	741,057	1,174
132	2,135	1,339	-113.086909	37.17443489	1,164	62	740,595	1,183
133	1,613	1,339	-113.086395	37.17423699	1,159	63	740,263	1,176

134	1,399	1,339	-113.085895	37.17399781	1,152	50	754,785	1,165
135	2,232	2,002	-113.076694	37.29903844	1,642	61	773,967	1,657
136	2,085	2,002	-113.079145	37.2997888	1,626	50	728,673	1,638
137	1,062	1,707	-113.087652	37.28781382	1,425	80	642,535	1,441
138	695	1,707	-113.087347	37.28813933	1,431	72	644,898	1,444
139	1,814	1,707	-113.088598	37.28736447	1,430	126	567,646	1,452
140	983	1,707	-113.089013	37.28661728	1,410	63	620,465	1,424
CEBR 5	7442	3221	-112.823221	37.64090601	3212	23	819,542	3,221

Table 23. ZION Talus Polygon Statistics

ID	Area (m2)	Area (ha)	Elev. Mean (m)	Elev. Min. (m)	Elev. Ma (m)	Slope Mean (%	Aspect Mean (deg	Aspect Mi (deg)	Aspect Max. (deg
1	1,078	0.1	2,335	2,332	2,3		59	50	6
2	1,187	0.1	2,324	2,319	2,3		75	68	8
3	647	0.1	2,345	2,344	2,3		75	64	8
4	36,224	3.6	2,352	2,276	2,3		79	16	14
5	6,045	0.6	2,340	2,332	2,3		120	27	15
6	7,821	0.8	2,375	2,365	2,4		108	71	12
7	7,961	0.8	2,380	2,368	2,4		84	69	10
8	5,835	0.6	2,349	2,343	2,3		101	67	12
9	1,572	0.2	2,405	2,398	2,4		269	257	27
10	15,624	1.6	2,397	2,370	2,4		86	55	20
11	1,020	0.1	2,394	2,388	2,4		240	234	24
12	11,336	1.1	2,386	2,371	2,4		242	2	36
13	105,622	10.6	2,344	2,274	2,4		224	154	26
14	4,222	0.4	2,404	2,401	2,4		43	1	35
15	192,216	19.2	2,296	2,184	2,4		90	47	20
16	17,261	1.7	2,350	2,335	2,3		63	0	36
17	595	0.1	2,389	2,382	2,3		70	59	7
18	1,667	0.2	2,377	2,369	2,3		137	130	14

ID	Area (m2)	Area (ha)	Elev. Mean (m)	Elev. Min. (m)	Elev. Ma (m)	Slope Mean (%	Aspect Mean (deg	Aspect Mir (deg)	Aspect Max. (deg
19	1,688	0.2	2,383	2,370	2,3		76	72	8
20	5,540	0.6	2,370	2,354	2,4		131	101	15
21	1,804	0.2	2,356	2,346	2,3		87	84	9
22	26,393	2.6	2,315	2,239	2,3		98	72	15
23	171,595	17.2	2,290	2,184	2,3		108	5	35
24	2,190	0.2	2,194	2,172	2,2		134	123	15
25	7,254	0.7	2,170	2,121	2,2		120	102	14
26	1,613	0.2	2,134	2,125	2,1		99	92	10
27	1,082	0.1	2,287	2,281	2,2		88	79	9
28	973	0.1	2,248	2,244	2,2		61	42	8
29	943	0.1	2,379	2,372	2,3		16	10	2
30	987	0.1	2,385	2,381	2,3		319	287	35
31	2,551	0.3	2,273	2,262	2,2		240	217	27
32	630	0.1	2,383	2,378	2,3		227	212	24
33	2,529	0.3	2,379	2,362	2,3		208	189	23
34	1,266	0.1	2,357	2,345	2,3		211	193	22
35	3,256	0.3	2,318	2,284	2,3		41	21	6
36	2,708	0.3	2,341	2,320	2,3		233	220	24
37	3,651	0.4	2,410	2,394	2,4		247	225	27
38	1,504	0.2	2,423	2,421	2,4	7	279	237	31
39	1,448	0.1	2,441	2,439	2,4		270	16	34
40	3,215	0.3	2,187	2,160	2,2		301	266	32
41	17,437	1.7	2,201	2,144	2,2		273	243	31
42	5,879	0.6	2,188	2,154	2,2		229	208	24
43	4,507	0.5	1,950	1,940	1,9		114	0	35
44	3,565	0.4	1,987	1,974	2,0		219	199	25
45	684	0.1	1,703	1,699	1,7		298	294	30
46	542	0.1	1,673	1,670	1,6		291	284	30
47		0.4			1,7				32

