Forecasting the Response of Terrestrial Habitats to Climate Change in the Northern Sierra: Climate Adaptation Strategies for the Northern Sierra Partnership

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Forecasting the Response of Terrestrial Habitats to Climate Change in the Northern Sierra: Adaptation Strategies for the Northern Sierra Partnership

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1 Introduction

1.1 The Northern Sierra Partnership

The Northern Sierra Partnership (NSP) is an alliance of organizations committed to protecting the most important lands and waters in the northern Sierra Nevada. The Partnership is comprised of the Feather River Land Trust (FRLT), Sierra Business Council (SBC), Truckee Donner Land Trust (TDLT), the Trust for Public Land (TPL), and The Nature Conservancy (TNC). The Partnership has identified, and is working in, priority areas on both public and private lands (Figure 1-1).

1.2 Conservation Context

The NSP region is home to exceptional natural, cultural, and recreational resources of statewide and global significance. The natural services derived from the mountain valleys, river corridors, and northern conifer forests are crucial to the future of California and Nevada residents and communities. Its rivers provide 60% of California developed water supply, and also support the Nevada cities of Reno and Sparks. Its forest systems are reservoirs of carbon, and its wetlands are home to the greatest diversity and abundance of bird life in the Sierra Nevada. These resources face colliding threats from inappropriate development, stand-replacing wildfire, invasive species, and climate change.

In terms of ownership and stakeholders, over 66% of the five million acre project area falls on public land (Figure 1-1). The public land is owned and managed by the US Forest Service (USFS)(62% of the project area), the Bureau of Land Management (BLM)(3%), and other state and federal agencies (1%). However, only 7% of the project area is managed explicitly for the protection of biodiversity (e.g., wilderness areas, parks, wildlife preserves). Approximately 4% of the area is water, leaving the remaining 29% in private ownership. After well over a decade of conservation action, the organizations of the Northern Sierra Partnership have conserved 101,000 acres of private lands (1% of total area) through a combination of fee title acquisition and conservation easements.

1.1 Climate Adaptation Assessment Components and Goals

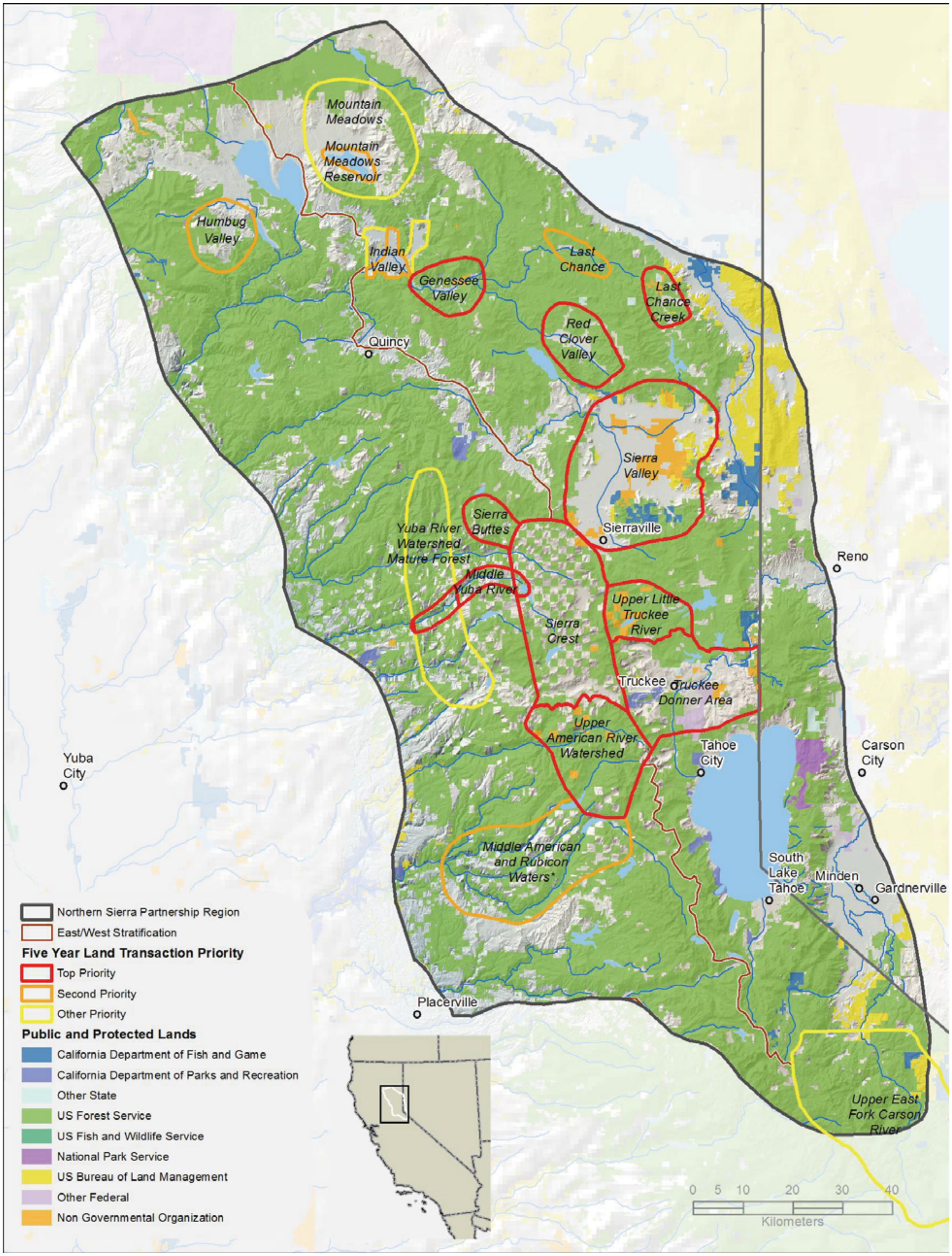
The Northern Sierra captures a substantial portion of diversity in species, habitats and physical environments of the greater Sierra Nevada ecoregion. The Northern Sierra Nevada supports endemic plants, butterflies, amphibians, and fishes. The natural habitats of the Northern Sierra include red fir forest, montane meadows, riparian corridors, and aspen groves. The physical environment across the Northern Sierra shows marked variation in topography, elevation, soils, slope, precipitation, and temperature.

This report integrates climate projections, forecasts of the response of major habitat types, and management simulations to determine: 1) where the northern Sierra's habitats may be at greatest risk from projected future climate changes, and 2) what conservation strategies might be most cost-effective for reducing or adapting to climate risks for selected at-risk ecosystems.

This assessment takes a two-part approach to evaluate what climate change means for the long-term protection of important lands and waters in the region. The first part, Section 2, tries to inform ‘where to work’ on climate adaptation in the project area. We employ a traditional gap analysis approach (Scott, 1993) to assess the degree to which the Partnership’s existing priority areas are capable of meeting current conservation goals under projected future climate scenarios. To evaluate the potential resilience of existing priority areas in the future, we map landscape features expected to promote cooler temperatures and enhance climate adaptation (e.g., north facing slopes, perennial water sources), and we derive future forecasts for each habitat type to identify those areas that are most likely to remain hospitable under future climate change scenarios. By comparing how both landscape features and potential climate refugia are distributed, inside versus outside of existing priority areas, we propose new ranks of current priority landscapes, and identify potential future land acquisitions, in light of climate adaptation.

The second part, Section 3, tries to inform ‘what to do’ for climate adaptation in those portions of the project area that contain vegetation types that are highly at-risk from climate change. Our approach experiments with novel and extensive modifications to an existing public land management tool, the Vegetation Dynamics Development Tool (**VDDT**), to incorporate climate change. Focusing on vegetation types that depart most greatly from their desired range of variability under a climate change scenario, this part evaluates current and future stresses on existing vegetation systems (e.g., mortality, invasion) and then evaluates existing NSP strategies (e.g., stream and meadow restoration, forest thinning, prescribed fire) in terms of cost-benefits for reducing ecosystem degradation and adapting to the risks of climate change. While Sections 2 and 3 detail independent methods and findings, Section 4 synthesizes conclusions and recommendations for the entire climate assessment.

Figure 1-1. Northern Sierra Partnership Region



2 Evaluation of Existing Priority Areas

2.1 Climate Adaptation Planning Methods

The Partnership has defined priority areas for conservation action, and assigned priority ranking for land acquisition in each priority area (see Figure 1-1). This study examines whether the explicit consideration of climate change in relation to major habitat types would alter these priority rankings. To do this, we first determined historical trends and the projected changes in climate for the entire project area. We then determined how well the current priority areas capture the diversity of major habitat types in the project area. For the purpose of this project, we classified major habitat types as Biophysical Settings (hereafter, **BpS**).

Next, we mapped landscape features that are expected to remain cool and wet in the face of climate change. Such features include springs, seeps, north-facing slopes, and river corridors. We defined such landscape features as climatic microrefugia because they may provide refuge to species from the adverse impacts of a changing climate. We determined which priority areas have a high density of microrefugia and thus are more likely to be resilient to climate change.

Finally, we modeled the distribution of major vegetation types to determine the landscape areas most likely to be stressed from climate change, as well as the landscape areas where climatic conditions may remain favorable to major habitat types. Those locations where major habitat types are forecast to persist are defined as Biophysical Setting refugia (henceforth, **BpS refugia**). We calculated the amount of BpS refugia in each priority area, assuming that these will be the areas that provide the most stability as the climate changes.

We combined all of this information to generate an alternative ranking for the priority areas, and then compared with the current priority areas. This information is intended to provide insights about climate change impacts and resilience, in order to help inform future conservation decisions. Section 2.1.1 outlines the specific methods we used to evaluate existing priority areas, and Section 2.2 presents the results of these methods.

2.1.1 Climate Forecast Methods

In order to best determine how to adapt to climate change, we need to understand the historical climate for an area, the recent observed trends, and the projected changes in climate. The historical data is based on direct observations from weather stations over time. These observations are used in a computer model to generate estimates for areas lacking climate stations based on topography, elevation, and other relevant features. Future climate projections are based on computer models that model the earth's atmosphere and ocean for a given trajectory of greenhouse gas emissions. These models are called general circulation models (**GCMs**). When combined, the historical trends and future projections can show how much different the future climate is likely to be from the observed climate.

While other studies have summarized projected climate change for this general area, this is the first summary we know of that includes both historical and future projections from an ensemble of GCMs that is specifically tailored to the Partnership study area.

2.1.1.1 Historical Climate Observations

We calculated the observed climatic averages and trends with the historical climatology developed using the PRISM (Parameter-elevation Relationships on Independent Slopes Model) interpolation method (Daly et al. 2008)[1]. These data provide estimates of minimum temperature, maximum temperature, and precipitation for each 30-arcsec (~800 meter) grid cell in the conterminous United States for each month from 1895 to 2007. We selected the 1961-1990 period as representative of the base climate before significant influences of anthropogenic climate change in order to calculate the magnitude of the projected climate change in the 21st Century.

2.1.1.2 Future Climate Projections

To estimate future climate for the NSP project area, we downscaled projections of future climate from an ensemble of General Circulation Models (GCMs) run to support the International Panel on Climate Change's (IPCC) Fourth Assessment Report archived in the World Climate Research Programme's (WCRP) Coupled Model Intercomparison Project (CMIP) phase 3 multi-model dataset (Table 2-1). We compiled monthly and annual climate data modeled from 11 GCMs for two 20-year time periods (2046-2065 or mid 21st Century, and 2081-2100 or end of the 21st Century). While all the GCMs in the CMIP multi-model dataset project changes in average temperature and precipitation, only 11 GCMs include forecasts of minimum temperature and maximum temperature for the A2 emissions scenario. Data on maximum and minimum temperature are important for species distribution modeling, so we focused our analysis on these 11 GCMs. We selected the A2 emissions scenario (Nakicenovic and Swart 2000) because of the three emissions scenarios analyzed by most modeling groups, the A2 scenario is the closest to the observed trends since 2000 (Raupach et al. 2007). For the GCMs that provided multiple realizations, we averaged the results. We then downscaled the future climate projections to the 30-arcsec (~800m) resolution of the PRISM historical climate data using the change factor approach as described in Klausmeyer and Shaw (2009).

[1] The original data were released in 2008; data for 2002-2006 were updated in March 2009.

Table 2-1. General Circulation Models (GCM) used in this analysis. Full documentation can be found here: http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php. We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modeling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. The U.S. Department of Energy's Office of Science provides support for this dataset.

Model Name	Country	Center Name
CGCM3.1(T47)	Canada	Canadian Centre for Climate Modeling & Analysis
CNRM-CM3	France	Météo-France / Centre National de Recherches Météorologiques
CSIRO-Mk3.5	Australia	CSIRO Atmospheric Research
CSIRO-Mk3.0	Australia	CSIRO Atmospheric Research
GFDL-CM2.0	USA	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory
GFDL-CM2.1	USA	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory
IPSL-CM4	France	Institut Pierre Simon Laplace
ECHO-G	Germany & Korea	Meteorological Institute of the University of Bonn (MIUB), Meteorological Research Institute of KMA (METRI), and Model and Data group (M&D)
ECHAM5/MPI-OM	Germany	Max Planck Institute for Meteorology
MRI-CGCM2.3.2	Japan	Meteorological Research Institute
MIROC3.2 (medres)	Japan	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)

2.1.2 Mapping of Current Vegetation

To map current vegetation we utilized a new classification approach called “biophysical settings” (BpS). The LANDFIRE program (http://gisdata.usgs.net/website/landfire/) provided the underlying vegetation pattern from which we derived the BpS classifications, and we also included minor refinements with more accurate fine-scale vegetation surveys. Biophysical settings describe the expected dominant vegetation in an area prior to European settlement, based upon what is known of today’s vegetation and physical environment, as well as historical disturbance regimes. Biophysical settings are in essence the major habitat types of the Northern Sierra Nevada and are identified by the dominant plant species present in each habitat type.

For details of the vegetation data processing see Appendix A.

2.1.3 Identification of Current Microrefugia

Microrefugia are locations on the landscape that are expected to retain cooler temperatures and higher water availability, compared to other locations, as climate change gradually warms and dries the Sierra Nevada in the future. Microrefugia may be more likely to provide the physical environmental conditions required by some plants and animals in the Sierra Nevada under a changing climate.

There is evidence that species have utilized microclimatic refugia in the past in response to dramatic climate changes between glacial and interglacial periods, and it is likely that microclimatic refugia will play a role in preserving species on a landscape in the current period of anthropogenic climate change (Dobrowski 2010). Features of the landscape can provide enduring microclimatic refugia to a hotter and potentially drier future. For the Northern Sierra, these features include:

- Cold air drainages. As the climate warms, species adapted to cold conditions such as frost may be outcompeted by more warm-adapted species. On cool still nights in mountainous areas, dense cold air drains down slope and pools in valleys. Areas with cold air pooling may continue to support cold-adapted species or meet the ecological requirements of species dispersing to cold air drainages as the surrounding landscape warms (Dobrowski 2010).
- North-facing and shaded slopes. High maximum temperatures in a warmer climate may stress species adapted to current conditions. Maximum temperatures on sunny days are highly dependent on the exposure and shading provided by the local topography, with steep north facing and shaded slopes receiving much less sun and reaching lower maximum temperatures. Evaporative demand is also lower on north-facing slopes, increasing soil moisture and water availability. These slopes may provide a refuge to species in comparison to flat and south facing slopes (Dobrowski 2010).
- Seeps and Springs**.** If the climate becomes warmer and/or precipitation becomes more variable while shifting to more rain-dominated precipitation during cold months, current surface flows may dry up earlier in the summer. Seeps and springs discharge water that has moved through bedrock and alluvium for decades to centuries so they are more likely to maintain steady flows as the climate becomes more variable. Areas on the landscape with a higher density of these features are more likely to provide refuge to plants and animals if the climate becomes drier and more variable.
- Riparian Corridors**.** Riparian corridors can provide multiple microclimatic refugia benefits because they collect water and cold air from the surrounding landscape, and they are often more shaded than exposed slopes (Seavy et al. 2009). Functionally, riparian areas serve as movement corridors for wildlife, aquatic biota, and nutrients serving a key role to adaptation (Wilme et al. 2006).

In order to locate these microclimatic refugia features in the Northern Sierra, we utilized the following methods and data sources:

- Cold air drainages**:** While there have been some recent papers describing methods to map cold air drainages, these methods require fine temporal and spatial scale temperature records for testing and calibration (Chung et al. 2006; Lundquist et al. 2008). These data were not available for this analysis, so we used an existing map of areas that are lower than the surrounding areas called “drainage channels” from the U.S. Geological Survey to identify potential locations for cold air drainage (Sayre et al. 2009). Sayre et al. (2009) identified drainage channels by calculating the topographic position index from ~30-meter National Elevation Dataset (United States Geological Survey (USGS) 2008). The topographic position index compares the elevation at a point to the mean elevation in a 1-kilometer^2 circle around the point (Weiss 2001). In areas where this value is negative, the elevation is lower than the surrounding landscape indicating a local valley. These values were standardized using the standard deviation of the elevation in the 1-kilometer^2 circle, and the lowest topographic position index values were assigned to the drainage channel class to remove some of the smaller localized valleys. This method does not take into account the size of the drainage or any potential blockages to cold air flow on still nights, so it should be regarded as a first-order approximation of cold air drainages.
- North-facing and shaded slopes: We calculated the annual total incoming solar radiation using the ~30-meter National Elevation Dataset (USGS 2008) and the solar insolation tools in ArcGIS. We then broke the landscape into four quartiles and chose the quartile with the lowest insolation (receiving less than 1,395 kilowatts hours per square meter per year) to identify the north-facing and shaded slopes.
- Seeps and Springs**.** We identified all of the seeps and springs from the National Hydrology Dataset. In order to fill in areas with missing data, we combined the seeps and springs from both the 1:100,000 scale National Hydrology Dataset Plus v1.1 (US EPA and USGS 2005) and 1:24,000 scale National Hydrology Datasets (USGS 2009).
- Riparian Corridors**.** We identified all second order perennial streams identified in the National Hydrology Dataset Plus v1.1 (US EPA and USGS 2005).

2.1.4 Forecasts of Vegetation Change Using Surrogate Plant Species

We ran models to forecast how vegetation may be affected by climate change in the Northern Sierra Nevada. We identified a tree or shrub species to serve as a surrogate for most of the BpS habitat types in the project area based on the dominant plant species for that habitat type. We then used the historical and projected future climate data and a method called species distribution modeling to map the climatically suitable conditions for the surrogate species found in the study area. This method provides us with a map of the climatically suitable conditions for species in the base time period (1960-1990) as well as in the future time period (2045-2065). In some cases, these two maps overlap, indicating the area may provide suitable conditions for the species as the climate changes.

BpS refugia are locations where current and future maps of climate suitability overlap. BpS refugia are likely to be more stable in terms of species composition as the climate changes. In the areas where the BpS habitat is currently found, but it is not forecast to be climatically suitable in the future, we assume this will be an area of stress for the surrogate tree or shrub species. As disease, fire, or other disturbances remove the existing vegetation, these areas may transition to another vegetation type. The fate of these areas is more uncertain, so we highlight them as a climate change adaptation feature in this analysis.

2.1.4.1 Biophysical Settings (BpS) Defined by Surrogate Species

The Nature Conservancy's California Climate Adaptation Science Team has generated maps of historical and future climate suitability for most species of trees and shrubs considered to be ecological dominants of the state's terrestrial wildlife habitat types, based upon the California Wildlife Habitat Relationships (**CWHR**) classification system (Mayer and Laudenslayer 1988). While these habitat forecasts were explicitly developed for species, the Partnership required forecasts for biophysical settings (BpS) to provide more relevant information to public land managers in the northern Sierra. We drew upon expert knowledge of vegetation patterns to develop a crosswalk from surrogate species to BpS types in the project area (Hugh Safford, Louis Provencher and Greg Low; pers. comm.)(Table 2-2).

Table 2-2. Biophysical settings (BpS) and the associated surrogate species chosen for forecasting in this climate adaptation assessment.

Biophysical Settings (BpS)	**Surrogate Species**
Subalpine Forests	
Lodgepole Pine - Dry	lodgepole pine
Lodgepole Pine - Wet	lodgepole pine
Red Fir - Western White Pine	red fir
Red Fir - White Fir	red fir
Subalpine Woodland	mountain hemlock
Mid-Elevation Forests	
Aspen-Mixed Conifer Forest	aspen
California Oak-Pine Forest	CA black oak
Mixed Conifer - Mesic	white fir
Ponderosa Pine - Mixed Conifer	ponderosa pine
Yellow Pine	jeffrey pine
Low-Elevation Forests	
Blue Oak–Foothill Pine Woodland	blue oak
Xeric Shrublands	
Montane Chaparral	greenleaf manzanita
Mid-Elevation Shrublands & Woodlands	
Aspen Woodland	aspen
Big Sagebrush Shrubland	big sagebrush
Curleaf Mountain Mahagony	curleaf mountain mahogany
Low Sagebrush	gray low sagebrush
Montane Sagebrush Steppe	mountain big sagebrush
Pinyon Juniper	singleleaf pinyon

In this report, we limit all BpS forecasts to only those areas where the BpS is mapped. If a BpS is not known to occur in an area, we do not consider associated forecasts. For example, as alluded to in Table 2-4, species forecasts for blue oak (*Quercus douglasii*) were used as a surrogate to generate forecasts for blue oak–foothill pine woodlands. Blue oak forecasts were only considered if they fell within areas where blue oak–foothill pine woodlands are known to occur today. For each BpS, current distributions are partitioned into those areas forecasted to be resilient to projected changes in future climate (i.e., BpS refugia) versus those areas forecasted to be at-risk (i.e., climate stress).