ID	Area (m2)	Area (ha)	Elev. Mean (m)	Elev. Min. (m)	Elev. Ma (m)	Slope Mean (%	Aspect Mean (deg	Aspect Mir (deg)	Aspect Max. (deg
	3,617		1,691	1,680			287	260	
48	5,090	0.5	1,665	1,653	1,6		264	253	27
49	2,552	0.3	1,666	1,647	1,6		255	248	26
50	3,709	0.4	1,690	1,670	1,7		113	107	11
51	1,856	0.2	1,686	1,668	1,6		106	102	11
52	1,645	0.2	1,638	1,616	1,6		258	252	26
53	367	0.1	1,636	1,627	1,6		129	128	12
54	2,598	0.3	1,613	1,584	1,6		134	112	15
55	2,481	0.2	1,531	1,519	1,5		233	225	24
56	2,675	0.3	1,417	1,386	1,4		140	131	14
57	6,175	0.6	1,286	1,269	1,3		87	76	12
58	10,798	1.1	1,288	1,277	1,3		122	61	19
59	7,572	0.8	1,201	1,185	1,2		54	5	7
60	3,172	0.3	1,324	1,318	1,3		203	88	34
61	2,319	0.2	1,272	1,260	1,2		215	1	35
62	2,319	0.2	1,293	1,283	1,2		230	2	35
63	3,086	0.3	1,303	1,295	1,3		161	7	35
64	5,184	0.5	1,223	1,197	1,2		27	2	36
65	2,940	0.3	1,305	1,304	1,3	3	244	(1)	36
66	21,005	2.1	1,241	1,186	1,2		131	36	23
67	3,325	0.3	1,308	1,304	1,3		47	3	11
68	1,433	0.1	1,201	1,186	1,2		119	95	14
69	797	0.1	1,232	1,227	1,2		200	194	20
70	3,215	0.3	1,316	1,314	1,3	6	133	0	36
71	1,916	0.2	1,316	1,315	1,3	4	100	-	35
72	5,407	0.5	1,198	1,179	1,2		299	4	35
73	7,982	0.8	1,187	1,172	1,2		77	14	12
74	2,866	0.3	1,211	1,203	1,2		335	318	34
75	1,560	0.2	1,198	1,178	1,2		92	85	9

ID	Area (m2)	Area (ha)	Elev. Mean (m)	Elev. Min. (m)	Elev. Ma (m)	Slope Mean (%	Aspect Mean (deg	Aspect Mir (deg)	Aspect Max. (deg
76	4,188	0.4	1,198	1,179	1,2		90	80	9
77	7,788	0.8	1,247	1,229	1,2		242	0	36
78	7,376	0.7	1,250	1,231	1,2		140	1	35
79	3,646	0.4	1,252	1,240	1,2		96	9	35
80	3,444	0.3	1,249	1,241	1,2		218	194	26
81	3,779	0.4	1,182	1,170	1,2		53	43	7
82	2,671	0.3	1,175	1,163	1,1		46	26	5
83	1,212	0.1	1,171	1,157	1,1		55	28	6
84	2,761	0.3	1,182	1,159	1,1		117	76	18
85	1,482	0.1	1,166	1,148	1,2		222	209	24
86	1,148	0.1	1,160	1,150	1,1		214	209	21
87	2,135	0.2	1,164	1,144	1,1		205	198	20
88	1,613	0.2	1,159	1,146	1,1		201	193	20
89	1,399	0.1	1,152	1,144	1,1		198	195	20
90	2,232	0.2	1,642	1,631	1,6		194	167	21
91	2,085	0.2	1,626	1,606	1,6		123	115	13
92	1,062	0.1	1,425	1,413	1,4		144	135	14
93	695	0.1	1,431	1,417	1,4		131	121	14
94	1,814	0.2	1,430	1,413	1,4	1	141	127	15
95	983	0.1	1,410	1,401	1,4		116	110	12
Total	868,537	87.0							

Table 24. Elevation Characteristics by Vegetation Group in CEBR

Vegetation Group	vg Elev. (m)	in Elev. (m)	ax Elev. (m)	tDev Elev.	rea (ha)	rea (%)
Abies lasiocarpa - Picea engelmannii Forest Complex	105	715	247	10.2	52.5	8.2
Perennial Disturbed Grassland Complex	172	041	245	0.8	3.9	.4
Mixed Mountain Shrubland Complex	200	142	246	0.9	1.2	.5
Park Infrastructure	186	143	230	6.7	0.5	.8

Populus tremuloides Forest Complex	788	469	228	45.0	3.1	.9
Bottomland Shrubland Complex	180	171	201	.6	2.8	.5
Dry Meadow Mixed Herbaceous Vegetation Mosaic	184	108	234	4.1	4.7	.4
Pinus ponderosa - (Pseudotsuga menziesii) Woodland Complex	639	463	955	2.0	21.0	.9
Salix spp. Temporarily Flooded Shrubland Complex	182	145	194	2.2	.4	.1
Carex spp.- Juncus spp. Wet Meadow Herbaceous Vegetation Mosaic	180	973	220	9.5	5.5	.0
Unvegetated surface (e.g., scree, sparse vegetation)	560	499	670	9.9	.2	.1
Red Claron Formation	924	645	208	05.8	82.3	5.5
White Claron Formation	954	686	183	56.1	5.1	.4
Pinus longaeva (Bristlecone Pine) Woodland Alliance	888	512	176	39.3	06.6	.3
Arctostaphylos patula Shrubland Alliance	648	540	832	9.8	0.0	.2
Mixed Desert Shrubland Complex	155	627	220	1.4	2.9	.5
Abies concolor / Arctostaphylos patula Forest	636	464	898	8.0	5.4	.4
Temporarily Flooded Wash Complex	602	461	905	1.6	9.5	.0
Abies concolor Forest Alliance	662	471	909	4.2	67.0	.7
Cercocarpus ledifolius Woodland Alliance	659	528	789	2.9	4.3	.0
Picea pungens Forest Alliance	704	498	954	20.2	0.4	.2
Pinus edulis. - Juniperus spp. Woodland Complex	643	523	810	4.0	7.3	.7
Dasiphora fruticosa ssp. floribunda Shrubland	177	175	178	.7	.1	.0
Ericameria (Chrysothamnus) spp. Shrubland Complex	153	146	159	.2	.7	.0
Total					483.3	00.0