For this exercise, BpS refugia are considered priority areas for conservation, particularly for large contiguous areas, because they may offer resilience to expected climatic threats and may increase the probability that major habitat types will persist over decades. In contrast, climate stress zones may identify geographies that are most vulnerable to climate change, as well as potential areas where monitoring programs might look for ecological thresholds and tipping points.

The plant species forecasts designed to represent BpS habitat types assess potential climate impacts from multiple (n=11) projected future climates simultaneously (description of climate data in Sections 2.1 - 2.2). Observation data used to infer species' climatic preferences include a compilation of statewide field surveys (Hannah et al. 2008), supplemented by herbarium specimen records from the California Consortium of Herbaria (http://ucjeps.berkeley.edu/consortium/index.html). All species distribution models were derived using default settings in Maxent (http://www.cs.princeton.edu/~schapire/maxent/), a method shown to model species distributions well in comparative studies (Elith et al. 2006). To summarize species forecasts herein, we use an ensemble approach that treats all futures as equally likely (Araujo and New 2006). For each species forecast, we overlay models of current and future climate suitability, resulting in each of 3 potential categories: (1) areas suitable both today and in the future (i.e., BpS refugia), (2) areas suitable today, but not in the future (i.e., climate stress) or (2) areas suitable in the future, but not today (i.e., expansion). To gauge uncertainty in species forecasts, we distinguish areas where forecasts are based upon high consensus (≥ 80% model agreement) versus moderate consensus (60-80% model agreement).

2.1.4.2 Biophysical Transition Rates

In order to support the dynamic BpS modeling presented in Section 3, we used the results from our BpS forecasts to estimate the rate at which each BpS type may transition to another BpS type as a result of the stresses associated with climate change. To approximate potential transition rates for each BpS type, we first calculated the percent current distribution which is modeled as climate stressed over a future ~80 year interval (1961-1990 to 2045-2065). To forecast annual transition rates, we simply divided % area forecasted to be stressed by the total years considered. For example, if BpS projections suggest 20% of the current distribution may be stressed by climate change over an 80 year interval, then the annual transition rate was calculated to be 0.25% loss per year. The constancy of this rate over 80 years was the simplest assumption in the absence of an alternative assumption (i.e., decreasing or increasing rate of stress) supported by data. For more details on the application of this transition rate, see the forecasting risk to ecosystems component (Section 3).

2.1.5 Evaluation of Current Priority Landscapes

2.1.5.1 Criteria for Existing Priority Landscapes

The current set of NSP priority areas captures the top landscape priorities for each participating organization in the Partnership. The NSP seeks to understand how well its current portfolio achieves landscape conservation goals in light of climate change.

2.1.5.2 Gap Analysis of Adaptation Factors

Three adaptation factors are explored here in a gap analysis to evaluate the suitability of priority areas for major habitat types under a changing climate. The first adaptation factor is the current distribution of major habitat types as mapped through the biophysical settings (BpS) approach. The second factor is climatic microrefugia that are expected to maintain favorable temperatures and water availability under a changing climate. The third factor is the BpS refugia where we expect major habitat types to persist in the future.

A general conservation gap analysis works by determining how much certain conservation elements (species, rare soil, vegetation type, etc) are found within a set of protected areas, and highlighting where representation is low, or, where the conservation "gaps" occur in the protected area network. Rather than species or rare soils, a climate adaptation gap analysis highlights the presence of climate adaptation factors, or factors that would allow existing biota to persist given future climate projections within NSP priority protection areas.

Conservation plans often aim for a minimum level of representation as a goal (e.g., 20% of current extent) to safeguard against loss of any characteristic conservation element in the region. As biodiversity is unevenly distributed (some habitats harbor more total or endemic species), many conservation plans vary the minimum level based on the importance of a given element for overall diversity (e.g., rare elements get a higher goal).

For all three factors considered in the gap analysis, we calculated representation within individual priority areas, representation within all priority areas east versus west of the Sierra crest (to account for the large difference in current climate on each side of the crest), and finally, representation within the entire project boundary (both priority and non-priority). We set a baseline goal of 20% representation in priority areas for all adaptation factors. We then used ratios from these assessments to evaluate how well adaptation features are represented in the current set of NSP priority landscapes.

2.1.5.3 Climate Adaptation Ranking of Priority Landscapes

The Partnership has established five year priorities for land transactions in each of the priority landscapes (Figure 1-1). We wanted to determine how these rankings might be altered to reflect the representation of adaptation factors in each priority landscape. To do this for the current distribution of BpS types, we simply ranked the priority landscapes by the count of unique BpS it contains. We assumed that priority landscapes containing a higher diversity of BpS today will likely be more resilient to change in the future, because as the climate changes, it is more likely that there will be species present to capitalize on the new conditions if there is a high diversity of species in the priority area now. For microrefugia and BpS refugia, we calculated the percent of each adaptation factor identified within a given priority area relative to the total available on that side of the Sierra Nevada crest. We then summed these percentages for all categories (e.g., north facing slopes microrefugia, ponderosa pine macrorefugia) to rank each priority area in terms of the representation of either microrefugia or BpS refugia. Since larger areas tend to contain more adaptation factors than smaller ones, we normalized (divided) this score by the area of each priority area relative to the size of its side of the study area. The resulting index can be used to rank the priority areas in terms of their density and diversity of microrefugia or BpS refugia.

Finally, we generated a summary score that synthesizes the ranks of the priority landscapes for each adaptation factor. To do this, we calculated the rank for each adaptation factor, then added the ranks together. Based on this analysis, the priority landscapes with the lowest summed ranks are the most important to protect to promote the adaptation of the species in the NSP region.

2.2 Climate Adaptation Key Findings About ‘Where to Work’

2.2.1 Climate Impacts

All of the GCMs analyzed project significant warming in the NSP region by 2050 (see Appendix B for maps and figures of the projected changes). When looking at a 20 year moving average, average annual minimum temperatures generally ranged from between 33.5° and 34.5°F in the region from 1900 to 1990 (Appendix B, Figure B1). Starting in the 1990s, the trend has increased so that the average annual minimum temperature for the 1988-2007 period was almost 36°F. The GCMs project temperatures will continue to increase, with the average annual minimum temperature for the 2046-2065 period ranging from 37° to 39°F (a 3° to 5°F projected increase from pre-1990 temperatures). By the end of the century, the hottest GCM project a 20-year average annual minimum temperature of 41°F. While the recent trends in average annual maximum temperatures are not so pronounced, the projected changes are similar (Appendix B, Figure B2).

While the GCMs all project warming in the future, they do not agree on the sign or magnitude of the projected changes in precipitation (Appendix B, Figure B3). The 20-year moving average of precipitation across the region varied from 36 to 48 inches over the 20th century. Most of the GCM projections for the mid 21st century also fall in this range, although two project significantly wetter conditions reaching 55 inches per year. Compared to the base period of 1961-1990, the majority if models project a drier future, but the projected change is small relative to historical variability. Appendix B also contains a series of maps showing the spatial patterns of the current climate in relation to the projected climate by the middle and end of the 21st Century.

2.2.2 Evaluation of Conservation Priority Landscapes

2.2.2.1 Representation & Interpretation of Current Vegetation Systems

The Northern Sierra Partnership assessment involves an approximately five million acre landscape that includes 25 major habitat types, called biophysical settings, ranging from sagebrush shrublands to subalpine woodlands and alpine shrublands (Figure 2-1). Five forest systems comprise over 75% of the project area. The largest major habitat type covers approximately 1,100,000 acres, the mesic mixed conifer forest, followed by approximately 900,000 acres of yellow pine and 784,000 acres of ponderosa pine.

In general the level of representation for the ten most extensive BpS habitats is quite high (>20%) across the study area (Figures 2-2, 2-3) with the exception of Ponderosa Pine-Mixed conifer and Big Sagebrush Shrubland. The BpS habitats most poorly represented within priority areas (Figures 2-4 – 2-5) on the west side include Lodgepole Pine–Dry (0%), Blue Oak-Pine Foothill Woodland (3%), Subalpine Meadow (4%), Pinyon-Juniper Woodland (5%) and Alpine Shrubland (5%). Yet, all of these types have less than 5000 acres in the west side of the study area, suggesting they are not widely distributed and may be more common elsewhere in the Sierra or Central Valley foothills. Two types, Alpine Shrubland and Subalpine Meadow are naturally limited but well-protected in existing Wilderness and National Parks in the Sierra, and will likely be strongly affected by warming temperatures. Blue Oak-Foothill Pine woodlands are more common lower in elevation around the Central Valley and as such are not common in the study area. More widely distributed types that fall below 20% on the west side include Ponderosa pine – Mixed conifer (11%), California Montane Riparian (11%), California Mixed Evergreen Forest (11%), and Yellow Pine–East Side (16%). The most extensive area that is missed is the Ponderosa Pine–Mixed Conifer, and as shown on Figure 2-2, this type is widely distributed along the western boundary of the study area. This would be a logical place to add an additional priority area(s) to better meet a minimum goal for representation within the NSP study areas. This BpS is typically found on National Forest lands and private timberlands outside of wilderness areas.

The Ponderosa Pine–Mixed Conifer habitat is also widely distributed on the east side, but falls just short of the 20% minimum, at 19%. A more significant gap is found in the Big Sagebrush Shrubland which is only 10% picked up by priority areas. This is not surprising given the distribution of this type in valley floors and low foothills just west of the major developed areas on the east side, far from the focus of the NSP on the higher elevation forest ecosystems. If there was a goal within the Partnership to have a representative mix of ecosystems within priorities, then this would be one of the first places to expand. Similar types that are poorly represented on the east side include Low sagebrush (2%) and Mixed Salt-Sodic Desert Scrub (3%). Several less common types fall below the 20% cutoff on the east side as well, including Curleaf Mountain Mahogany, Lodgepole Pine–Dry, and Aspen Woodland.

Figure 2-1. Map of Northern Sierra biophysical settings.

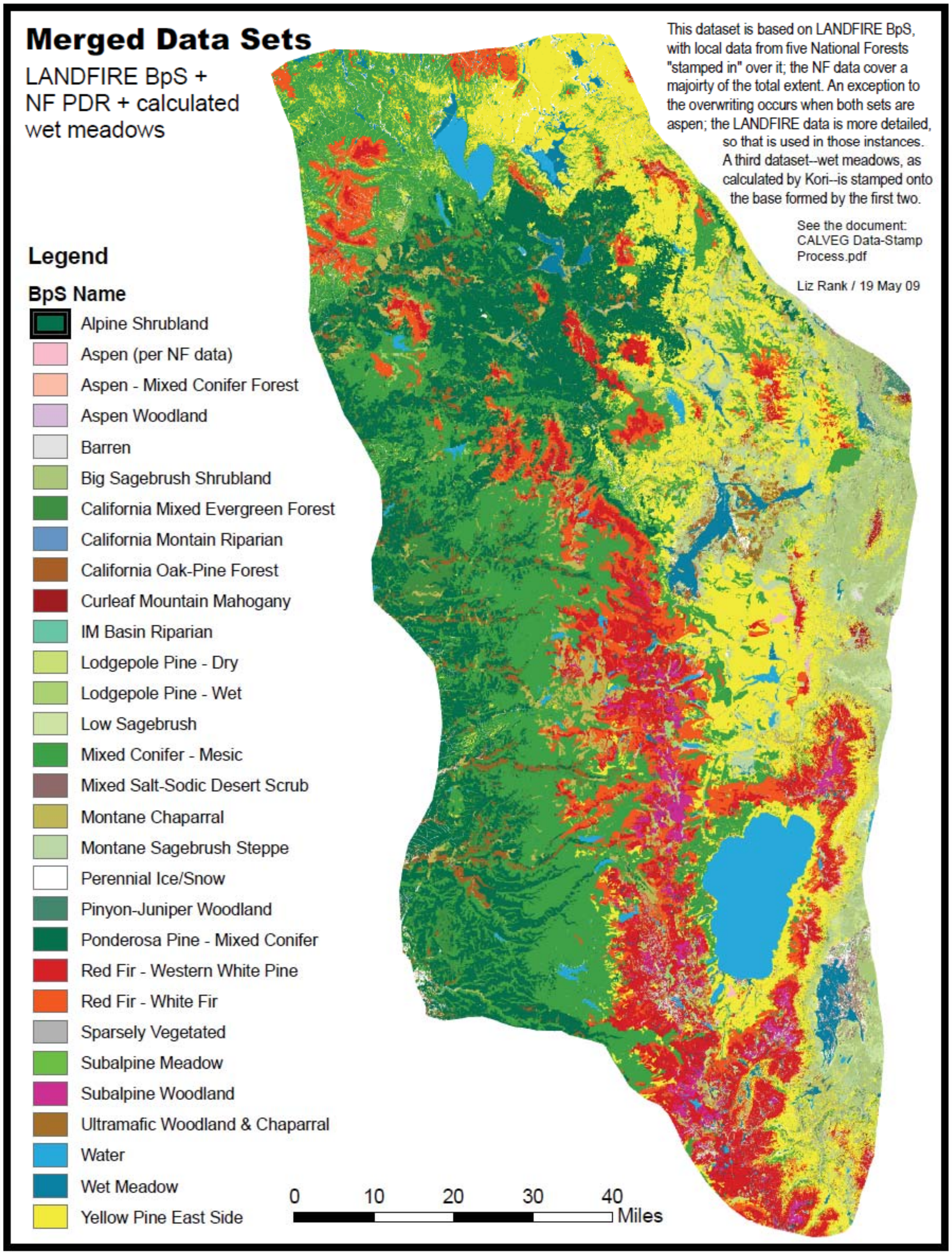


Figure 2-2. Current representation of common biophysical setting (BpS) types (> 40,000 acres in the study area) within NSP priority areas east of the Sierra Nevada crest.

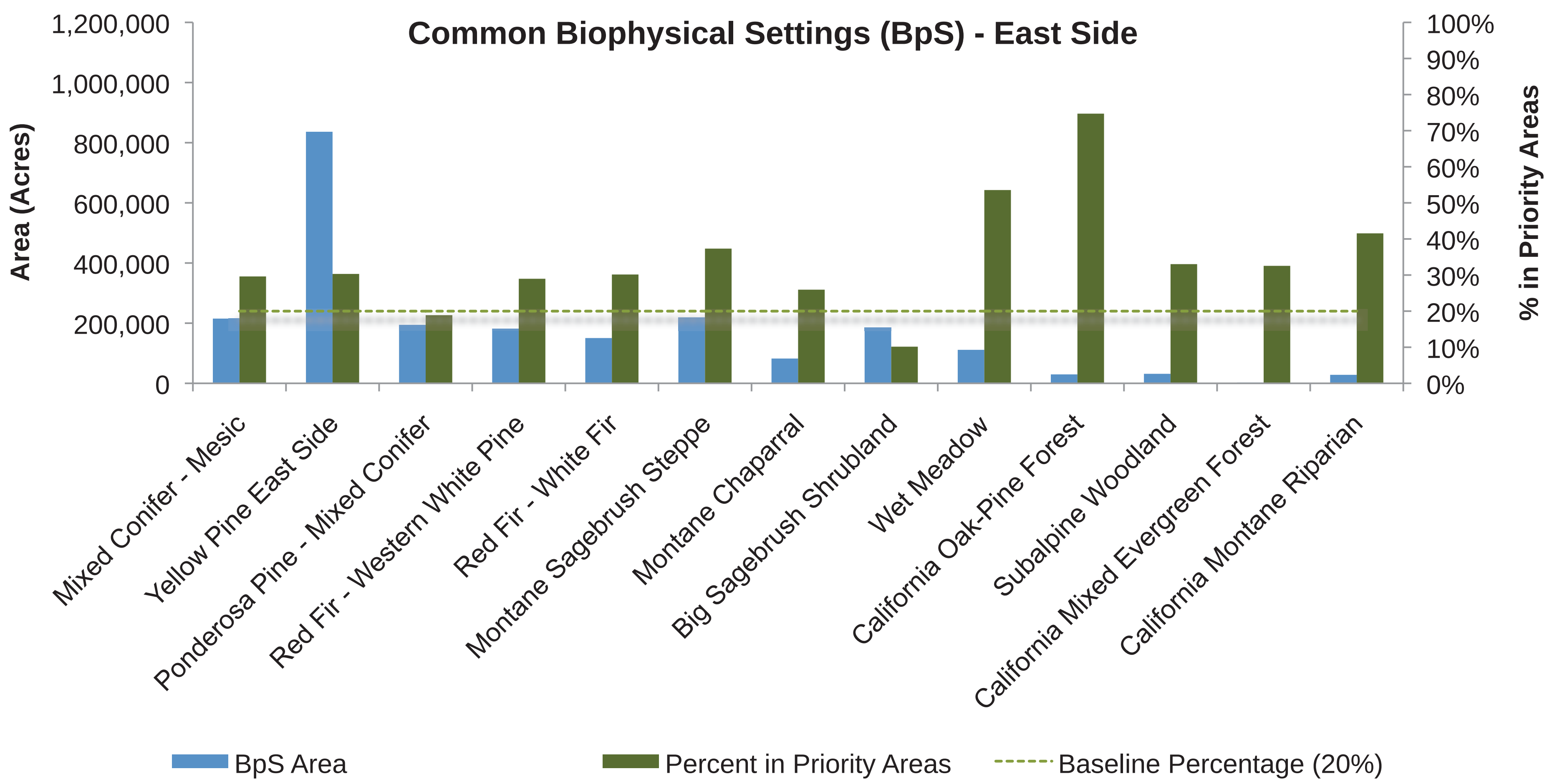


Figure 2-3. Current representation of common biophysical setting (BpS) types (> 40,000 acres in the study area) within NSP priority areas west of the Sierra Nevada crest.

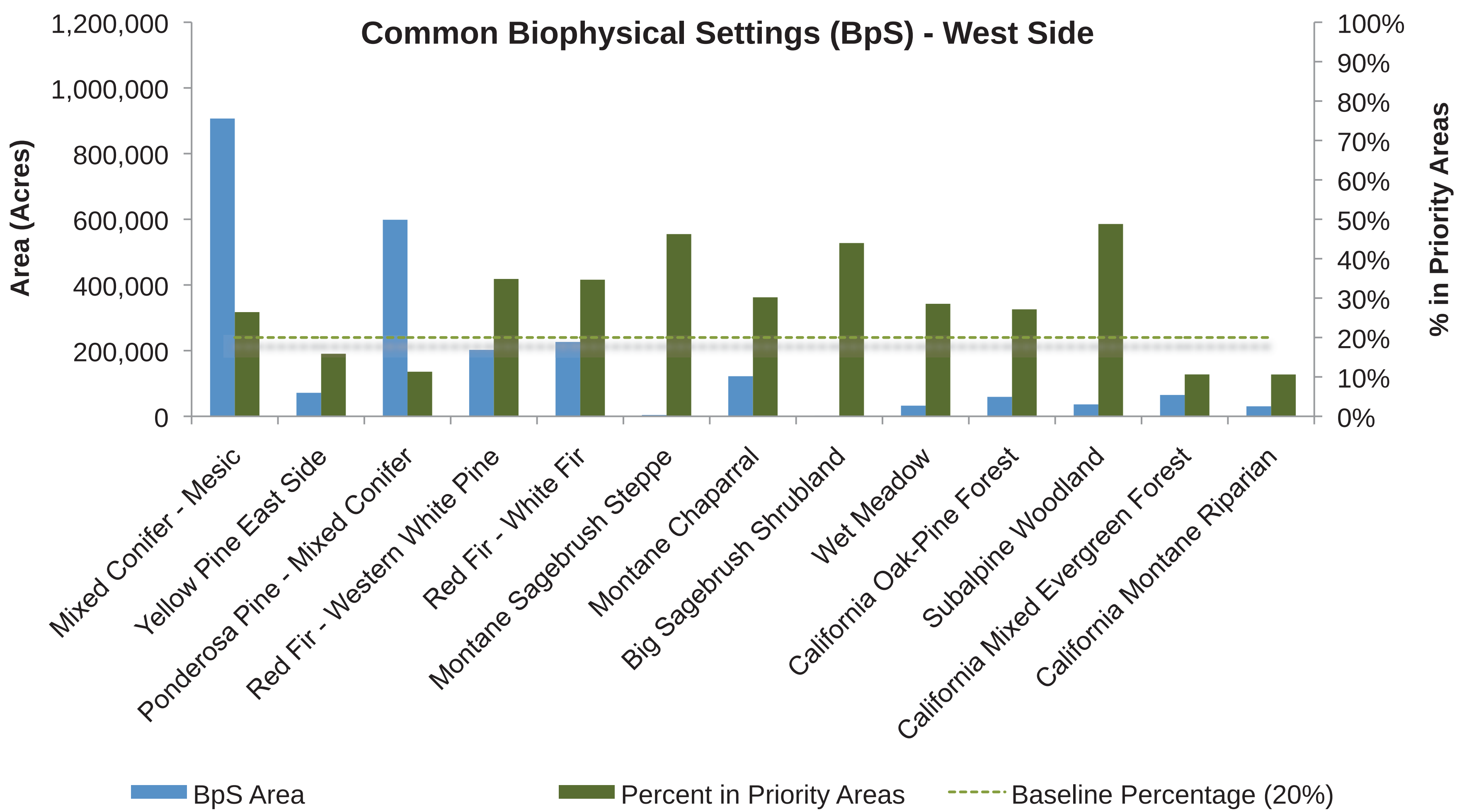


Figure 2-4. Current representation of less common biophysical setting (BpS) types (< 40,000 acres in the study area) within NSP priority areas east of the Sierra Nevada crest.