Table 25. Slope Characteristics by Vegetation Group in CEBR

Vegetation Group	vg Slope (%)	in Slope (%)	ax Slope (%)	tDev Slope	rea (ha)	rea (%)
Abies lasiocarpa - Picea engelmannii Forest Complex	5.4	.0	3.9	0.5	52.5	8.2
Perennial Disturbed Grassland Complex	.7	.0	1.4	.1	3.9	.4
Mixed Mountain Shrubland Complex	.2	.0	6.4	.2	1.2	.5
Park Infrastructure	.0	.0	7.2	.8	0.5	.8
Populus tremuloides Forest Complex	8.4	.1	5.9	.2	3.1	.9
Bottomland Shrubland Complex	.1	.0	1.5	.0	2.8	.5
Dry Meadow Mixed Herbaceous Vegetation Mosaic	.1	.0	6.5	.7	4.7	.4
Pinus ponderosa - (Pseudotsuga menziesii) Woodland Complex	2.8	.0	6.5	0.7	21.0	.9
Salix spp. Temporarily Flooded Shrubland Complex	.2	.0	3.1	.0	.4	.1
Carex spp.- Juncus spp. Wet Meadow Herbaceous Vegetation Mosaic	.2	.0	5.2	.0	5.5	.0
Unvegetated surface (e.g., scree, sparse vegetation)	6.3	2.6	0.7	.6	.2	.1
Red Claron Formation	4.7	.1	4.4	0.1	82.3	5.5
White Claron Formation	1.0	.7	1.1	0.2	5.1	.4
Pinus longaeva (Bristlecone Pine) Woodland Alliance	0.7	.3	8.3	0.0	06.6	.3
Arctostaphylos patula Shrubland Alliance	4.5	.3	2.8	.7	0.0	.2
Mixed Desert Shrubland Complex	0.4	.0	1.5	2.3	2.9	.5
Abies concolor / Arctostaphylos patula Forest	5.7	.0	2.4	.3	5.4	.4
Temporarily Flooded Wash Complex	0.6	.2	5.3	4.9	9.5	.0
Abies concolor Forest Alliance	6.6	.4	0.9	.8	67.0	.7
Cercocarpus ledifolius Woodland Alliance	0.5	.8	0.0	.9	4.3	.0
Picea pungens Forest Alliance	2.0	.5	6.6	.1	0.4	.2
Pinus edulis. - Juniperus spp. Woodland Complex	5.3	.9	7.7	.7	7.3	.7
Dasiphora fruticosa ssp. floribunda Shrubland	.0	.0	.3	.3	.1	.0
Ericameria (Chrysothamnus) spp. Shrubland Complex	4.3	.9	2.9	.8	.7	.0
Total					483.3	00.0

Table 26. Slope Characteristics of Vegetation in BRCA

Vegetation Group	vg Slope (%)	in Slope (%)	ax Slope (%)	tDev Slope	rea (ha)	rea (%)
White Fir Forest Complex	5.1	.0	8.4	.5	038.6	.1
White Fir / Gambel Oak – (Bigtooth Maple) Forest	7.3	.2	0.7	0.2	02.0	.7
White Fir / Manzanita – Mixed Shrub Forest	8.7	.0	5.1	0.7	268.9	.7
White Fir / Mixed Herbaceous Forest	0.3	.0	2.6	.1	75.0	.2
Blue Spruce Forest Complex	8.8	.2	9.3	.5	3.4	.6
Ponderosa Pine – (Douglas Fir) / Manzanita Woodland Complex	5.3	.0	6.2	.7	297.1	2.7
Ponderosa Pine / Mixed Mountain Shrub Woodland Complex	0.0	.0	9.0	.9	62.5	.5
Ponderosa Pine / Mixed Herbaceous Woodland Complex	.8	.0	0.9	.3	89.5	.4
Ponderosa Pine / Gambel Oak Woodland	6.7	.1	8.4	0.4	83.6	.9
Ponderosa Pine / Pinyon Pine – Juniper spp. / Gambel Oak Forest	7.3	.0	3.3	1.7	36.3	.3
Ponderosa Pine / Pinyon Pine – Juniper spp. / Mixed Mountain Shrub Forest	8.2	.0	6.6	.7	17.8	.2
Pinus longaeva (Bristlecone Pine) Woodland	1.4	.0	3.2	0.6	94.7	.8
Pinyon Pine – Juniper spp. / Saline Wildrye Woodland	2.8	.4	1.8	1.7	67.9	.2
Pinyon Pine – Juniper spp. / Sagebrush spp. Woodland Complex	1.4	.0	1.7	.6	5.4	.2
Pinyon Pine – Juniper spp. / Mixed Mountain Shrub Woodland Complex	1.0	.0	6.1	0.6	132.0	4.6
Pinyon Pine – Juniper spp. / Gambel Oak Woodland Complex	7.1	.0	0.3	0.0	38.4	.4
Pinyon Pine – Juniper spp. / Sparse Understory Woodland	1.4	.1	6.1	.1	8.8	.5
Aspen Forest Complex	0.5	.0	5.4	.7	7.7	.1
Narrowleaf Cottonwood Woodland Alliance	.7	.8	2.9	.1	.7	.0
Curl-leaf Mountain-mahogany Woodland Complex	8.2	.6	3.1	3.6	2.1	.2
Gambel Oak Shrubland Complex	6.4	.0	9.7	0.9	19.1	.8
Mixed Mountain Shrubland Complex	1.2	.0	7.1	3.7	51.8	.7
Water Birch Shrubland	9.6	.1	6.5	4.6	.8	.0
Willow spp. Temporarily Flooded Shrubland Complex	.4	.2	7.8	.9	.3	.0
Black Sagebrush Shrubland Complex	.6	.0	8.9	.2	76.8	.9
Manzanita Shrubland	6.0	.0	4.0	0.7	26.6	.9
Rabbitbrush spp. Shrubland Complex	.2	.0	2.6	.5	9.6	.3
Bottomland Shrubland Complex	1.1	1.7	1.1	.4	.6	.0
Big Sagebrush Shrubland Complex	.2	.0	4.9	.9	3.9	.5
Pygmy Sagebrush Dwarf-shrubland	.6	.0	7.8	.9	.8	.0
Dry Meadow Mixed Herbaceous Vegetation Mosaic	1.2	.0	8.7	1.3	08.4	.7
Perennial Disturbed Grassland Complex	.2	.0	1.0	.9	4.6	.2