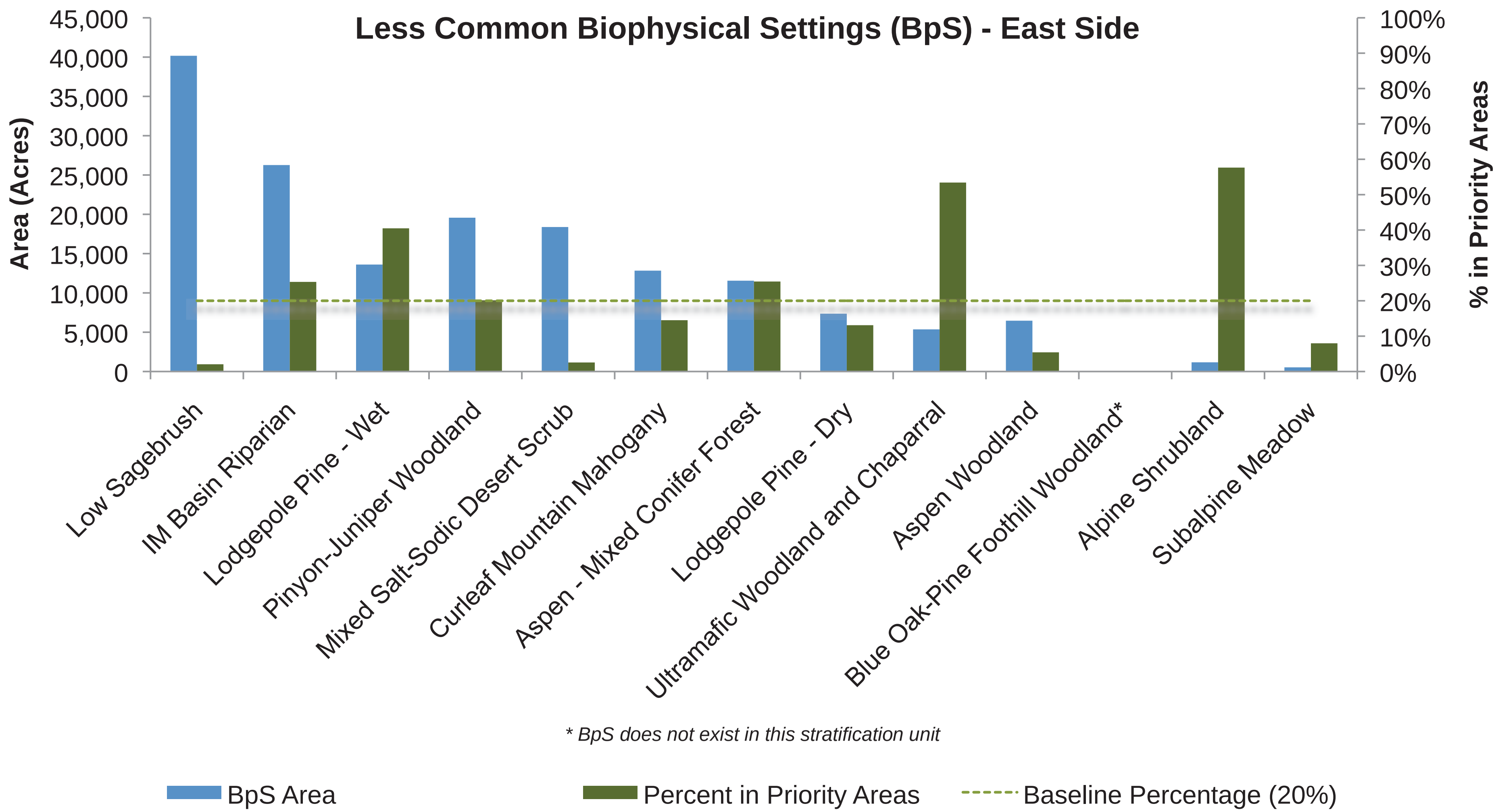


Figure 2-5. Current representation of less common biophysical setting (BpS) types (< 40,000 acres in the study area) within NSP priority areas west of the Sierra Nevada crest.

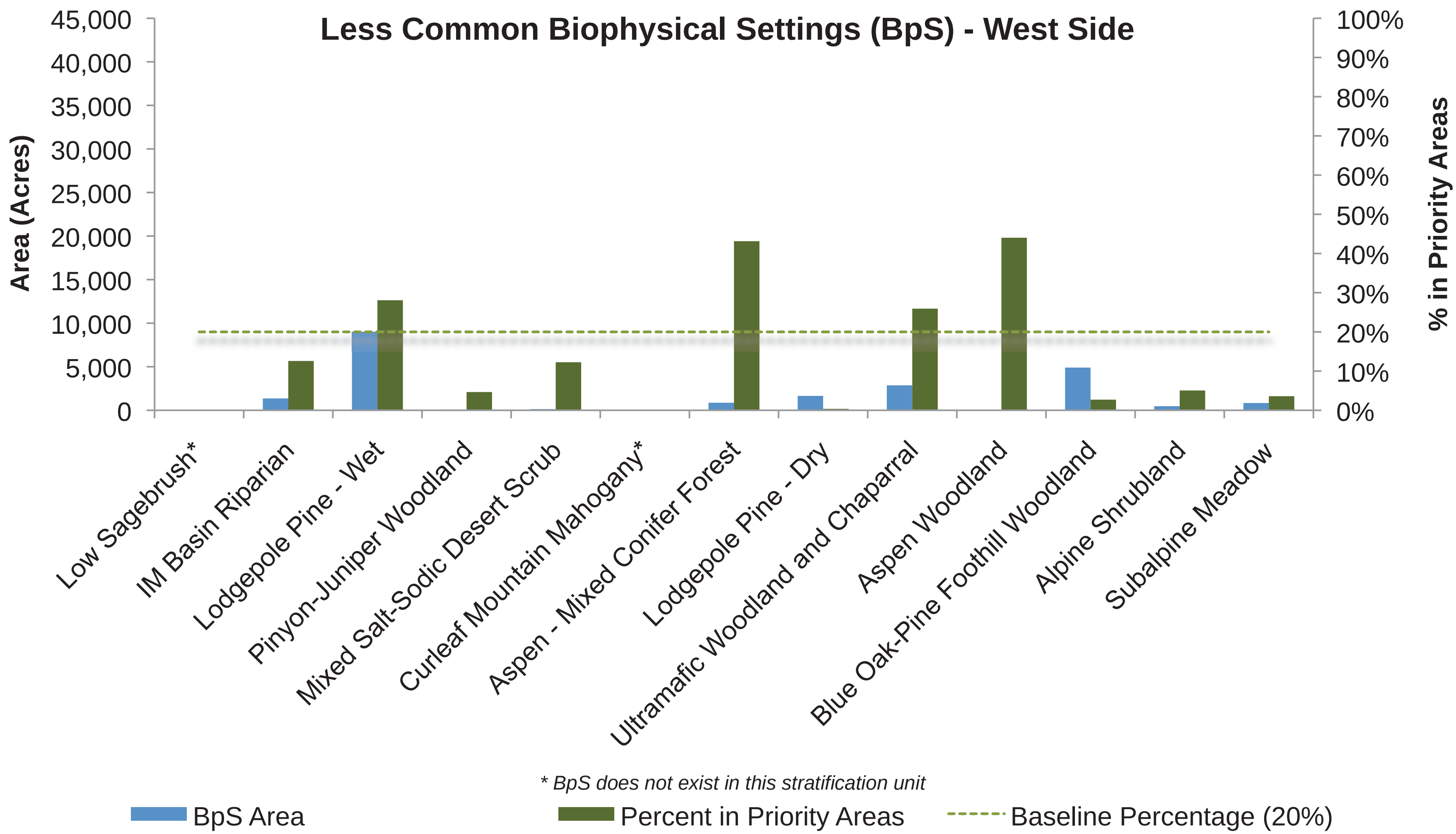
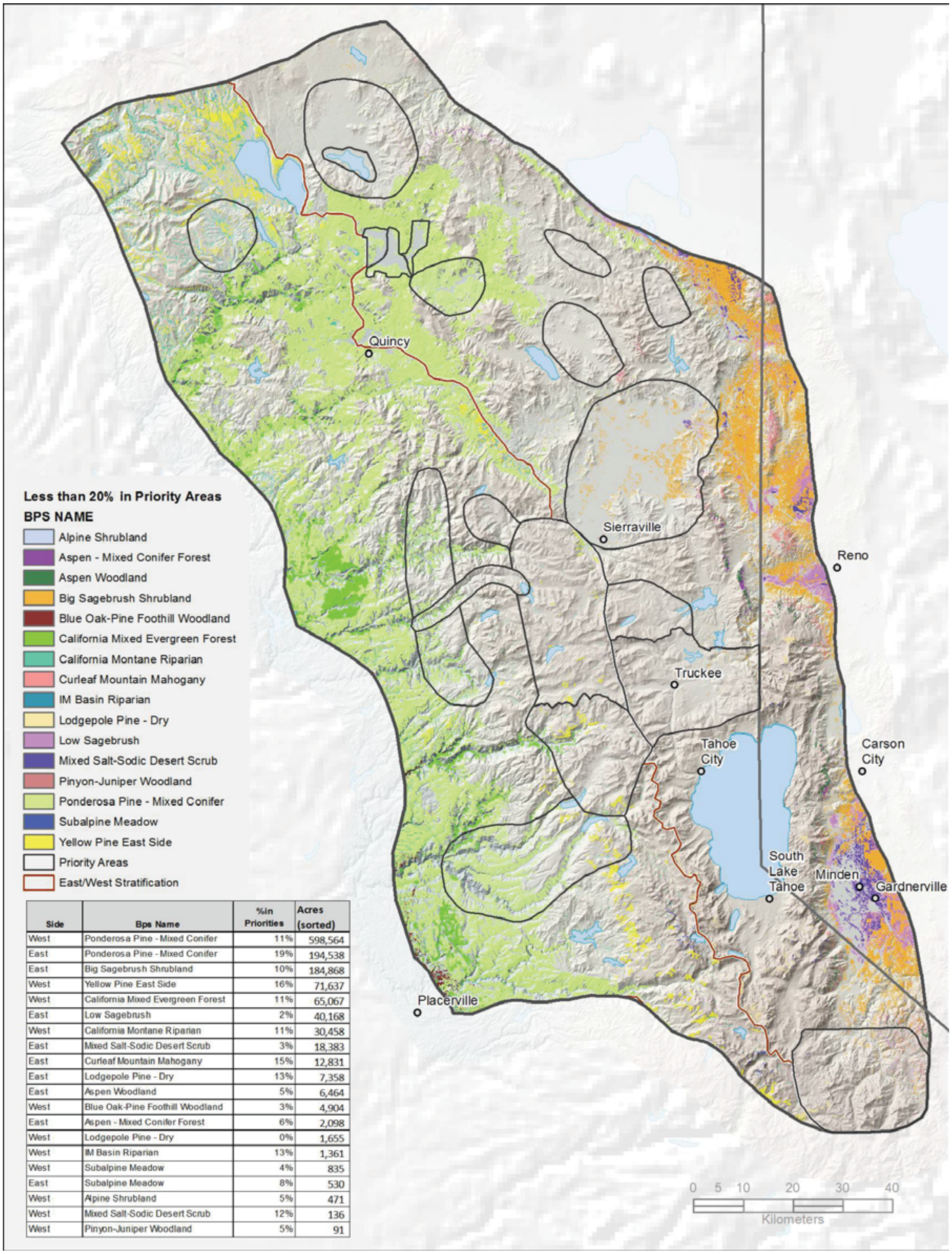


Figure 2-6. Current distribution of under-represented biophysical settings (BpS) within NSP priority areas.



Side	Bps Name	%in Priorities	Acres (sorted)
West	Ponderosa Pine - Mixed Conifer	11%	598,564
East	Ponderosa Pine - Mixed Conifer	19%	194,538
East	Big Sagebrush Shrubland	10%	184,868
West	Yellow Pine East Side	16%	71,637
West	California Mixed Evergreen Forest	11%	65,067
East	Low Sagebrush	2%	40,168
West	California Montane Riparian	11%	30,458
East	Mixed Salt-Sodic Desert Scrub	3%	18,383
East	Curleaf Mountain Mahogany	15%	12,831
East	Lodgepole Pine - Dry	13%	7,358
East	Aspen Woodland	5%	6,464
West	Blue Oak-Pine Foothill Woodland	3%	4,904
East	Aspen - Mixed Conifer Forest	6%	2,098
West	Lodgepole Pine - Dry	0%	1,655
West	IM Basin Riparian	13%	1,361
West	Subalpine Meadow	4%	835
East	Subalpine Meadow	8%	530
West	Alpine Shrubland	5%	471
West	Mixed Salt-Sodic Desert Scrub	12%	136
West	Pinyon-Juniper Woodland	5%	91

Table 2-3. Diversity of BpS types in each of the 19 NSP priority areas. The Upper East Fork Carson River priority area contains the highest diversity with 28 unique BpS types, followed closely by Truckee Donner Area (26), Sierra Crest (25) and Upper American River Watershed (25). The Last Chance priority area has the lowest diversity with 11 BpS types. This does not suggest that lower ranking sites should not be priority areas, only that such sites include lower diversity of BpS types than others.

Table 2-3 Diversity of BpS types in each Priority Area

Zone	Priority area name	Count of BpS types	Feature rank
East	Upper East Fork Carson River	28	1
East	Truckee Donner Area	26	2
West	Sierra Crest	25	3
West	Upper American River Watershed	25	3
East	Mountain Meadows (rank 3)	23	5
East	Upper Little Truckee River	23	5
East	Sierra Valley	22	7
West	Middle American and Rubicon Waters	20	8
East	Genessee Valley	19	9
East	Red Clover Valley	19	9
West	Sierra Buttes	19	9
West	Humbug Valley	18	12
West	Middle Yuba River	17	13
West	Yuba River Watershed Mature Forest	17	13
East	Last Chance Creek	16	15
East	Indian Valley (rank 2)	15	16
East	Mountain Meadows (rank 2)	15	16
East	Indian Valley (rank 3)	14	18
East	Last Chance	11	19

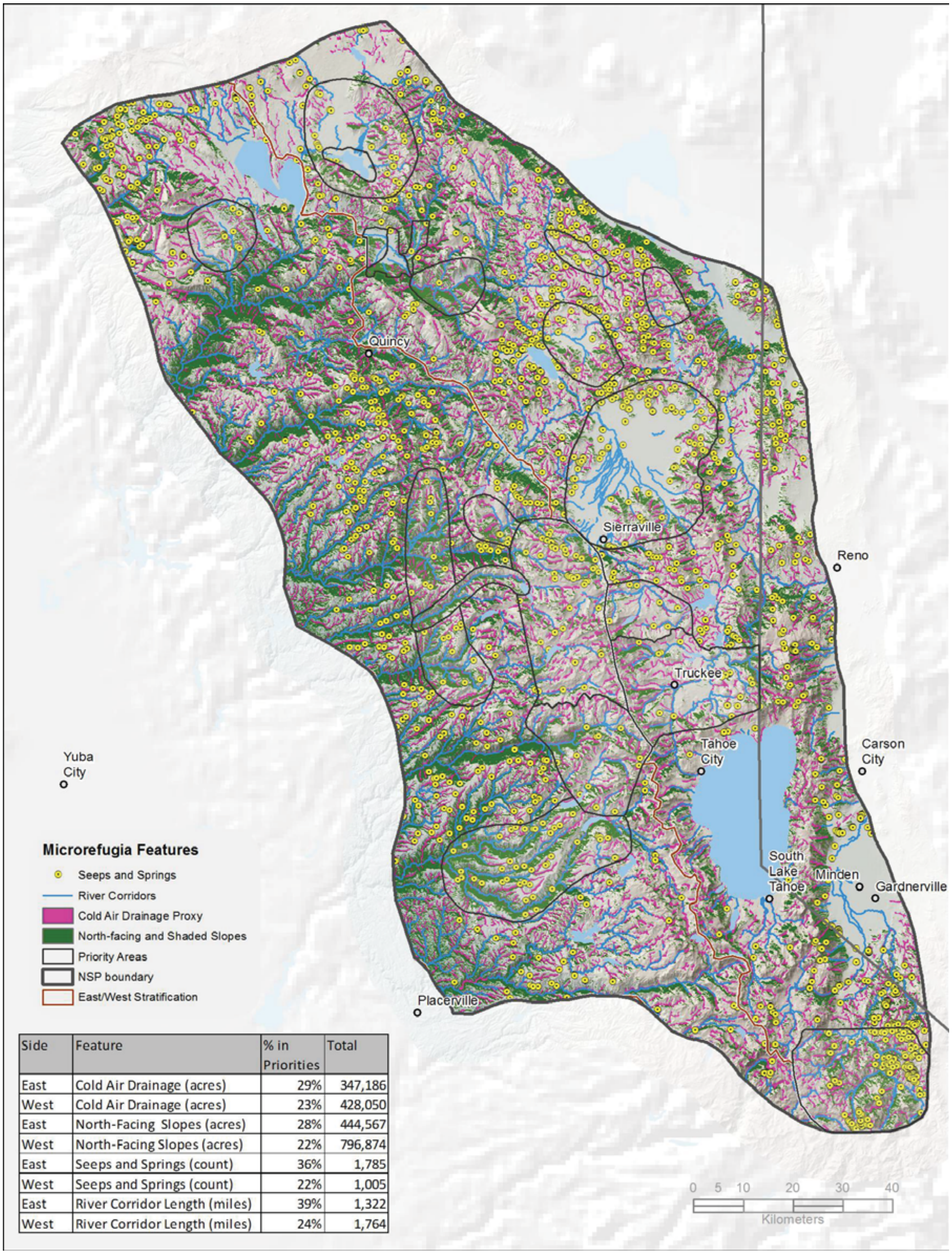
2.2.2.2 Representation & Interpretation of Existing Microrefugia

The Northern Sierra Partnership study area contains a high density of microrefugia (Figure 2-7), including over 775,000 acres of cold air drainages, 1.2 million acres of north-facing and shaded slopes, 2,790 seeps and springs, and over 3,000 miles of river corridors. The higher elevation areas contain relatively more cold air drainages and seeps and springs, while the steep slopes associated with the major drainages on the west side and the escarpments on the east side contain the majority of the north-facing and shaded slopes. River corridors are distributed throughout the study area.

The existing priority areas include a good representation of these microrefugia features on both the east and west side of the Sierra Nevada crest. As shown in Figure 2-8, the priority areas on the east side of the study area contain 39% of the river corridors, 36% of the seeps and springs, 29% of the cold air drainages, and 28% of the north-facing and shaded slopes. As shown in Figure 2-9, the priority areas on the west side of the study area contain 24% of the river corridors, 22% of the seeps and springs, 23% of the cold air drainages, and 22% of the north-facing and shaded slopes. While in general the representation percentages are a little lower in the west side, all of the features are better represented than our 20% baseline on both sides of the Sierra Nevada crest.

Figure 2-7 shows the percentage of the total microrefugia features represented in each priority area. In general, the microrefugia features are well distributed throughout the study area, but some priority areas contain a higher percentage of a given feature. The Upper Each Fork Carson River priority area contains the highest percentage (6.4%) of the cold air drainage area and the highest percentage (17.6%) of the seeps and springs. The Middle American and Rubicon Waters priority area contains the highest percentage (7.6%) of the north-facing and shaded slopes, and the Sierra Valley contains the highest percentage (12.3%) of river corridor length. After summing the percentages and normalizing by area, the Upper East Fork Carson River has the most diversity and highest density of microrefugia features, followed by Genessee Valley, Indian Valley, and the Middle American and Rubicon Waters.

Figure 2-7. Current distribution of all microrefugia within NSP study area.



Side	Feature	% in Priorities	Total
East	Cold Air Drainage (acres)	29%	347,186
West	Cold Air Drainage (acres)	23%	428,050
East	North-Facing Slopes (acres)	28%	444,567
West	North-Facing Slopes (acres)	22%	796,874
East	Seeps and Springs (count)	36%	1,785
West	Seeps and Springs (count)	22%	1,005
East	River Corridor Length (miles)	39%	1,322
West	River Corridor Length (miles)	24%	1,764

Figure 2-8. Current representation of microrefugia within NSP priority areas east of the Sierra Nevada crest.

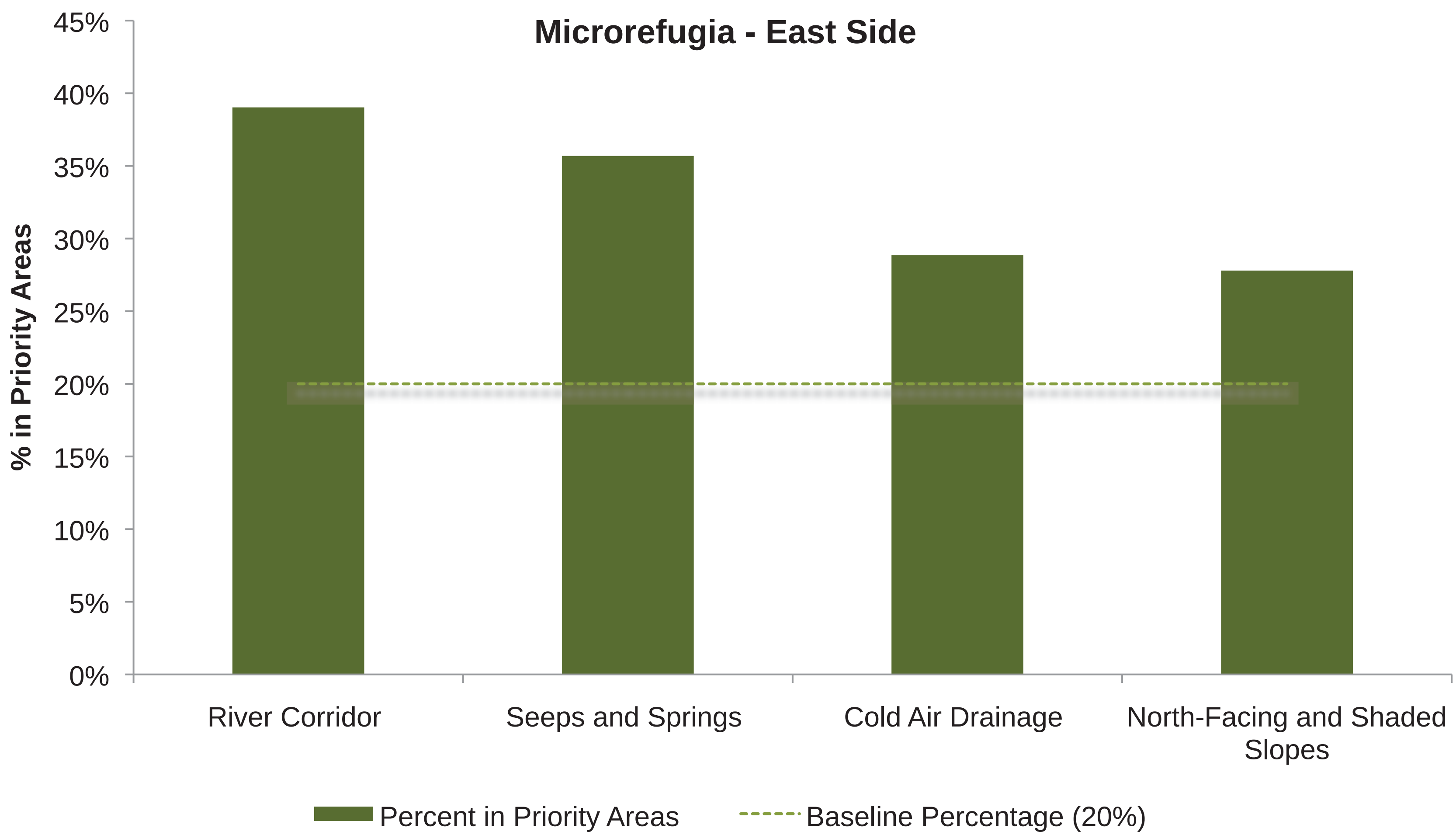


Figure 2-9. Current representation of microrefugia within NSP priority areas west of the Sierra Nevada crest.

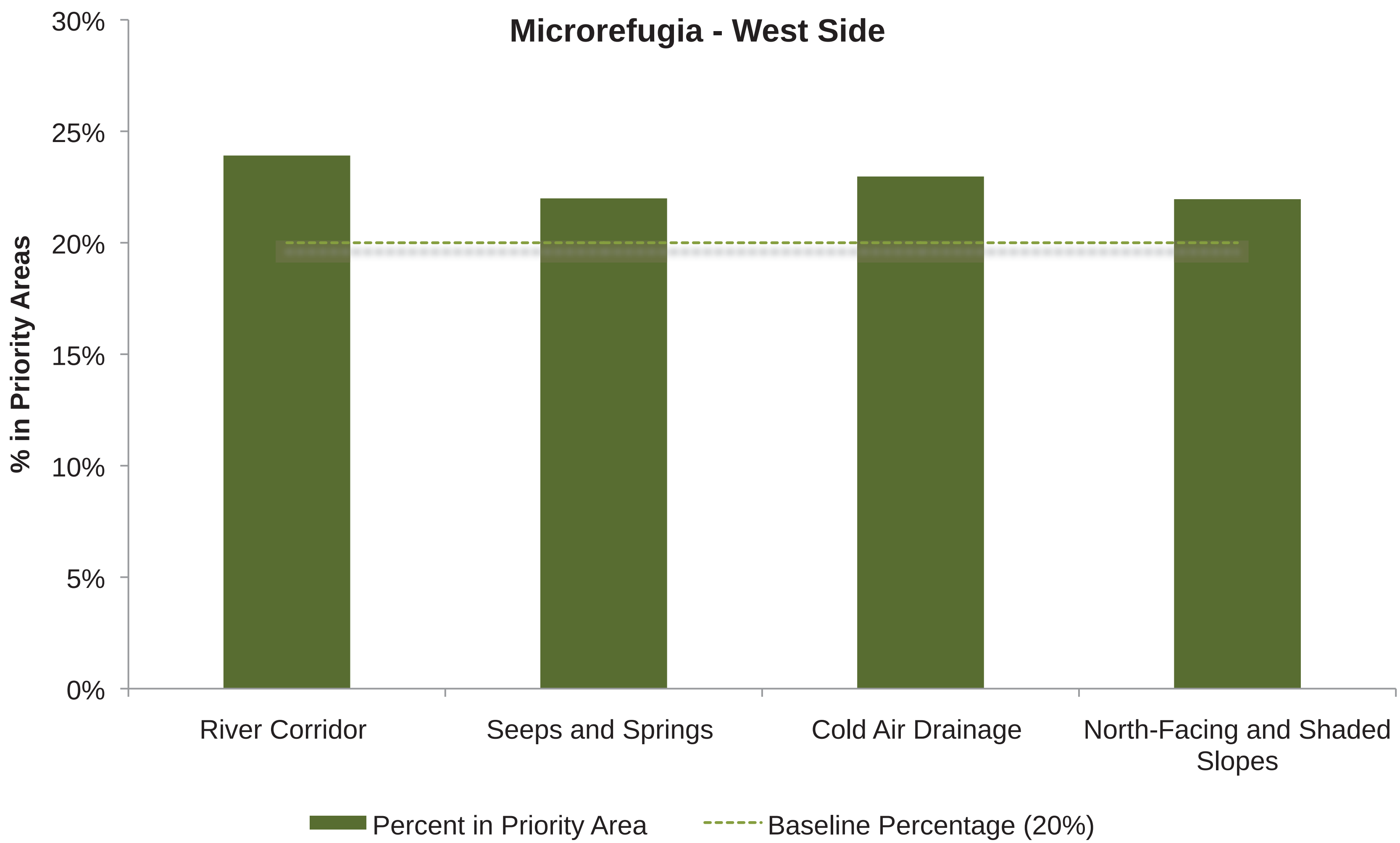


Table 2-4. Density and Diversity of Microrefugia within NSP Priority Areas	**Priority area name**	**Percent of the microrefugia for a given side in each priority area**					**Index normalized by area**	**Feature rank**
		Cold air drainage (%)	North-facing and shaded slope (%)	Seeps and springs (%)	River corridor (%)	Sum (%)		
East	Upper East Fork Carson River	6	6	18	7	37	7.8	1
East	Genessee Valley	2	4	0	2	8	6.4	2
East	Indian Valley (rank 2)	0	1	0	1	2	6.1	3
East	Indian Valley (rank 3)	0	1	0	1	3	5.9	4
West	Middle American and Rubicon Waters	5	8	8	7	28	4.8	5
West	Yuba River Watershed Mature Forest	5	6	3	5	19	4.5	6
East	Last Chance	1	0	1	0	3	4.4	7
East	Sierra Valley	4	5	11	12	33	4.3	8
East	Truckee Donner Area	6	4	2	7	18	4.1	9
East	Upper Little Truckee River	2	1	1	3	6	3.8	10
West	Middle Yuba River	1	1	0	1	4	3.7	11
East	Last Chance Creek	1	1	0	1	3	3.7	12
West	Humbug Valley	2	1	1	2	5	3.5	13
West	Sierra Buttes	1	1	1	1	3	3.4	14
East	Red Clover Valley	2	2	1	1	6	3.4	15
East	Mountain Meadows (rank 3)	4	4	1	3	12	3.2	16
West	Sierra Crest	6	3	6	5	19	3.2	17
West	Upper American River Watershed	4	3	3	3	12	3.1	18
East	Mountain Meadows (rank 2)	0	0	0	0	1	1.9	19

2.2.2.3 Representation & Interpretation of Forecasted BpS Refugia

BpS refugia provide an estimate of the relative resilience of the BpS habitat type to projected climate change. Refugia may also indicate where current conservation action is likely to protect a given BpS into the foreseeable future. To assess the performance of our BpS forecasts, we tested how well each BpS forecast accurately recovered known BpS distributions today (Figures 2.10, 2.11) High performance implied our forecasts provide future projections of habitat distributions for most of the range where habitats actually occur today. Forecasts varied significantly in terms of recovering current BpS extents, with most (n=11 of 15) providing future projections for over half of each known BpS distribution. Two forecasts showed high levels of uncertainty (e.g., < 80% model consensus across 11 futures, or no forecast at all) thus they were excluded from consideration for evaluation of conservation priorities (i.e., Pinyon-Juniper Woodlands, Montane Chaparral). Similarly, two forecasts for BpS types representative of foothill (i.e., Blue Oak–Foothill Pine) and Great Basin communities (i.e., Big Sagebrush Shrublands) were excluded from evaluations of our priorities because they are considered peripheral systems for the NSP.

Forecasts of BpS refugia often identified surprising similarities in the proportions of climate refugia versus climate stress east and west of the Sierra Nevada crest, despite stark environmental differences between the areas. Potential climate refugia dominated the current extent for five BpS forecasts (Mixed Conifer–Mesic, Yellow Pine–East Side, Ponderosa Pine–Mixed Conifer, Subalpine Woodland, Lodgepole Pine–Dry), whereas potential climate stress dominated four BpS forecasts (Red Fir–White Fir, Lodgepole Pine–Wet, Aspen Woodland, Aspen–Mixed Conifer).

Existing NSP priority areas capture ≥ 20% of projected refugia for most BpS types (Figures 2-12, 2-13) in the East (n = 12 of 15) and West (n = 7 of 15). BpS types with under-represented climate refugia forecasts in current NSP priority areas (< 20% available; Figures 2-14 – 2-17) include what appear to be a mix of patchy vulnerable systems (e.g., Lodgepole Pine–Wet, Lodgepole Pine–Dry, Aspen Woodland, Aspen–Mixed Conifer) and abundant systems in the East (Yellow Pine – East Side) and West stratification units (Ponderosa Pine – Mixed Conifer).

Some priority areas capture a greater diversity and density of projected BpS refugia than others (Table 2-5). The Upper East Fork Carson River priority area captures the most refugia for the most BpS, even after normalizing by area. Genessee Valley, Upper Little Truckee River and Sierra Crest priority areas follow as the most significant areas for BpS refugia. Mountain Meadows (rank 2) contains almost no projected refugia for the species studied.

Figure 2-10. Climate Forecasts for Biophysical Settings (BpS) East of the Sierra Nevada Crest.

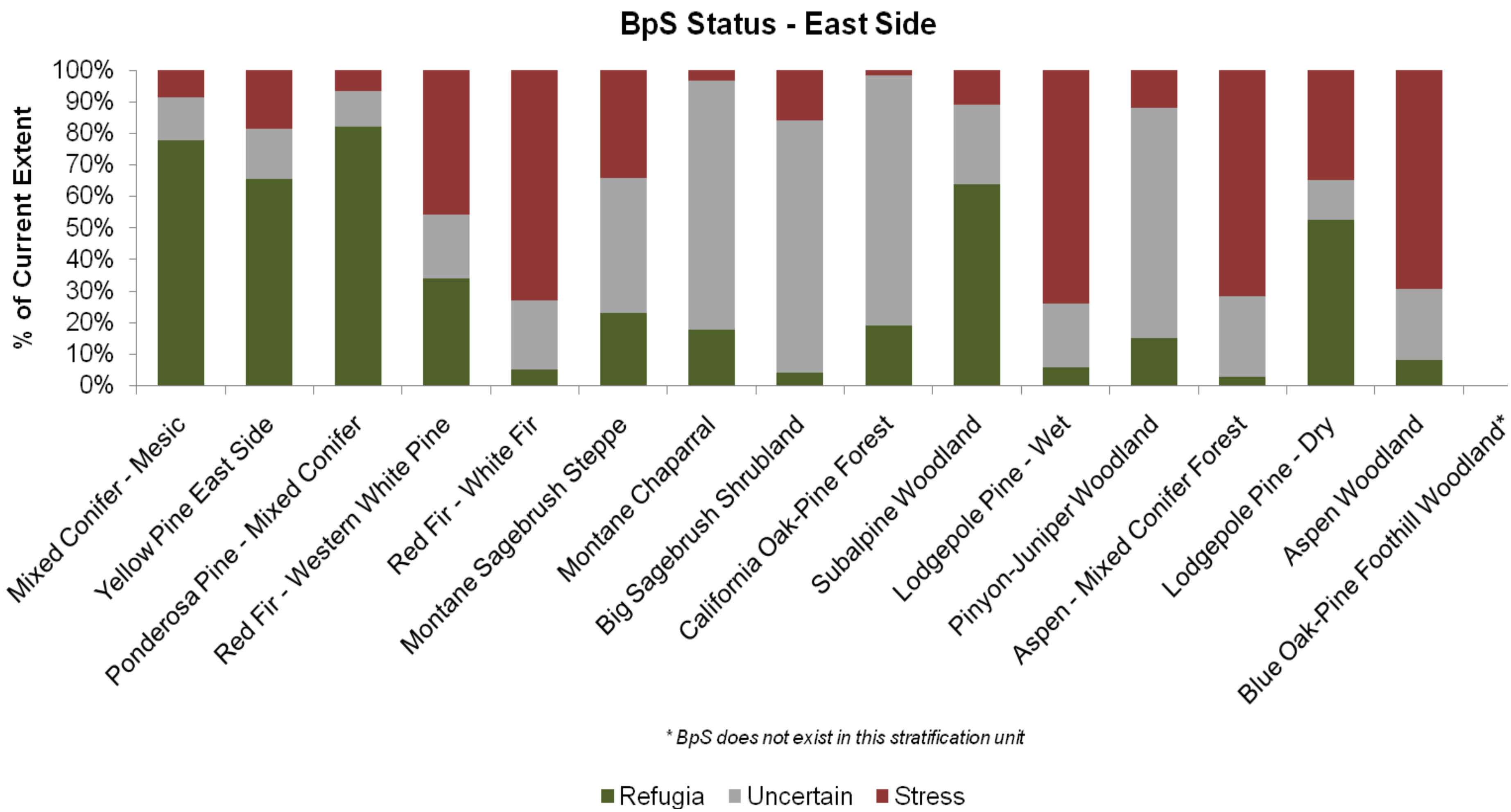


Figure 2-11. Climate forecasts for biophysical settings (BpS) west of the Sierra Nevada crest.

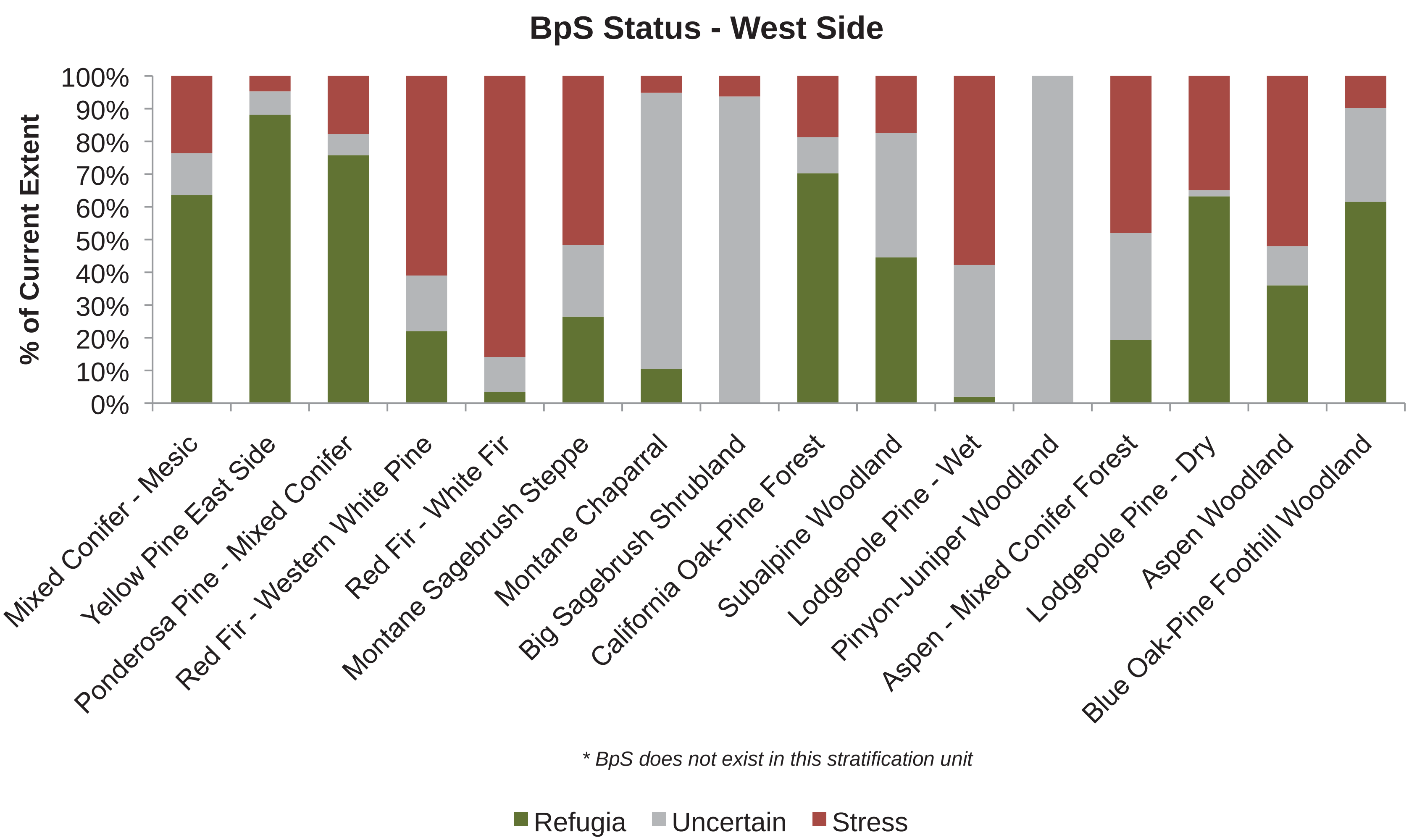


Figure 2-12. Current representation of potential climate refugia for biophysical setting (BpS) types within NSP priority areas east of the Sierra Nevada crest.