Sedge and Rush Wet Meadow Herbaceous Vegetation Mosaic	.0	.0	9.3	.8	8.6	.3
Roadside Restored Herbaceous Vegetation	.2	.0	2.6	.3	3.8	.3
Mixed Desert Shrubland Complex	1.1	.0	0.1	2.0	11.5	.8
Claron Formation	7.6	.1	9.4	4.3	84.2	.8
Barren Washes	.0	.0	5.3	.2	0.7	.6
Siltbush Shrubland	2.3	.5	5.9	.4	6.4	.1
Transportation, Communications, and Utilities	.3	.0	4.7	.6	4.8	.5
Mixed Urban or Built-up Land	.4	.0	6.8	.9	4.3	.1
Reservoirs	.3	.3	.5	.5	.1	.0
Strip Mines, Quarries, and Gravel Pits	.6	.4	.4	.0	.9	.0
Seeps and Springs	4.3	3.4	4.2	.6	.2	.0
Total					4555.2	00.0

Table 27. Elevation Characteristics of Vegetation in BRCA

Vegetation Group	Avg Elev. (m)	in Elev. (m)	ax Elev. (m)	tDev Elev.	rea (ha)	rea (%)
White Fir Forest Complex	2581	151	777	11	038.6	.1
White Fir / Gambel Oak – (Bigtooth Maple) Forest	2391	269	610	8	02.0	.7
White Fir / Manzanita – Mixed Shrub Forest	2548	264	779	6	268.9	.7
White Fir / Mixed Herbaceous Forest	2665	300	761	1	75.0	.2
Blue Spruce Forest Complex	2466	275	754	5	3.4	.6
Ponderosa Pine – (Douglas Fir) / Manzanita Woodland Complex	2389	069	776	31	297.1	2.7
Ponderosa Pine / Mixed Mountain Shrub Woodland Complex	2376	073	617	9	62.5	.5
Ponderosa Pine / Mixed Herbaceous Woodland Complex	2431	109	745	3	89.5	.4
Ponderosa Pine / Gambel Oak Woodland	2291	072	545	5	83.6	.9
Ponderosa Pine / Pinyon Pine – Juniper spp. / Gambel Oak Forest	2221	009	580	02	36.3	.3
Ponderosa Pine / Pinyon Pine – Juniper spp. / Mixed Mountain Shrub Forest	2288	048	663	8	17.8	.2
Pinus longaeva (Bristlecone Pine) Woodland	2292	086	763	3	94.7	.8
Pinyon Pine – Juniper spp. / Saline Wildrye Woodland	2120	018	335	7	67.9	.2
Pinyon Pine – Juniper spp. / Sagebrush spp. Woodland Complex	2073	018	209	7	5.4	.2
Pinyon Pine – Juniper spp. / Mixed Mountain Shrub Woodland Complex	2224	011	664	00	132.0	4.6
Pinyon Pine – Juniper spp. / Gambel Oak Woodland Complex	2203	008	495	01	38.4	.4
Pinyon Pine – Juniper spp. / Sparse Understory Woodland	2082	012	164	1	8.8	.5
Aspen Forest Complex	2456	300	717	07	7.7	.1