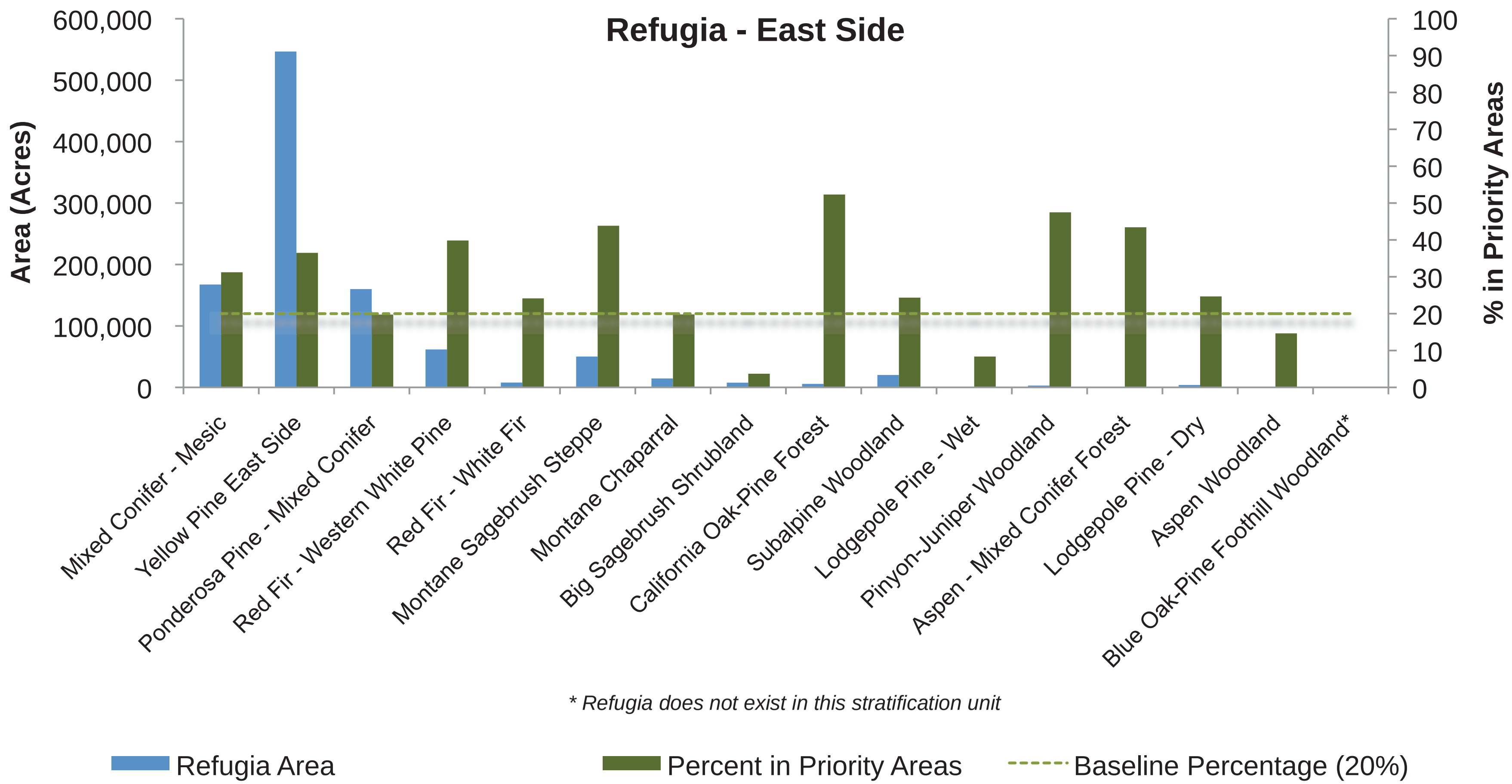


Figure 2-13. Current representation of potential climate refugia for biophysical setting (BpS) types within NSP priority areas west of the Sierra Nevada crest.

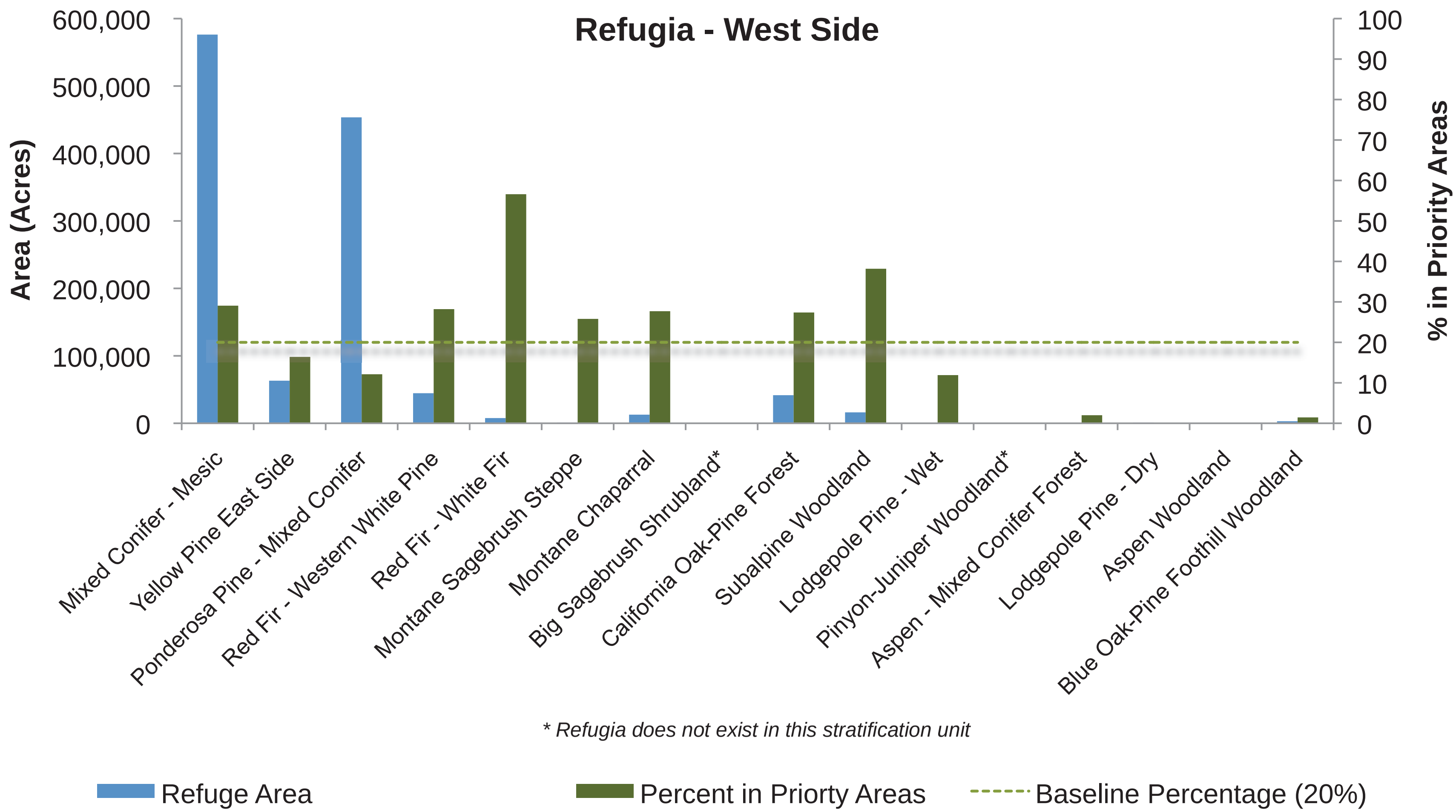


Figure 2-14. Map of potential climate refugia for both Aspen Woodlands and Aspen–Mixed Conifer forests, which are currently under-represented biophysical setting (BpS) within NSP priority areas.

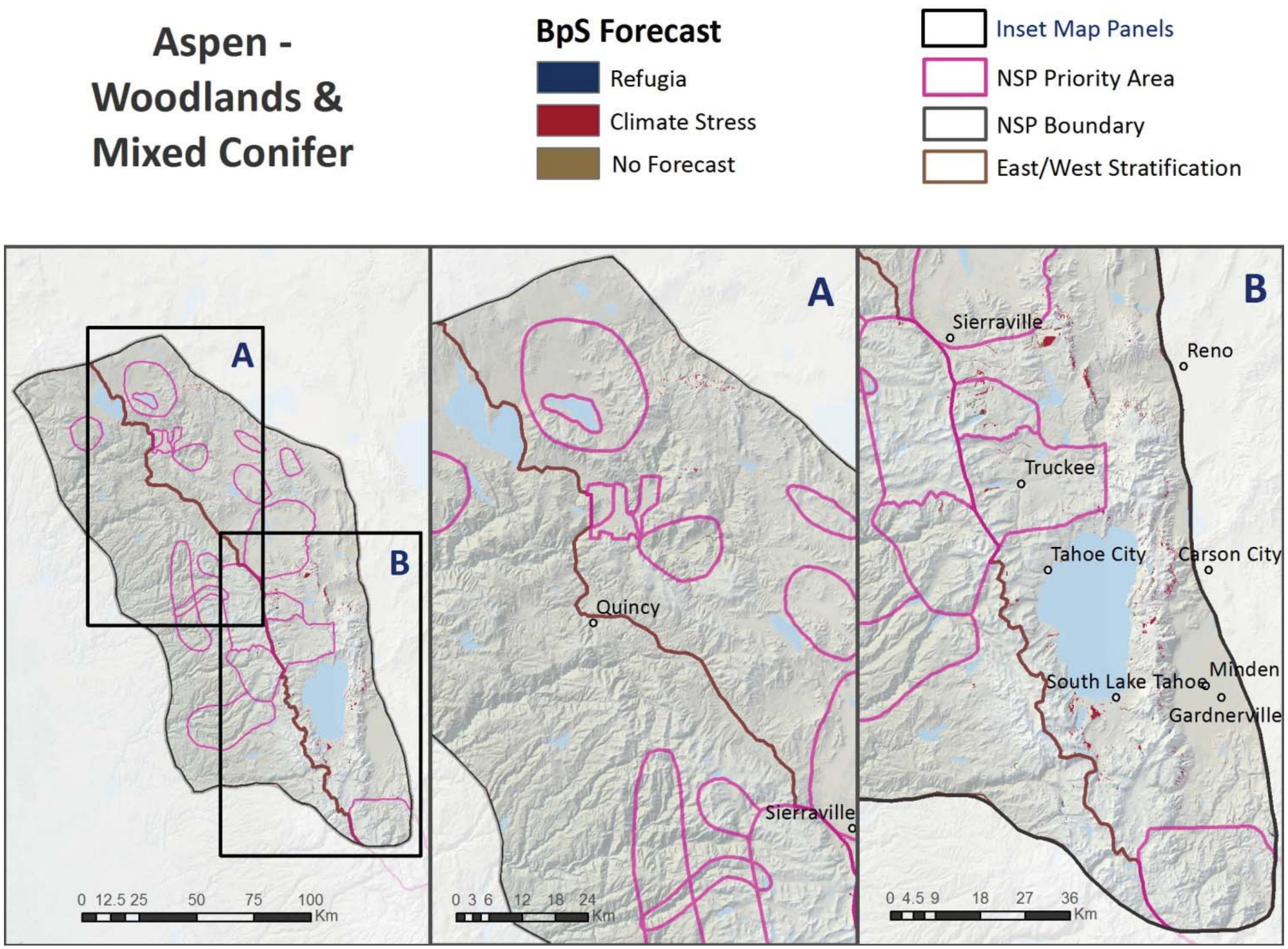


Figure 2-15. Map of potential climate refugia for both Wet and Dry Lodgepole Pine forests, which are currently under-represented biophysical setting (BpS) within NSP priority areas.

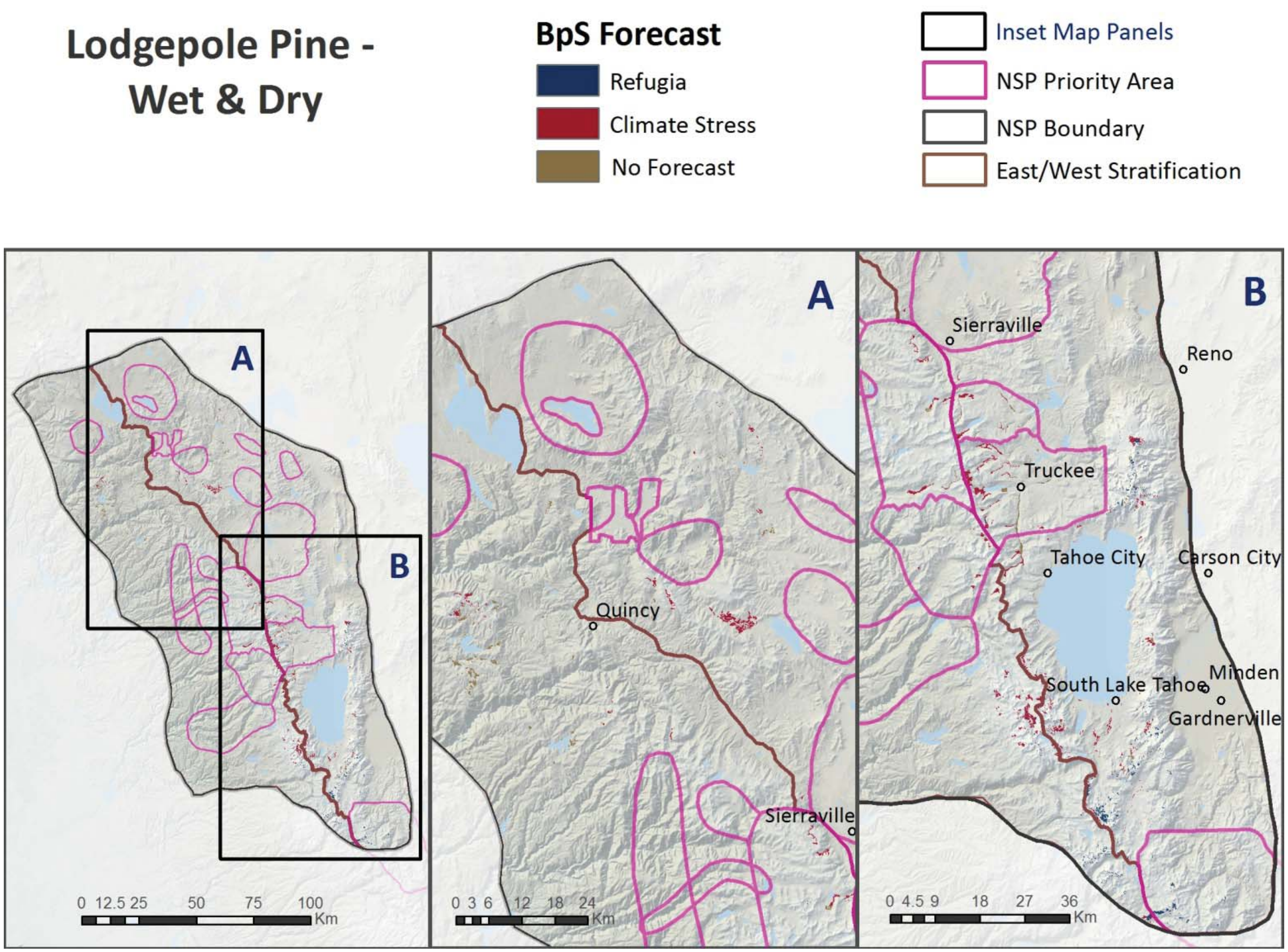


Figure 2-16. Map of potential climate refugia for Ponderosa Pine–Mixed Conifer, which is currently under-represented biophysical setting (BpS) within NSP priority areas.

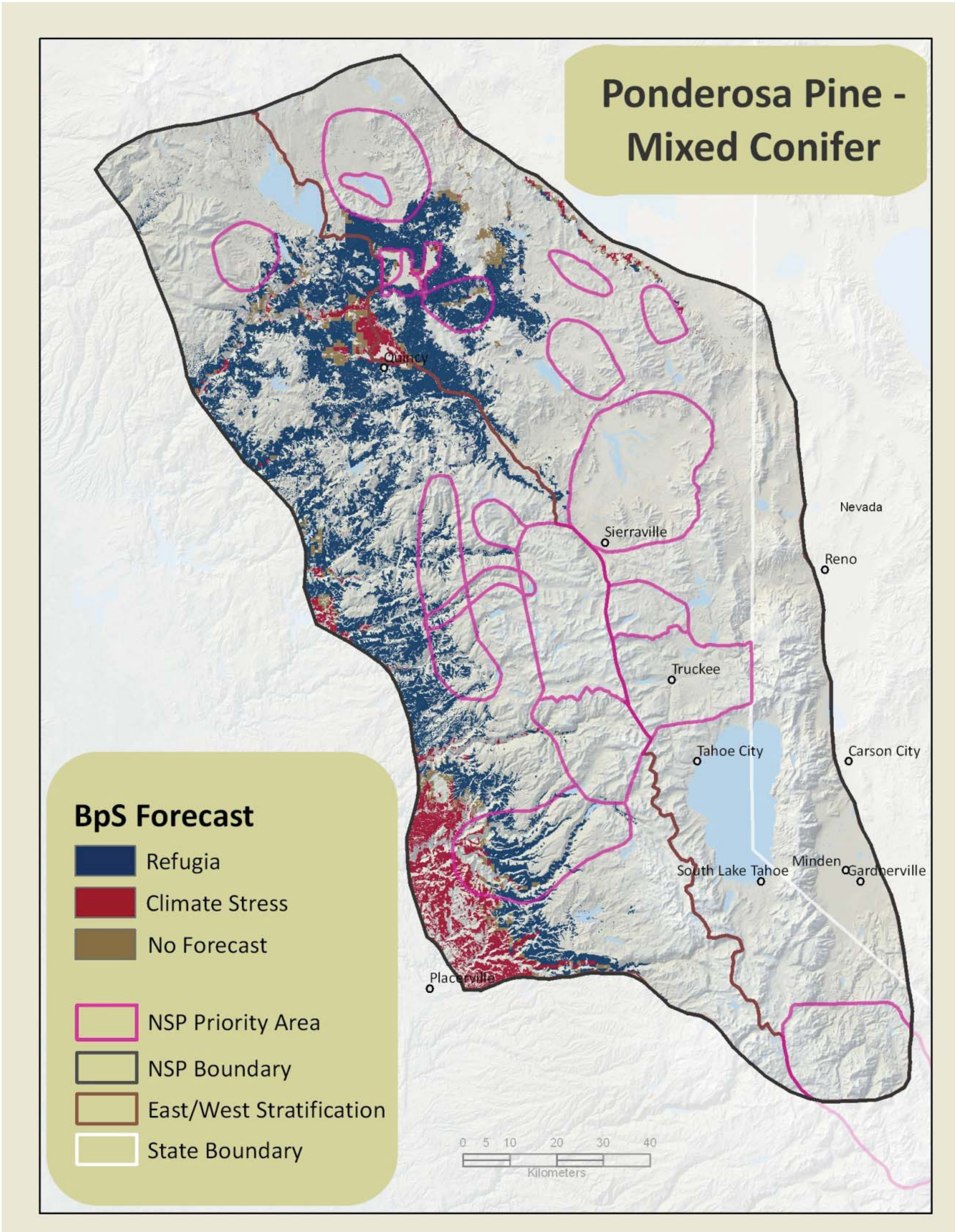


Figure 2-17. Map of potential climate refugia for Yellow Pine–East Side, which is currently under-represented biophysical setting (BpS) within NSP priority areas.

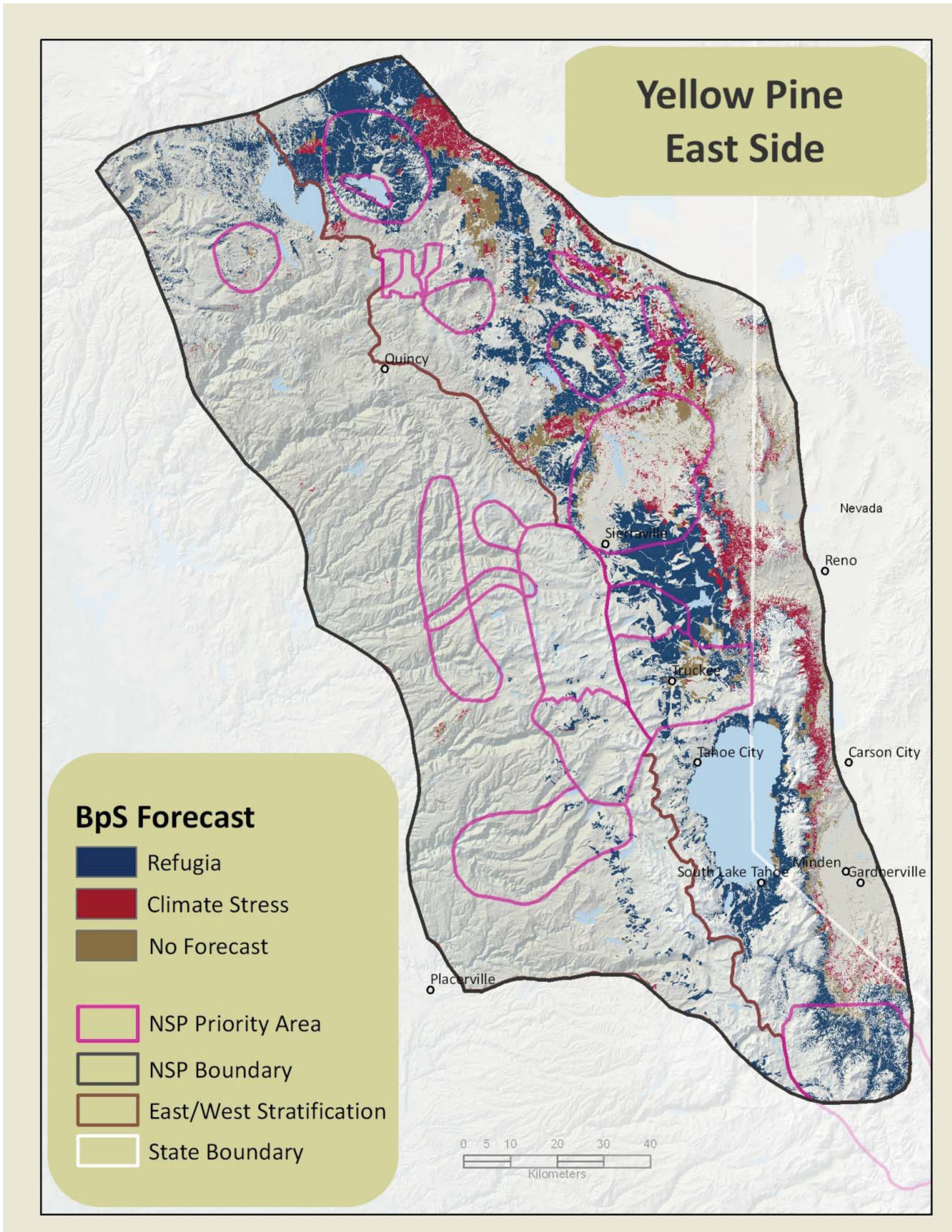


Table 2-5. Density and Diversity of BpS refugia within NSP priority areas.

Zone	Priority area name	Percent (%) of the BpS refugia for a given side in each priority area																	Index normalized by area	Feature Rank
		Mixed Conifer - Mesic	Yellow Pine East Side	Ponderosa Pine - Mixed Conifer	Red Fir - Western White Pine	Red Fir - White Fir	Montane Sagebrush Steppe	Montane Chaparral	Big Sagebrush Shrubland	California Oak-Pine Forest	Subalpine Woodland	Lodgepole Pine - Wet	Pinyon-Juniper Woodland	Aspen - Mixed Conifer Forest	Lodgepole Pine - Dry	Aspen Woodland	Blue Oak-Pine Foothill Woodland	Summed %s		
East	Upper East Fork Carson River	2	7	0	40	24	7	0	3	0	16	3	47	4	25	15	n/a	192	40	**1**
East	Genessee Valley	1	0	13	0	0	0	2	0	25	0	0	0	0	0	0	n/a	41	34	**2**
East	Upper Little Truckee River	5	3	0	0	0	1	0	0	0	2	0	0	40	0	0	n/a	50	32	**3**
West	Sierra Crest	2	4	0	26	46	21	4	n/a	0	13	12	n/a	2	0	0	0	130	21	**4**
East	Indian Valley (rank 3)	0	0	2	0	0	0	0	0	7	0	0	0	0	0	0	n/a	9	18	**5**
West	Upper American River Watershed	6	5	0	1	6	5	3	n/a	2	25	0	n/a	0	0	0	0	53	13	**6**
East	Last Chance	1	1	0	0	0	0	4	0	0	0	0	0	0	0	0	n/a	6	10	**7**
East	Truckee Donner Area	10	5	0	0	0	14	0	0	0	7	6	0	0	0	0	n/a	43	10	**8**
East	Red Clover Valley	2	3	0	0	0	4	7	0	0	0	0	0	0	0	0	n/a	16	9	**9**
West	Sierra Buttes	2	0	0	0	4	0	1	n/a	0	0	0	n/a	0	0	0	0	8	9	**10**
West	Middle Yuba River	2	0	0	1	1	0	2	n/a	2	0	0	n/a	0	0	0	0	9	9	**11**
West	Yuba River Watershed Mature Forest	8	0	4	0	0	0	12	n/a	11	0	0	n/a	0	0	0	0	36	8	**12**
East	Indian Valley (rank 2)	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	n/a	3	7	**13**
East	Sierra Valley	3	5	0	0	0	13	6	0	20	0	0	0	0	0	0	n/a	48	6	**14**
West	Middle American & Rubicon Waters	6	4	7	0	0	0	5	n/a	11	0	0	n/a	0	0	0	1	35	6	**15**
East	Mountain Meadows (rank 3)	8	11	2	0	0	0	0	0	0	0	0	0	0	0	0	n/a	21	6	**16**
East	Last Chance Creek	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	n/a	4	6	**17**
West	Humbug Valley	3	4	0	0	0	0	0	n/a	0	0	0	n/a	0	0	0	0	7	5	**18**
East	Mountain Meadows (rank 2)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	n/a	1	2	**19**

2.2.2.4 Ranking of Priority Areas for Adaptation

After ranking the priority areas for each of the three categories of adaptation factors (BpS richness, climatic microrefugia, BpS refugia), we combined the ranks into one summary table (Table 2-6). After adding the ranks, the priority areas with the lowest summary ranks contain the highest density and diversity of climate change adaptation factors. Based on this analysis, the Upper East Fork Carson River is clearly the best suited for climate change adaptation because it ranks highest for all three of the climate change adaptation factors we analyzed. Genessee Valley ranks well for microrefugia and BpS refugia, and the Upper Little Truckee River ranks well for BpS refugia and richness. The Mountain Meadows (rank 2) priority area is primarily a reservoir so it is not surprising that it does not rank high in this analysis that is heavily weighted towards terrestrial vegetation and landforms.

Table 2-6. Ranking of existing NSP areas for adaptation.

Zone	Priority Area Name	NSP Rank	BpS Richness Rank	Micro-refugia Rank	BpS Refugia Rank	Summary
East	Upper East Fork Carson River	3	1	1	1	3
East	Genessee Valley	1	9	2	2	13
East	Upper Little Truckee River	1	5	10	3	18
East	Truckee Donner Area	1	2	9	8	19
West	Sierra Crest	1	3	17	4	24
East	Indian Valley (rank 3)	3	18	4	5	27
West	Upper American River Watershed	1	3	18	6	27
West	Middle American and Rubicon Waters	2	8	5	15	28
East	Sierra Valley	1	7	8	14	29
West	Yuba River Watershed Mature Forest	3	13	6	12	31
East	Indian Valley (rank 2)	2	16	3	13	32
East	Last Chance	2	19	7	7	33
East	Red Clover Valley	1	9	15	9	33
West	Sierra Buttes	1	9	14	10	33
West	Middle Yuba River	1	13	11	11	35
East	Mountain Meadows (rank 3)	3	5	16	16	37
West	Humbug Valley	2	12	13	18	43
East	Last Chance Creek	1	15	12	17	44
East	Mountain Meadows (rank 2)	2	16	19	19	54

3 Strategy Development for At-Risk Major Habitat Types

3.1 Climate Adaptation Planning Methods

The goal of this section is to assess the projected impact of climate change on vegetation types in the entire Northern Sierra Partnership planning area, and to use the results to identify a suite of climate change adaptation strategies for those vegetation types that are predicted to be most at-risk from climate change. In contrast to the analysis in section 2, which focused on the NSP priority areas, the analysis in section 3 addresses all lands within the NSP boundary.

This section undertakes novel and experimental modifications to an existing public land management tool, the Vegetation Dynamics Development Tool (VDDT), in an attempt to address climate change. We present the results of a set of model runs based on a series of assumptions. We view the analytical approach as interesting and promising, but the results presented here should not be considered conclusive. Different model runs, utilizing different (and in some cases equally plausible) assumptions, would produce different conclusions. We believe there are fruitful opportunities for adjusting the basic model presented here, utilizing different assumptions and values, to address a whole host of specific questions regarding the impacts of climate change on vegetation on the northern Sierra Nevada and the steps that might be taken to address these changes.

3.1.1 Forecasting Risk to Ecosystems

A primary objective of our approach was to determine which major habitat types are at greatest "risk" due to the anticipated effects of climate change. Computerized state-and-transition models were used to assess future risk to major habitat types, as defined in terms of three metrics: (1) predicted departure from the natural range of variability (e.g., from moderate to high departure); (2) predicted conversion to high-risk vegetation (e.g., invasive species); and (3) predicted shifts in vegetation type (e.g., from red fir-western white pine to mixed conifer). The definition of risk that we used did not consider the total acreage of a habitat type as a factor; weighting the acreage proportionally would have produced different results, with vegetation types having larger acreage being considered to be at higher risk. Similarly, although wildfire was considered at various stages of our analysis, the risk of high-intensity wildfire causing damage to property and lives was also not elevated in importance relative to other projected changes in this analysis.

The methods previously described in this paper helped provide a foundation: climate models were used to help develop species distribution models, and in turn both of these were used to help refine the ecological models to forecast future conditions. Section 3.3 of this report describes how the ecological models were further used to test alternative management strategies to help abate the predicted impacts to at-risk systems. The following description is an overview of methods, whereas Appendix A presents the full account.

We quantitatively assessed the current condition of 25 BpS habitat types using LANDFIRE classifications (http://gisdata.usgs.net/website/landfire/) in the project area by measuring ecological departure for each system (Hann and Bunnel 2001; Provencher et al. 2008; Rollins 2009). *Ecological departure* is the dissimilarity between a BpS's current (or future simulated) condition and its natural range of variability (**NRV**). NRV reflects the distribution of vegetation classes that would be expected under naturally functioning ecological processes, as predicted by field studies, expert opinion, and computer simulations. We assessed projected future conditions – with and without projected climate change impacts – for ecological systems using the Vegetation Dynamics Development Tool software (**VDDT**, by ESSA Technologies, Ltd; Barrett 2001; Beukema et al. 2003) that is used for vegetation modeling and landscape conservation forecasting (Forbis et al. 2006; Provencher et al. 2007, 2008; Low et al. 2010). Based upon these results, we identified which BpS habitat types are "at risk" due to projected climate changes impacts.

Temporal multipliers are a key component to modeling climate variability and change. A temporal multiplier is a number in a yearly time series that multiplies a base disturbance rate in the VDDT models: for example, for a given year, a temporal multiplier of one implies no change in a disturbance rate, whereas a multiplier of zero is a complete suppression of the disturbance rate, and a multiplier of three triples the disturbance rate. We used time-series data of observed historical events (droughts, fires, floods, insect and disease invasions) as the basis of our temporal multipliers. Most often, temporal multipliers were converted to a unitless value by dividing each annual value from the historical time-series by the average value from the entire time-series. Temporal multipliers can further by modified to reflect a hypothesized change caused by external factors, such as climate change.

For estimating the natural range of variability (NRV), the Palmer Drought Severity Index (PDSI) was used as the basis for most temporal multipliers, including three different levels of fire severity (surface, mixed, and replacement), for three major vegetation groups (Taylor and Beatty 2005; Westerling et al. 2006; Westerling and Bryant 2008). Flow data were used to create temporal multipliers for montane riparian systems. For management models, a different set of historical data was used for temporal multipliers. The methods and data used to generate the temporal multipliers are presented in Appendix A.

The project area was stratified into two large sub-regions – Eastside and Westside – which have very different climates and differing arrays of ecological systems. All analyses were conducted for both the Eastside and Westside sub-regions.

3.1.1.1 Modifying a Vegetation Model to Reflect Climate Change

3.1.1.1.1 Hypotheses of Change

We developed a table of predicted ecological impacts resulting from climate change (hypotheses of change) for each system based upon future climate scenarios described in Appendix A. Some hypotheses were directly supported by recent publications, albeit few, whereas the remaining hypotheses were inferred. Hypotheses of change, the type or magnitude of the disturbances causing change in the models, and temporal multipliers as described below in "Future Annual Variability" were reviewed in expert workshops or by selected natural resources experts:

Directly supported hypotheses:

- More frequent, larger fires (Brown et al. 2004; Westerling and Bryant 2008; Westerling, *in press*)
- Higher tree mortality during longer growing season droughts (Pennisi 2009)
- Longer period of low flows (Dettinger et al. 2004; Maurer 2007; Stronestrom and Harrill 2006)
- Longer period of groundwater recharge during colder months (more effective recharge) (Stronestrom and Harrill 2006; personal communication, Dr. Rick Niswonger, USGS Carson City, 2008)
- Increased dispersal of non-native species (Bradley 2009; Brown et al. 2004; Smith et al. 2000)

Inferred hypotheses:

- Greater conifer and deciduous tree species recruitment and growth in meadows/wetlands/riparian due to drought and CO_2 fertilization (Brown et al. 2004)
- Impaired recruitment of willow and cottonwood due to modified hydrology (Maurer 2007)
- Faster growth of fast-growing native tree species (Brown et al. 2004; personal communication, Dr. Hugh Safford, US Forest Service, University of California at Davis, 2008)
- Increased recruitment of high-elevation trees (personal communication, Dr. Hugh Safford, US Forest Service, University of California at Davis, 2008)
- Increased dispersal of pinyon and juniper in shrublands (Tausch and Nowak 1999).

3.1.1.1.2 Future Annual Variability

In order to model the impacts of climate change on the BpS, we incorporated the hypotheses of change into our ecological models by making several changes to the input data. We modified several temporal multipliers (see Appendix A) from the east and west sides using predictions from the Parallel Climate Model (PCM; Dettinger et al. 2004) with the A1Fi business-as-usual emissions scenario. These modifications to the ecological models require a full time series of future climate projections (i.e., every year from 2000-2050). While data from the other 11 GCMs listed in Table 2.1 were available for one 20-year period (2046-2065) for this area, a downscaled time-series of data for this area was not readily available. Thus, we focused only on the results of the PCM GCM for this portion of the analysis.

We modified the fire temporal multiplier to simulate future forest fires under a hotter climate, with increasing greenhouse gases, but same total precipitation (Figure 3-1; IPCC 2007; Dettinger et al. 2004). To make this change, we multiplied the fire temporal multipliers for each of the five major vegetation groups, for the three different fire severities, by the predicted temperature temporal multiplier (yearly temperature predicted by PCM divided by the temperature in the first year of the time series; Figure 3-1). Under this assumption higher temperature caused more fire activity in a linear manner, which is the simplest assumption.[2]

We similarly modified the other temporal multipliers relating to drought, invasion rates, soil moisture, and flows. Drought was modified using the PSDI (Appendix A) and predicted temperature increases from Dettinger et al. (2004; Figure 2-6). Flow temporal multipliers were generated with historic USGS gage data from the Truckee River and Feather River. The peak flow temporal multiplier was modified for climate change under the assumptions that peak flows and their variability would increase with time due to more frequent rain-on-snow events and early snow melt (Dettinger et al. 2004; Maurer 2007). With climate change, peak flow is predicted to occur increasingly earlier (Maurer 2007), which would be before flowering and seed deposition of cottonwood and willow. Although not documented in the literature, we hypothesized that earlier onset of future peak flow will have a depressing effect on cottonwood and willow recruitment, but higher and more variable future peak flows will partly compensate for loss of recruitment success. Early snow melt would also cause greater late summer mortality of willow and cottonwood seedlings by desiccation, as captured by the seedling mortality temporal multiplier (personal communication, Dr. Rick Niswonger, USGS Carson City, 2008). Finally, we hypothesized that carbon from enhanced atmospheric green house gases (IPCC 2007; Figure 3-1) would fertilize exotic forb species growth during year of greater

[2] Westerling and Bryant (2008) showed nonlinearities between area burned and maximum temperature; however, their predictions under the A2 emissions scenario showed a nearly linear relationship between percent change in number of voxels (i.e., unit of latitude × longitude × month) burned with fires >200 ha and future years of simulation.

soil moisture (Bradley 2009; Smith et al. 2000), which we equated with annual flows. Appendix A describes more fully the modifications to the temporal multipliers used to simulate future conditions under climate change.

3.1.1.1.3 Vegetation Shifts

To simulate potential future shifts in BpS, we first determined the *rate* of projected shift, and then determined the *type* of projected vegetation shift.

As described in Section 2.1.4.2, we used future "climate envelope" projections for major tree and shrub species to show predicted *rates* of stress over the next 80 years for the associated biophysical settings. The rate of stress in the VDDT models was the proportion of a BpS experiencing stress as calculated in Section 2.4 divided by the number of years projected (i.e., 80 years). Projected stress areas for a given species were assumed to equate with likely conversion because the species would not reproduce under the new climatic conditions. It was realized that a BpS might persist beyond the 80 years of predicted stress because adult trees can survive although their offspring fail to establish. To minimize this problem, BpS conversion in the models only occurred when a stand-replacing disturbance killed adults; in other words, a BpS could persist for longer than predicted if it did not experience significant stand replacing events. This adjustment led to another problem: some subalpine and aspen BPSs that were predicted to experience very high levels of stress did not experience vegetation shifts rapid enough to "keep up" with predicted stress over 80 years because the natural disturbance rates are too slow (for example, a long mean fire return interval). In these cases, 100% of all stand-replacing events caused a vegetation shift, although conversion was still not "fast enough."

To forecast the *type* of biophysical settings that would replace a stressed one, we used Dr. Jim Thorne's shared data (http://ice.ucdavis.edu/project/wieslander) on actual vegetation conversions based on the analysis of Wieslander Vegetation Type data for the Sierra Nevada (http://vtm.berkeley.edu). One critical assumption made here was that vegetation transitions from the last 80 years were the best guess to future transitions for our VDDT simulations with climate change effects. Another critical assumption is that historical vegetation transitions relate to climatic changes, as opposed to alternative drivers (e.g., human activity, fire, succession, disease, error). Using recently interpreted aerial and satellite imagery and USFS plot data and maps, Thorne and others determined the California Wildlife Habitat Relationship (WHR) vegetation types currently at the location of the Wieslander plots (Thorne et al. 2008).

Thorne's matrix of "before and after" frequency transitions among WHR types over a period of approximately 80 years revealed often different pathways of vegetation change for the same starting vegetation type. We crosswalked the WHR types to the closest BpSs using characteristic species and type descriptions (Appendix A). We eliminated from the "after" types those that represented the outcome of fire exclusion pathways that are contained in the VDDT management models. For example, mixed conifer in 2009 that replaced ponderosa pine from 1920 was considered a false change because fire exclusion or logging alone could explain the results and our models already account for these false changes. As a general rule, a transition was termed “true” if the new vegetation type had a mean fire return interval that was comparable or shorter than the original Wieslander type’s mean fire return interval. An example of a “true” transition would be the ponderosa pine type being replaced by the California mixed evergreen type. The data for true conversion when more than one transition pathways were documented were used to split proportionally the rate of transition (previous paragraph) using ratios calculated from the Thorne data. Further justification and explanations are found in Appendix A.

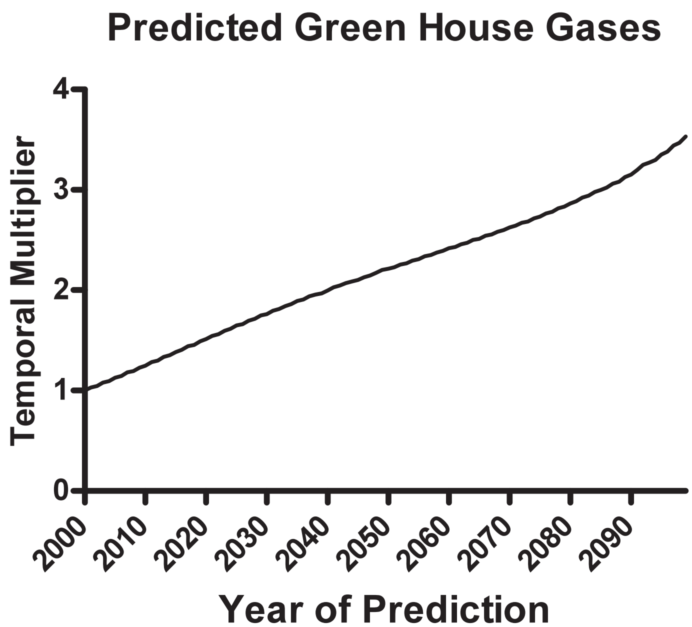
3.1.1.2 Simulating Future Conditions – With and Without Climate Change

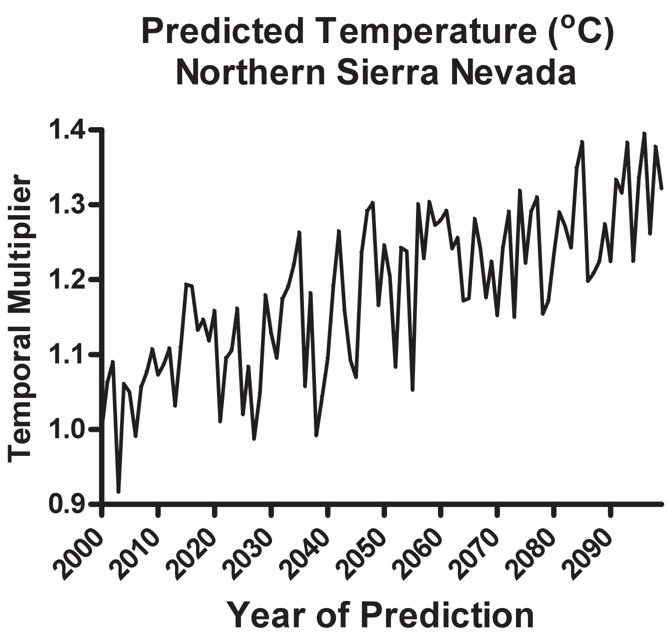
Using VDDT models, we simulated the likely future condition of each ecological system after 20, 50 and 80 years, assuming minimum management (e.g., no treatment of exotic forbs, no prescribed fire, and no active management of livestock). Potential sources of future impairment were explicitly modeled, and included the following: non-native species (cheatgrass and exotic forbs) invasion, tree encroachment, altered fire return intervals, entrenchment of and water diversion from creeks and wet meadows, and excessive herbivory by livestock.