Narrowleaf Cottonwood Woodland Alliance	2197	143	224	9	.7	.0
Curl-leaf Mountain-mahogany Woodland Complex	2304	117	503	04	2.1	.2
Gambel Oak Shrubland Complex	2223	006	552	22	19.1	.8
Mixed Mountain Shrubland Complex	2347	024	766	31	51.8	.7
Water Birch Shrubland	2181	103	225	9	.8	.0
Willow spp. Temporarily Flooded Shrubland Complex	2202	044	313	6	.3	.0
Black Sagebrush Shrubland Complex	2379	322	515	6	76.8	.9
Manzanita Shrubland	2440	134	738	09	26.6	.9
Rabbitbrush spp. Shrubland Complex	2378	181	672	0	9.6	.3
Bottomland Shrubland Complex	2170	154	191		.6	.0
Big Sagebrush Shrubland Complex	2078	008	427	1	3.9	.5
Pygmy Sagebrush Dwarf-shrubland	2335	325	352		.8	.0
Dry Meadow Mixed Herbaceous Vegetation Mosaic	2452	027	749	55	08.4	.7
Perennial Disturbed Grassland Complex	2402	328	540	1	4.6	.2
Sedge and Rush Wet Meadow Herbaceous Vegetation Mosaic	2398	158	526	5	8.6	.3
Roadside Restored Herbaceous Vegetation	2578	033	778	54	3.8	.3
Mixed Desert Shrubland Complex	2094	007	320	5	11.5	.8
Claron Formation	2446	070	778	42	84.2	.8
Barren Washes	2207	006	618	26	0.7	.6
Siltbush Shrubland	2079	041	136	9	6.4	.1
Transportation, Communications, and Utilities	2451	027	778	70	4.8	.5
Mixed Urban or Built-up Land	2426	403	478	1	4.3	.1
Reservoirs	2388	387	390		.1	.0
Strip Mines, Quarries, and Gravel Pits	2736	732	739		.9	.0
Seeps and Springs	2498	486	514		.2	.0
Total					4555.2	00.0

Appendix B: Project Description and Proposal

Rocky Mountains Cooperative Ecosystem Studies Unit (RM-CESU)
RM-CESU Cooperative Agreement Number: H1200090004 (IMR)

PROJECT COVER SHEET
R# **TBD**

TITLE OF PROJECT: **Climate Change Scenario Planning: Four Species of Concern in Southwestern Utah Parks/Monuments**

NAME OF PARK/NPS UNIT: **Zion National Park, Bryce Canyon National Park, Cedar Breaks National Monument**

NAME OF UNIVERSITY PARTNER: **Montana State University**

RESEARCHER:
Dr. Henry Shovic, Montana State University, Department of Ecology, hshovic@montana.edu; hshovic@bridgeband.com

PROJECT SCHEDULE, FINAL PRODUCTS, AND PAYMENTS:

Date of Project Initiation: September 15, 2010

Project Schedule
Draft report and Preliminary Findings – January 31, 2011
Database and Maps Provided to Park Management – July 31, 2011
Draft Final Report – January 28, 2012
Project End Date – December 31, 2012

List of Products:

Technical Report, incorporating an appropriate level of peer review, detailing the study methods, data, and results.

Interim technical and management scenario planning workshops on-site (four meetings).