For each simulation, the models were run with five replicates to introduce natural and future alternative variability, with each replicate incorporating a different set of temporal multipliers for each of the different disturbance parameters in the VDDT models. We measured three outcomes using the mean of the five replicates: Ecological Departure; Percentage of High-Risk Vegetation Classes; and Percentage of Vegetation Shifts.

These simulations were conducted under two scenarios: (1) with no future climate change effects incorporated in the models; and, (2) with the above-described climate change effects incorporated as uniquely expressed by temporal multipliers and vegetation conversion pathways. The *with* versus *without* scenarios allowed us to project the marginal effects that are expected as a result of climate change.

Figure 3-1. Temporal multiplier of temperature for the Northern Sierra Nevada (based on Dettinger et al. 2004) and global green house gases (based on IPCC 2007) under the "business-as-usual" (A1Fi) climate change scenario. Temperature raw data obtained from Dr. M. Dettinger, USGS, 2009 based on the PCM simulations. The green house gases and temperature temporal multipliers were each calculated by dividing each yearly value by the value of the first year of the time series.





3.1.2 Testing Strategies for At-Risk Ecosystems

The methods used for strategy forecasting have been deployed previously by TNC with public land management agencies for landscape-scale conservation planning in Nevada, Utah and California, including projects with the U.S. Forest Service (USFS), Bureau of Land Management (BLM) and National Park Service (NPS). We used VDDT models to test alternative management strategies for the subset of ecosystems which were forecast to be most at-risk due to projected climate change impacts, in terms of (1) departure from NRV; (2) increase in high-risk vegetation classes (high-risk vegetation classes are unrelated to climate change risk; Low et al. 2010); and/or, (3) vegetation shifts. Strategies were sought that would meaningfully reduce the climate change risk and increase ecosystem resilience (described below).

Working with USFS and members of the Partnership and drawing upon previous strategy simulations developed with USFS, BLM and USGS natural resources management staff, a suite of potential management strategies (below) was developed for each of the at-risk ecological systems, as well as the estimated costs of implementing each strategy. The projected ecological effects of each strategy were incorporated into the VDDT models as disturbances with average implementation rates (e.g., prescribed fire is the disturbance applied at about 5,000 acres per year). The models also included a "failure rate" expressed as a proportion for some management strategies to reflect that some management actions only partially succeed at restoring a vegetation class. Failure rates were drawn from our experience with past agency projects (Provencher et al. 2007, 2009; Low et al. 2008) and discussion with USFS Region 5 staff. The array of management strategies included the following:

<u>Forest and woodland strategies</u>

- prescribed fire
- mechanical thinning

<u>Riparian and wet meadow strategies</u>

- weed inventory
- spot application of herbicides
- restoration of entrenched areas
- restoration of shrub-forb encroached areas
- grazing management

Various combinations of management strategies were explored for each targeted ecosystem, using VDDT computer simulations to test their effectiveness and adjust the scale of application. A management strategy is an action applied to specific vegetation classes of a BpS, such as prescribed fire used in closed late-succession aspen mixed-conifer forest, whereas a combination of strategies represents all such actions applied to a single BpS. Since VDDT software does not have an optimization mechanism, we tested different combinations of alternative management strategies (e.g., prescribed fire and thinning versus just prescribed fire) and levels of treatment (yearly average area of application per action). Through this trial-and-error process of changing types of actions and yearly application rates, we created a set of strategies designed to reduce ecological departure and high-risk vegetation classes (including reducing the area of vegetation conversions).

Management strategies were modeled over 50 years using a two-step approach, with 20 year model run outputs calculated as the first step. The outputs were then used as the starting conditions followed by 30 year model runs that incorporated climate change impacts. This approach was used for two reasons. First, climate change effects are expected to accelerate over the 50 year time horizon, with the most dramatic impacts occurring later rather than sooner. Model runs from previous projects (Provencher et al. 2009) and model calibration for this project showed that the signal of climate change effects started being detected from the large variability introduced by temporal multipliers at about 40 years. Secondly, previous management model runs for Great Basin National Park often showed dramatic improvements as a result of front-loading management treatments in early years. The two-step approach – 20 years, then 30 years with climate effects kicking in – allowed us to more accurately capture the likely effects of early management actions. These outcomes are compared to the more dramatic "minimum management" scenario in which climate change impacts are modeled to begin immediately in year one.

Estimated costs for each management strategy were based upon estimates provided by public agency and land trust partners. In actual on-the-ground applications, these costs will vary greatly depending upon local circumstances. For purposes of this coarse-scale benefit-cost strategy assessment we are using a mid-point or a typical cost for a given treatment.

Strategies were tested using two broad scenarios: (1) maximum management, which sought to achieve the best ecological outcomes regardless of cost; and, (2) streamlined management, which sought to achieve positive ecological outcomes while minimizing cost over the duration of simulations, using a return-on-investment approach (greatest combined improvement in the three metrics for the lowest cost).

3.2 Climate Adaptation Key Findings About 'What to Do'

3.2.1 Development of Cost-Effective Adaptation Strategies

3.2.1.1 Presentation & Interpretation of Ecological Departure Forecasts

A primary objective of the Northern Sierra climate adaptation planning is to forecast the future condition of the region's ecological systems and determine which systems may be at greater risk due to the anticipated effects of climate change. Future risk to the ecological systems was assessed using ecological models via three metrics: (1) predicted departure from the natural range of variability; (2) predicted percentage of high-risk vegetation; and, (3) predicted shifts in vegetation type. As discussed above, using different risk criteria would have produced different results. Active management will be needed to reduce these future risks for several systems under a changing climate, and will be discussed in Sections 3.2.1.1.1 and 3.2.1.1.2.

3.2.1.1.1 Current Condition: Ecological Departure

The current condition of the Northern Sierra's ecological systems varies in terms of departure from their NRV. Of the area's 25 ecological systems, ten are considered slightly departed from their NRV, twelve are considered moderately departed, and three are considered highly departed (Table 3-1). The actual reason for current departure – that is, the dissimilarity between the mix of vegetation classes currently present versus the mix of classes "expected" in NRV – differs for each individual ecological system. Appendix C provides a written summary description of the current condition of each system across the region. Appendix D shows for each ecological system the acreage, percentage of current vegetation classes, percentage of classes in NRV, and resulting ecological departure score – broken out by eastside and Westside. The overall Northern Sierra departure scores were calculated as a weighted average of the eastside and westside scores.

We stress that the descriptive terms "low," "moderate," and "high" are subjective, and that depending upon the circumstances, ecological values, and acreage involved, our conclusions regarding which deviations are considered "low," "moderate," or "high" might differ. In addition, the net effect of departure on ecosystem functioning and dynamics is not linearly related to the magnitude of departure. To assume that the NRV was always a preferred state for all species and ecosystem processes is likely too simplistic given the complexity of habitat use preferences and shifts in response to environmental change. Additionally, a relatively small departure in a widespread system may have greater ecological consequences than a large departure in a restricted system. The geographic extent of the ecosystem in question can provide a greater influence on landscape dynamics, including surface water flows, disturbance regimes and habitat values, than the degree of departure. Other reviewers might consider many or all the departures that we report here to be ecologically significant. We also note that the results presented here lump together all seral stages within each vegetation class, which may obscure significant departures from NRV for particular seral stages within some ecological systems.

For example, as shown in Table 3-1, “mixed conifer mesic” is currently considered to have “low departure” from NRV. Yet, as shown in Appendix D, large tree forests within this type (class D and E) are currently significantly underrepresented compared to NRV – 28% current versus 41% NRV on the westside, and 24% current versus 41% NRV on the eastside, for a weighted average of approximately 27% current versus 41% NRV. Similarly, an examination of the NRV departure for large tree classes within other widespread forest types, such as Yellow Pine eastside, Ponderosa Pine–Mixed Conifer, and Red Fir–Western White Pine, shows that late seral stage forests are significantly underrepresented compared to NRV. This result is consistent with the scientific literature indicating that old forest habitat in the northern Sierra Nevada has been greatly depleted. However, for purposes of simplicity in this analysis, we do not weight departure from any one seral stage or class higher than any other class when calculating ecological departure for a ecological system.

3.2.1.1.2 High-Risk Vegetation Classes

A high-risk class was defined as an uncharacteristic vegetation class that met at least one of the three following criteria: (1) ≥5% cover of invasive non-native species, (2) vegetation type conversion or (3) very expensive to restore. “Very expensive” represents a subjective judgment based on per acre costs. For purposes of this analysis, large areas requiring restoration, such as mixed conifer forests that are at high risk of stand-replacing wildfire due to past logging and fire suppression, are not considered “very expensive” to restore, even though the total costs of restoration, based on the large acreage involved, could be very large.

Similar to the grouping of ecological departure scores into three ecological condition classes, the cover of high-risk vegetation classes was stratified into four categories.

- **Low**: 0% cover of high-risk vegetation classes, no future risk posed to ecological system condition.
- **Medium**: 1-10% cover of high-risk vegetation classes, acceptable future risk posed to ecological system.
- **High**: 11-30% cover of high-risk vegetation classes, future vegetation classes have the potential to catalyze even greater degradation of a ecological system and will require significant resources to contain, let alone restore.

- **Very High**: >30% cover of high-risk vegetation classes, the system will be highly degraded, perhaps beyond the ability of managers to recover the ecological system.

The Northern Sierra's ecological systems vary in terms of the current amount of high-risk classes that they possess, but most systems currently have no or little high risk classes. Of the area's 25 systems, only two have a Very High amount of high-risk vegetation classes, one system has a High amount; six systems have a Medium amount; and sixteen systems have no high-risk classes (Table 3-2). We acknowledge that some of these results appear to be counter-intuitive, especially with respect to fire-adapted forest ecosystems in the northern Sierra. We emphasize that we define "high risk" quite conservatively and many systems for which structural characteristics and functional regimes (e.g., disturbance) have changed with past extraction and management objectives do not register as "high risk" yet represent significant management challenges currently.

Table 3-1. Percent departure of ecological systems of the Northern Sierra from their natural range of variability, grouped by elevation and/or vegetation type and their respective size. Ecological departure is color-coded: green = low departure, yellow = moderate departure, and red = high departure.

Ecological System	Acres	Current Condition
Subalpine		
Alpine Shrubland	1,600	13
Lodgepole Pine – Dry	8,900	59
Lodgepole Pine – Wet	21,800	53
Red Fir – Western White Pine	379,000	37
Red Fir – White Fir	370,600	34
Subalpine Meadow	1,300	27
Subalpine Woodland	66,100	20
Mid-Elevation Forests		
Aspen-Mixed Conifer Forest	12,100	62
California Oak-Pine Forest	63,300	50
Mixed Conifer – Mesic	1,100,200	26
Ponderosa Pine – Mixed Conifer	783,600	41
Yellow Pine	889,900	54
Low-Elevation Forests		
Blue Oak-Pine Foothill Woodland	4,700	49
California Mixed Evergreen Forest	66,300	13
Xeric Shrublands		
Montane Chaparral	187,200	5
Serpentine Woodland & Chaparral	8,100	68
Mid-Elevation Eastside Shrublands/Woodlands		
Aspen Woodland	6,400	28
Big Sagebrush Shrubland	184,400	46
Curlleaf Mountain Mahagony	12,600	48
Low Sagebrush	16,500	14
Montane Sagebrush Steppe	206,200	30
Pinyon Juniper	19,200	32
Riparian and Wet Meadows		
California Montane Riparian	58,100	36
Great Basin Riparian	27,300	71
Wet Meadow	108,400	83

Table 3-2. Current percent of high-risk vegetation classes for Northern Sierra ecological systems. Stress to ecological systems is ranked as: low (0%, dark green); medium (1-10%, light green); high (11-30%, yellow), and very high (>30%, red).

Subalpine	
Alpine Shrubland	0
Lodgepole Pine - Dry	0
Lodgepole Pine - Wet	0
Red Fir - Western White Pine	0
Red Fir - White Fir	0
Subalpine Meadow	0
Subalpine Woodland	0
Mid-Elevation Forests	
Aspen-Mixed Conifer Forest	1
California Oak-Pine Forest	0
Mixed Conifer - Mesic	0
Ponderosa Pine - Mixed Conifer	0
Yellow Pine	0
Low-Elevation Forests	
Blue Oak-Pine Foothill Woodland	0
California Mixed Evergreen Forest	0
Xeric Shrublands	
Montane Chaparral	0
Serpentine Woodland & Chaparral	0
Mid-Elevation Eastside Shrublands/Woodlands	
Aspen Woodland	0
Big Sagebrush Shrubland	14
Curlleaf Mountain Mahagony	3
Low Sagebrush	8
Montane Sagebrush Steppe	6
Pinyon Juniper	3
Riparian and Wet Meadows	
California Montane Riparian	5
Great Basin Riparian	58
Wet Meadow	72

3.2.2 Ecological Departure With Climate Change

3.2.2.1.1 Predicted Future Ecological Condition – With and Without Climate Change

Ecological departure scores predicted under minimum management for the Northern Sierra's 25 ecological systems, with and without projected climate change impacts, are presented in Table 3-3. <u>In the absence of climate change</u> over a 50 year period, 11 systems show a predicted *improvement* (i.e., decline) in ecological departure score (reduced by five percent or greater), whereas eight show *little predicted change*, and six show a predicted *decline* in condition of five percent or greater (higher departure score).

When climate change impacts were included in the simulations, eight systems showed a decline of five percent or greater (higher departure score) as compared to their projected conditions in the absence of climate change. A total of five systems are projected to depart highly from their natural range of variability, as compared to only two systems without climate change. The two riparian systems and wet meadow systems, along with aspen-mixed conifer forest and lodgepole pine on dry sites were the systems at highest forecasted ecological departure. Conversely, three systems showed predicted *improvement* in ecological departure as compared to scores with no climate change.

The predicted ecological improvements of many systems in the absence of any active management despite climate impacts may seem counter-intuitive. The primary explanation for this result is the fact that the ecological models provided the "escape" of fires into the systems, even in the face of ongoing management for fire suppression (which is not always effective). Moreover, for some systems the climate change impacts increased the frequency of fire. The return of fire allowed many fire-dependent systems to "reset" closer to the natural range of variability – for example, to more early succession or open classes. A different analysis, with different assumptions about the likely use and effectiveness of fire suppression in the future, would have produced different results, with greater predicted departures from NRV under climate change scenarios for some forest types.

Table 3-3. Current and predicted 50-year future (under minimum management) ecological departure of ecological systems of the Northern Sierra, with and without projected climate change impacts. Ecological departure scores are classed as slightly departed from NRV (0-33%, green); moderately departed (34-66%, yellow); and highly departed (>66%, red).

Ecological System	Acres	Current Condition	Future Condition without CC	Future Condition with CC
Subalpine				
Alpine Shrubland	1,600	13	12	12
Lodgepole Pine – Dry	8,900	59	51	69
Lodgepole Pine – Wet	21,800	53	46	65
Red Fir – Western White Pine	379,000	37	24	27
Red Fir – White Fir	370,600	34	20	20
Subalpine Meadow	1,300	27	60	65
Subalpine Woodland	66,100	20	28	27
Mid-Elevation Forests				
Aspen–Mixed Conifer Forest	12,100	62	41	86
California Oak–Pine Forest	63,300	50	38	35
Mixed Conifer – Mesic	1,100,200	26	33	32
Ponderosa Pine – Mixed Conifer	783,600	41	44	43
Yellow Pine	889,900	54	44	45
Low-Elevation Forests				
Blue Oak–Pine Foothill Woodland	4,700	49	63	61
California Mixed Evergreen Forest	66,300	13	17	12
Xeric Shrublands				
Montane Chaparral	187,200	5	10	17
Serpentine Woodland & Chaparral	8,100	68	14	13
Mid-Elevation Eastside Shrublands/Woodlands				
Aspen Woodland	6,400	28	24	46
Big Sagebrush Shrubland	184,400	46	47	43
Curlleaf Mountain Mahagony	12,600	48	33	34
Low Sagebrush	16,500	14	19	11
Montane Sagebrush Steppe	206,200	30	30	21
Pinyon Juniper	19,200	32	25	27
Riparian and Wet Meadows				
California Montane Riparian	58,100	36	50	73
Great Basin Riparian	27,300	71	73	74
Wet Meadow	108,400	83	78	89

3.2.2.1.2 High Risk Vegetation Classes

Eight of the Northern Sierra's ecological systems are projected to experience increases in high-risk vegetation classes, and almost all of these increases occur *with or without climate change* (Table 3-4). The primary causes are: (1) increased cheatgrass in the understory of ponderosa pine, yellow pine, and three sagebrush systems; and, (2) increases in exotic forbs in the wet meadow and riparian systems. Dramatic increases are projected in California montane riparian systems' exotic forbs. Climate change is predicted to exacerbate the high-risk classes in the wet meadow and riparian systems, by accelerating the rate of exotic forb invasion.

Table 3-4. Northern Sierra ecological systems with predicted 50-year increases in high-risk vegetation classes (under minimum management), with and without projected climate change impacts. Stress to ecological systems is ranked as: low (0%, dark green); medium (1-10%, light green); high (11-30%, yellow), and very high (>30%, red). Minimum management assumes no treatment of exotic forbs, no prescribed fire, traditional management of livestock and continued management for fire suppression.

	Current	Without Climate Change	With Climate Change
Mid-Elevation Forests			
Ponderosa Pine – Mixed Conifer	0	15	15
Yellow Pine	0	18	16
Mid-Elevation Eastside Shrublands/Woodlands			
Big Sagebrush Shrubland	14	28	28
Low Sagebrush	8	13	11
Montane Sagebrush Steppe	6	20	11
Riparian and Wet Meadows			
California Montane Riparian	5	50	73
Great Basin Riparian	58	73	75
Wet Meadow	72	78	85

3.2.2.1.3 Vegetation Shifts

Eighteen of the Northern Sierra's 25 ecological systems are projected to experience some degree of vegetation shift or conversion over 50 years due to climate change impacts (Table 3-5). However, only two systems are projected to have conversions greater than 10% – Aspen-Mixed Conifer Forest and Aspen Woodland, both of which see a large conversion of aspen to sagebrush, chaparral or conifer.

However, many other systems that show conversions are projected to counteract these "losses" with "gains" coming as conversions from other systems. Six percent of the existing montane sagebrush steppe, for example, is projected to convert to Wyoming sagebrush, but overall the systems gains more acres than it loses, in conversions from yellow pine.

Table 3-5. Northern Sierra ecological systems with predicted 50-year vegetation shifts due to climate change (under minimum management).

Ecological System	Conversion %
Subalpine	
Alpine Shrubland	3
Lodgepole Pine - Dry	7
Lodgepole Pine - Wet	7
Red Fir - Western White Pine	7
Red Fir - White Fir	2
Subalpine Meadow	5
Subalpine Woodland	1
Mid-Elevation Forests	
Aspen-Mixed Conifer Forest	31
California Oak-Pine Forest	1
Mixed Conifer - Mesic	3
Ponderosa Pine - Mixed Conifer	3
Yellow Pine	7
Low-Elevation Forests	
Blue Oak-Pine Foothill Woodland	1
Xeric Shrublands	
Montane Chaparral	9
Mid-Elevation Eastside Shrublands/Woodlands	
Aspen Woodland	19
Big Sagebrush Shrubland	9
Montane Sagebrush Steppe	6
Riparian and Wet Meadows	
Wet Meadow	4

3.2.2.2 Summary of Ecological Systems At-Risk from Climate Change

Five ecological systems are deemed to be at-risk due to projected climate change effects (Table 3-6). These systems and their forecasted conditions after 50 years are:

- **Aspen-Mixed Conifer Forest:** 12,100 acres, found almost exclusively on the eastside. Forecasted 86% ecological departure (highly departed) with climate change, versus only 51% (moderately departed) without climate change. Much of this increased departure is due to a 31% predicted vegetation conversion to montane sagebrush, chaparral and conifer forest with no aspen.
- **Aspen Woodland:** 6,400 acres, found solely on the eastside. Forecasted 19% vegetation conversion to montane sagebrush and chaparral.
- **California Montane Riparian:** 58,100 acres, found on both the eastside and westside. Forecasted 73% high-risk vegetation classes, versus 50% without climate change.
- **Lodgepole Pine (dry):** 8,900 acres, found predominantly on the eastside. Forecasted 69% ecological departure (highly departed from NRV) with climate change, versus only 51% (moderately departed) without climate change.
- **Wet meadows:** 108,400 acres, found on both east and west sides, but more so on the eastside. Forecasted 85% high-risk vegetation classes, versus 78% without climate change.