All spatial data, GIS models, and NDVI results through time. All data and associated layers, metadata, and linked images will be done in accordance with the National Park Service Geographic Information System (GIS) Data Specifications for Resource Mapping, Inventories, and Studies Guidelines and Requirements (http://imgis.nps.gov/gis_data_specifications.html) and other National Park Service regulations.

Maps showing modeled habitat change results (both pdf and jpg images).

Presentation of results to NPS managers to discuss findings (two presentations on location).

Tools, techniques, and effectiveness ratings of alternatives from scenario workshops posted on insidenps.gov.

A presentation, if appropriate**,** at the George Wright Society Meeting would be made on project completion to share methods, results, and lessons learned.

Payment Schedule:

Payment of regular invoices from the University, as received by the NPS, unless otherwise stipulated.

Final invoices are payable only if the reports and/or products have been received and approved by the NPS key official. The NPS will withhold payment of the final 10% of project funds until the NPS Key Official receives and approves the final report and/or products. The NPS will not pay invoices for less than $500, unless it is the last invoice to close the project account. Form SF 270 shall be used when submitting invoices for payment.

DETAILED SCOPE OF WORK, SCHEDULE, PRODUCTS

Problem Definition: Though climate change is well-defined on a global and regional scale, it is still difficult to define what local effects might be and an appropriate management response at a National Park level.

This short-term study is designed to forecast management opportunities as a response to the local effects of climate change, using existing data available at the National Park level. Three units of the National Park System in southern Utah were selected for this project. They are Zion National Park (146,597 acres), Bryce Canyon National Park (35,835 acres), and Cedar Breaks National Monument (6,154 acres). They represent part of the range of each target species. They are in close proximity and share administrative and environmental factors, and their total area is at an appropriate scale for this analysis. A buffer of surrounding lands is included for context.

Four target species were chosen to represent flora and fauna known to occupy these units, specifically due to climate-related concerns. They have well-defined habitat parameters: American pika (*Ochotona princeps*), Desert tortoise (*Xerobates [Gopherus] agassizii*), Shivwits milkvetch (*Astragalus ampullarioides*), and Great Basin bristlecone pine (*Pinus longaeva*).

Although each of the four species is not found individually within each of the NPS units, this offers the opportunity to broadly test project methods for both plant and animal species, and across NPS boundaries, and therefore should demonstrate opportunity for transferability to other species and NPS units. Products include:

Technical Report, incorporating an appropriate level of peer review, detailing the study methods, data, and results.

Interim technical and management scenario planning workshops on-site (four meetings).

All spatial data, GIS models, and NDVI results through time. All data and associated layers, metadata, and linked images will be done in accordance with the National Park Service Geographic Information System (GIS) Data Specifications for Resource Mapping, Inventories, and Studies Guidelines and Requirements (http://imgis.nps.gov/gis_data_specifications.html) and other National Park Service regulations.

Maps showing modeled habitat change results (both pdf and jpg images).

Presentation of results to NPS managers to discuss findings (two presentations on location).

Tools, techniques, and effectiveness ratings of alternatives from scenario workshops posted on insidenps.gov.

A presentation, if appropriate**,** at the George Wright Society Meeting would be made on project completion to share methods, results, and lessons learned.

Scope of Work and Schedule:

Purpose: Provide analysis for alternative development and scenario planning in order to conserve biodiversity; support decision making with transferable tools and methods**.** This study proposes to explore potential effects of climate change on critical natural resources and develop a range of responses at the National Park/Monument level. Over the long-term recent climate change will likely be expressed by changes in overall vegetation type. In the short term, that expression may be seen primarily in plant productivity and vigor, rather than ecotype. Satellite-based measures of vegetation productivity (e.g., normalized difference vegetation index or NDVI) will be used to identify recent spatial and temporal trends in existing types. This is a one year study, using existing data and local specialist input, but spanning three NPS units that encompass a broad range of elevations, ecotypes, and species. Areas where NDVI trends overlap with target species habitat are candidates for early management response. Identifying the intersection of climate-induced change in vegetation and critical habitat should determine location, magnitude and direction of change expected if climate trends continue. Management opportunities in these areas will be explored using the integrated spatial/temporal data as part of an adaptive scenario planning process.

1. Develop Habitat Models for Target Species: Develop spatially-explicit models of selected species habitat for the study area Parks/National Monuments. Extant, proven models may be adapted for use in this project. These models predict location of potential habitat for each species within and near the study area. Literature and consultation are used to determine relevant landscape factors. In cooperation with subject matter specialists spatial models are built using these factors to map probable habitat. Data from existing monitoring programs will inform the models. (September/October/November 2010)

2. Climate-related Vegetation Change: Determine trends in greenness and productivity of the dominant vegetation types that occur within and around the study area. Isolate climate-induced change by combining normalized difference vegetation index (NDVI) trends with landscape data to isolate change from disturbance or land use- related change. Use I&M processed MODIS satellite NDVI to identify spatial and temporal trends in vegetation change over the last eight years. Produce fine-resolution climate surfaces for study area using existing I&M climate station histories. Augment and compare climate results with NVDI results. Determine phenology metrics for the study area. (October/November/December 2010)

3. Climate-related Habitat Change: Identify intersection of spatially coincident areas of target species habitat and climate-related change in vegetation. Model and estimate potential effects of these spatial changes on target species habitat present in the study areas. Estimate potential change or addition of habitat within or near administrative boundaries, given the inferred effects of climate change by feeding results from activity 2 into activity 1. (February/March/April 2011)

4. Develop Management Opportunities: Describe the location and extent of potential reduction or increase in habitat for target species. Describe alternatives for managing NPS

resources to adapt to these effects using scenario planning. Scenario planning will involve analysis generated from this project to consider a variety of possible futures, with the goal of reducing risk of species loss to an uncertain future resulting from changing climate. Interaction with local managers and interested public via a series of workshops will determine effective ways to deliver conservation results and their value. (April/May/June/July 2011)

This project may be extended depending on changing conditions and adequacy of findings.

Methods:

This is an exploratory study using relatively standard data and analysis capability available on a National Park level. Methods are directly transferable and are based on current, relatively simple methodology using existing standard NPS software. Eventually all NPS units will have to address local effects, and this study may be useful in suggesting methods and results that can be achieved at the park level.

Methods include standard NPS/USGS protocols for interpretation of satellite imagery (NDVI), use of standardized spatial data (e.g. NPS vegetation mapping), geographic analysis methods using standard NPS software (ARCGIS © ESRI), and readily available specialized software such as FRAGSTATS. The project is designed to be timely (one year after implementation of the Agreement). Selection of study areas and species was completed by National Park resource specialists, external specie/ecology specialists, and in contact with park management. Soil data collection and spatial models would be completed by the PI, a qualified soil scientist. The methods developed and tested here would be published as a stepwise progression of information acquisition, modeling, and framing results in a management-oriented format. All GIS data would comply with NPS and Federal Government Data Collection (FGDC) meta-data standards.

The principal investigator (a member of the Rocky Mountain CESU) has 30 years experience in applied natural resource inventory and applied scientific analysis in the National Park Service and the U.S. Forest Service, and a PhD in Soil Inventory and Classification. He has experience in project management, wildlife modeling, spatial analysis, remote sensing (including NDVI), and applied vegetation/ecology projects.

Products:

Technical Report, incorporating an appropriate level of peer review, detailing the study methods, data, and results.

All spatial data, GIS models, and NDVI results through time. All data and associated layers, metadata, and linked images will be done in accordance with the National Park Service Geographic Information System (GIS) Data Specifications for Resource Mapping, Inventories, and Studies Guidelines and Requirements (http://imgis.nps.gov/gis_data_specifications.html) and other National Park Service regulations.

Maps showing modeled habitat change results (both pdf and jpg images).

Presentation of results to NPS managers to discuss findings (two presentations on location).

Tools, techniques, and effectiveness ratings of alternatives from scenario workshops posted on insidenps.gov.

A presentation, if appropriate**,** at the George Wright Society Meeting would be made on project completion to share methods, results, and lessons learned.