Table 3-6. "At-Risk" Northern Sierra ecological systems over 50 years where ecological departure, high-risk vegetation, or vegetation shifts are exacerbated due to climate change (under minimum management).

Ecological System	Acres	Ecological Departure	High-Risk Vegetation	Vegetation Conversion
Subalpine				
Lodgepole Pine – Dry	8,900			
Mid-Elevation Forests				
Aspen–Mixed Conifer Forest	12,100			
Mid-Elevation Eastside Shrublands/Woodlands				
Aspen Woodland	6,400			
Riparian and Wet Meadows				
California Montane Riparian	58,100			
Wet Meadow	108,400			

3.2.2.3 Adaptation Strategies

Implementation of traditional management strategies substantially improved the resilience of the five at-risk ecosystems and their ability to adapt in the face of predicted future climate effects over 50 years. Table 3-7 shows the projected improvements achieved in the three metrics (ecological departure, high-risk vegetation, and vegetation conversion) using the above management treatments without consideration of cost (i.e., maximum management).

- **Aspen-Mixed Conifer Forest**. A combination of prescribed fire and mechanical thinning substantially improved ecological departure in 50 years as compared to minimum management, and also reduced the projected percentage of vegetation conversion. Prescribed fire treatments were front-loaded during the initial 20 year period, while thinning was conducted over the full 50 years to achieve the desired results.

- **Aspen Woodland**. A small amount of thinning over the initial 20 years produced the optimal ecological outcomes. However, little management action may be needed for aspen woodland if climate change effects are indeed minimal during the initial 20 year period, in that the system is projected to be in good condition after 20 years, and if so, is then projected to remain relatively resilient over the subsequent 30 years.

- **California Montane Riparian**. Weed inventory and weed control achieved major improvements in ecological departure and large reduction of high-risk vegetation. Floodplain restoration (e.g., pond and plug) achieved additional improvements, as did the inclusion of grazing management systems. All strategies were conducted continuously over the 50 year period to achieve desired results.

- **Lodgepole Pine (dry)**. Prescribed fire conducted during the initial 20 year period improved ecological departure and reduced vegetation conversion. Like aspen woodland, this system may require little management if climate change effects are minimal during the initial 20 year period.

- **Wet Meadows**. Weed inventory, weed control, floodplain restoration, restoration of shrub-forb encroached areas, and restoration of conifer encroached areas achieved large improvements in ecological departure and dramatic reduction of high-risk vegetation. Weed management strategies were continuous over the 50 years, whereas the physical restorations strategies were front-loaded in the initial 20 years.

Table 3-7. Ecological forecasts for five at-risk Northern Sierra ecological systems over 50 years, assuming climate change impacts, under minimum management and with maximum management treatments.

BpS	*Minimum Management - 50 Yrs*			*Maximum Management - 50 Yrs*		
	Ecological Departure	High Risk Vegetation	Vegetation Conversion	Ecological Departure	High Risk Vegetation	Vegetation Conversion
Aspen-Mixed Conifer Forest (Eastside)	86	0	30	28	0	24
Aspen Woodland (Eastside)	48	0	19	25	0	8
California Montane Riparian (West & Eastside)	74	73	0	21	6	0
Lodgepole Pine - Dry (Eastside & Westside)	68	0	7	20	0	2
Wet Meadow (Eastside & Westside)	89	85	4	33	7	5

3.2.2.4 Cost-Benefit Analysis

Table 3-8 shows the projected improvements achieved using selected management treatments designed to achieve the greatest benefits for the lowest costs (i.e., streamlined management). While improvements were not as great as with the unconstrained maximum management treatments, ecological resilience was still substantially increased through improved ecological departure and reduced high-risk vegetation for all five systems, as well as reduced vegetation conversion for three systems.

Table 3-8. Ecological forecasts for five at-risk Northern Sierra ecological systems over 50 years, assuming climate change impacts, under minimum management and with "streamlined" management treatments.

Ecological System	*Minimum Management - 50 Years*			*Streamlined Management - 50 Years*		
	Ecological Departure	High Risk Vegetation	Vegetation Conversion	Ecological Departure	High Risk Vegetation	Vegetation Conversion
Aspen-Mixed Conifer Forest (Eastside)	86	0	30	42	0	26
Aspen Woodland (Eastside)	48	0	19	23	0	6
California Montane Riparian (West & Eastside)	74	73	0	29	26	0
Lodgepole Pine - Dry (Eastside & Westside)	68	0	7	31	0	2
Wet Meadow (Eastside & Westside)	89	85	4	52	45	5

The cost differential between maximum and streamlined management treatments varies considerably among the five ecological systems, as shown in Table 3-9. The cost of restoring wet meadows is the most challenging of the systems, totaling almost $100 million dollars over 50 years, even under streamlined management.

Table 3-9. Average annual costs of maximum and streamlined management treatments for five at-risk ecological systems.

BpS	Acres	Ave. Annual Cost Maximum Mgmt	Ave. Annual Cost Streamlined Mgmt
Aspen-Mixed Conifer Forest (Eastside)	11,000	$ 248,000	$ 153,000
Aspen Woodland (Eastside)	6,000	$ 3,000	$ -
California Montane Riparian	58,000	$ 680,000	$ 263,000
Lodgepole Pine - Dry	9,000	$ 60,000	$ 40,000
Wet Meadow	108,000	$ 4,606,000	$ 1,944,000

Tables 3-10 through 3-14 show for each of the five at-risk ecosystems, the types and levels of management treatments, the timing of their application over an initial 20 year period and subsequent 30 year period, the approximate costs of the varied treatments, and the ecological outcomes.

Table 3-10. Types and levels of management treatments, the timing of their application over an initial 20 year period and subsequent 30 year period, the approximate costs of the varied treatments, and the ecological outcomes for Aspen-Mixed Conifer.

Strategy Worksheet	*Aspen-Mixed Conifer Forest (Eastside)*					11,000	acres	1000000
			Enter percentages from "Final Conditions" as a whole number					
Vegetation Class (describe) *typo x in loft box if high-risk*	**NRV**	**Current Condition**	**Min Mgmt - No CC - 50 yrs**	**Min Mgmt CC - 50 Years**	**Max Mgmt - 1st 20 Yrs**	**Max Mgmt (CC) 2nd 30 Yrs**	**Streamlined - 1st 20 Yrs**	**Streamlined - 2nd 30 Yrs**
A - Early	34%	1%	16%	0%	38%	9%	27%	6%
B - Mid Closed	54%	25%	33%	2%	45%	59%	33%	40%
C - Mid Closed	11%	27%	13%	13%	11%	9%	20%	24%
D - Late Open	1%	5%	18%	27%	2%	0%	7%	3%
E - Late Closed	0%	41%	17%	27%	3%	0%	12%	1%
Montane Sagebrush				21%		18%		18%
Mixed Conifer			2%	3%	1%	0%	1%	2%
Chapparal				6%		6%		6%
Ecological Departure		**62**	**39**	**86**	**9**	**28**	**28**	**42**
High-Risk Classes		**1**	**0**	**0**	**0**	**0**	**0**	**0**
Vegetation Conversion			**2**	**30**	**1**	**24**	**1**	**26**
Total Cost			$ -	$ -	$ 5,625,000	$ 6,750,000	$ 3,125,000	$ 4,500,000
ROI (vs. Min. Mgmt)				-	5.2	4.9	3.2	4.7
	Enter Notes		Enter Management Strategies, Number of Acres/Year, Costs & Number of Years					
Scenarios (enter name below)	**Transitions & Multipliers**		RxFire	Thinning	RxFire	Thinning		
Min Mgmt - No CC - 50 yrs								
Min Mgmt CC - 50 Years								
Max Mgmt - 1st 20 Yrs			**225**	**225**				
Max Mgmt (CC) 2nd 30 Yrs					**0**	**300**		
Streamlined - 1st 20 Yrs			**125**	**125**				
Streamlined - 2nd 30 Yrs					**0**	**200**		
Cost of Strategy (net per acre)			$ 500	$ 750	$ 500	$ 750		
Number of Years			20	20	30	30		

Table 3-11. Types and levels of management treatments, the timing of their application over an initial 20 year period and subsequent 30 year period, the approximate costs of the varied treatments, and the ecological outcomes for Aspen Woodland.

Strategy Worksheet	*Aspen Woodland (Eastside)*					6,000	acres	1000000
			Enter percentages from "Final Conditions" as a whole number					
Vegetation Class (describe) *type x in left box if high-risk*	**NRV**	**Current Condtion**	**Min Mgmt - No CC - 50 yrs**	**Min Mgmt CC - 50 Years**	**Max Mgmt - 1st 20 Yrs**	**Max Mgmt (CC) 2nd 30 Yrs**	**Streamlined - 1st 20 Yrs**	**Streamlined - 2nd 30 Yrs**
A - Early	10%	3%	12%	3%	11%	2%	10%	2%
B - Mid Closed	32%	12%	30%	11%	21%	19%	18%	20%
C - Late Closed	57%	60%	36%	38%	50%	54%	52%	55%
D- Late Open	0%	25%	21%	29%	19%	18%	19%	17%
Montane Sagebrush		0%	0%	14%	0%	6%	0%	4%
Chaparral				5%	0%	2%	0%	2%
Ecological Departure		28	24	48	19	25	20	23
High-Risk Classes		0	0	0	0	0	0	0
Vegetation Conversion			0	19	0	8	0	6
Total Cost			$ -	$ -	$ 150,000	$ -	$ -	$ -
ROI (vs. Min. Mgmt)				-	33.3	-	-	-
	Enter Notes		Enter Management Strategies, Number of Acres/Year, Costs & Number of Years					
Scenarios (enter name below)	**Transitions & Multipliers**		RxFire	Thinning	RxFire	Thinning		
Min Mgmt - No CC - 50 yrs								
Min Mgmt CC - 50 Years								
Max Mgmt - 1st 20 Yrs			0	10				
Max Mgmt (CC) 2nd 30 Yrs					0	0		
Streamlined - 1st 20 Yrs			0	0				
Streamlined - 2nd 30 Yrs					0	0		
Cost of Strategy (per acre)			$ 500	$ 750	$ 500	$ 750		
Number of Years			20	20	30	30		

Table 3-12. Types and levels of management treatments, the timing of their application over an initial 20 year period and subsequent 30 year period, the approximate costs of the varied treatments, and the ecological outcomes for California Montane Riparian.

Strategy Worksheet	California Montane Riparian					58,000	acres	1000000
		Enter percentages from "Final Conditions" as a whole number						
Vegetation Class (describe) *typo x in left box if high-risk*	**NRV**	**Current Condtion**	**Min Mgmt - No CC - 50 yrs**	**Min Mgmt CC - 50 Years**	**Max Mgmt - 1st 20 Yrs**	**Max Mgmt (CC) 2nd 30 Yrs**	**Streamlined - 1st 20 Yrs**	**Streamlined - 2nd 30 Yrs**
A - Early	10%	1%	5%	4%	9%	24%	8%	14%
B - Mid	45%	18%	13%	9%	30%	47%	22%	33%
C - Late	45%	74%	30%	13%	59%	24%	53%	28%
x DES		5%	5%	3%	0%	0%	6%	5%
x EXF			36%	65%	1%	2%	6%	12%
x SFEnc			6%	3%	1%	4%	4%	6%
Fenced								
x Conifer			3%	2%	0%	0%	1%	3%
Ecological Departure		36	51	74	16	21	25	29
High-Risk Classes		5	50	73	2	6	17	26
Vegetation Conversion								
Total Cost			$ -	$ -	$ 14,000,000	$ 42,800,000	$ 1,750,000	$ 11,400,000
ROI (vs. Min. Mgmt)				-	5.9	1.7	33.7	4.0
	Enter Notes		Enter Management Strategies, Number of Acres/Year, Costs & Number of Years					
Scenarios (enter name below)	**Transitions & Multipliers**		Weed Inventory	Exotic Control	Floodplain Restoration	Grazing Systems	Weed Inventory	Exotic Control
Min Mgmt - No CC - 50 yrs								
Min Mgmt CC - 50 Years								
Max Mgmt - 1st 20 Yrs			2000	1000	150	10000		
Max Mgmt (CC) 2nd 30 Yrs			3000	2000	150	10000	3200	2400
Streamlined - 1st 20 Yrs			500	250	0	0		
Streamlined - 2nd 30 Yrs							1600	1200
Cost of Strategy (per acre)			$ 50	$ 250	$ 2,000	$ 5	$ 50	$ 250

Table 3-13. Types and levels of management treatments, the timing of their application over an initial 20 year period and subsequent 30 year period, the approximate costs of the varied treatments, and the ecological outcomes for dry Lodgepole Pine.

Strategy Worksheet	***Lodgepole Pine - Dry***					9,000	acres	1000000
		Enter percentages from "Final Conditions" as a whole number						
Vegetation Class (describe) *type x in left box if high-risk*	**NRV**	**Current Condtion**	**Min Mgmt - No CC - 50 yrs**	**Min Mgmt CC - 50 Years**	**Max Mgmt - 1st 20 Yrs**	**Max Mgmt (CC) 2nd 30 Yrs**	**Streamlined - 1st 20 Yrs**	**Streamlined - 2nd 30 Yrs**
A - Early	20%	1%	6%	0%	48%	0%	33%	0%
B - Mid Closed	0%	3%	1%	1%	2%	2%	2%	1%
C - Mid Open	50%	11%	13%	2%	21%	57%	16%	39%
D - Late Open	26%	70%	52%	55%	20%	27%	33%	37%
E - Late Closed	4%	14%	27%	35%	9%	12%	16%	20%
Red Fir				4%		1%		1%
Mixed Conifer				3%		1%		1%
Ecological Departure		**58**	**51**	**68**	**35**	**20**	**34**	**31**
High-Risk Classes		**0**	**0**	**0**	**0**	**0**	**0**	**0**
Vegetation Conversion		**0**	**0**	**7**	**0**	**2**	**0**	**2**
Total Cost			$ -	$ -	$ 3,000,000	$ -	$ 2,000,000	$ -
ROI (vs. Min. Mgmt)				-	5.4	-	8.6	-
	Enter Notes		Enter Management Strategies, Number of Acres/Year, Costs & Number of Years					
Scenarios (enter name below)	**Transitions & Multipliers**		RxFire					
Min Mgmt - No CC - 50 yrs								
Min Mgmt CC - 50 Years								
Max Mgmt - 1st 20 Yrs			**1,200**					
Max Mgmt (CC) 2nd 30 Yrs			**0**					
Streamlined - 1st 20 Yrs			**800**					
Streamlined - 2nd 30 Yrs								
Cost of Strategy (per acre)			$ 500					
Number of Years			5					

Table 3-14. Types and levels of management treatments, the timing of their application over an initial 20 year period and subsequent 30 year period, the approximate costs of the varied treatments, and the ecological outcomes for Wet Meadow.

Strategy Worksheet	*Wet Meadow*					108,000	acres	1000000
		Enter percentages from "Final Conditions" as a whole number						
Vegetation Class (describe) *type x in left box if high-risk*	**NRV**	**Current Condtion**	**Min Mgmt - No CC - 50 yrs**	**Min Mgmt CC - 50 Years**	**Max Mgmt - 1st 20 Yrs**	**Max Mgmt (CC) 2nd 30 Yrs**	**Streamlined - 1st 20 Yrs**	**Streamlined - 2nd 30 Yrs**
A - Early	7%	0%	1%	0%	11%	10%	6%	6%
B - Mid Closed	73%	0%	5%	2%	54%	40%	24%	22%
C - Late Open	20%	27%	16%	9%	27%	38%	26%	21%
x DES		36%	32%	31%	3%	3%	22%	21%
x EXF		0%	2%	10%	2%	2%	1%	0%
x TrEnc		36%	33%	38%	0%	2%	19%	19%
x AG		0%	5%	4%	0%	0%	0%	2%
x SFEnc		0%	4%	2%	2%	0%	1%	3%
Lodgepole Pine-wet				4%		5%		5%
Ecological Departure		80	78	89	19	33	50	52
High-Risk Classes		72	76	85	7	7	43	45
Vegetation Conversion				4	0	5	0	5
Total Cost			$ -	$ -	$ 210,050,000	$ 20,250,000	$ 86,700,000	$ 10,500,000
ROI (vs. Min. Mgmt)				-	0.6	5.9	0.7	5.9

	Enter Notes	Enter Management Strategies, Number of Acres/Year, Costs & Number of Years							
Scenarios (enter name below)	**Transitions & Multipliers**	Weed Inventory	Exotic Control	Floodplain Restoration	Shrub-Forb Encroached Restoration	Tree Encroached Restoration	Weed Inventory (2nd 30 Yrs)	Exotic Control (2nd 30 yrs)	Shrub-Forb Encroached Restoration (2nd 30 Yrs)
Min Mgmt - No CC - 50 yrs									
Min Mgmt CC - 50 Years									
Max Mgmt - 1st 20 Yrs		300	200	5000	1000	500			
Max Mgmt (CC) 2nd 30 Yrs							2500	1200	500
Streamlined - 1st 20 Yrs		200	100	2000	800				
Streamlined - 2nd 30 Yrs							2000	1000	0
Cost of Strategy (per acre)		$ 50	$ 250	$ 2,000	$ 500	$ 500	$ 50	$ 250	$ 500

4 Conclusions and Recommendations

4.1 Conclusions

The best available climate projections available today suggest the Northern Sierra faces a future climate that is likely hotter, has less snowfall, more rain, and earlier snowmelt. Temperatures have been rising over the past century and shifts in vegetation patterns are already occurring. Nevertheless, the region's ecological systems have many inherent "competitive advantages" as compared to other regions in facing a different climate. These advantages include a diversity of environmental gradients (i.e., elevation, landforms, precipitation, temperature) that provide a broader "stage" for future adaptation, as well as local systems that are well adapted to tremendous annual climatic variability.

The Northern Sierra Partnership's priority areas are generally well situated for conserving the region's major habitat types in a changing future climate. These priority areas are embedded within a matrix of public lands that are legally protected from conversion to agricultural or urban land uses. Most major habitat types are well represented in the NSP priority areas, even though these areas were not selected to be representative of the entire Northern Sierra Nevada region. NSP priority areas, which comprise about 1,000,000 acres of the 5,000,000 acre region, include over 20% of the distribution for region's ten most abundant habitat types. Habitat types that are under-represented in NSP priority areas, but common to the Northern Sierra Nevada and adjacent regions, tend to occur at the periphery of the region (i.e., Ponderosa Pine–Mixed Conifer to the west, and Big Sagebrush Shrubland to the east), or have been previously noted as significant gaps on federal lands (i.e., oak woodlands in the Sierra Nevada foothills, and montane meadow in the northern Sierra Nevada) by the Sierra Nevada Ecosystem Project (http://www.ceres.ca.gov/snep/).

The NSP priority areas also do a good job of capturing climatic microrefugia (e.g., colder, wetter, and/or more connected landscape features) of the Northern Sierra Nevada region. The NSP priority areas capture at least 20% of the river corridors, seeps and springs, cold air drainages, and north-facing and shaded slopes. The Upper East Fork Carson River has the most diversity and highest density of microrefugia features, followed by Genessee Valley, Indian Valley, and the Middle American and Rubicon Rivers.

Biophysical setting (BpS) refugia are those places on the landscape with the highest likelihood of sustaining existing major habitat types in the face of climate change. Comparing between priority areas, the Upper East Fork Carson River includes the most refugia for the most BpS, even after normalizing by area. Genessee Valley, Upper Little Truckee River and Sierra Crest priority areas follow as the most significant areas for BpS refugia. Comparing between habitat types, potential refugia dominated the current extent for five BpS forecasts (Mixed Conifer–Mesic, Yellow Pine–East Side, Ponderosa Pine–Mixed Conifer, Subalpine Woodland, Lodgepole Pine–Dry), whereas potential climate stress dominated four BpS forecasts (Red Fir–White Fir, Lodgepole Pine–Wet, Aspen Woodland, Aspen–Mixed Conifer). BpS types with under-represented climate refugia forecasts in current NSP priority areas include what appear to be a mix of patchy vulnerable systems (i.e., Lodgepole Pine–Wet, Lodgepole Pine–Dry, Aspen Woodland, Aspen–Mixed Conifer) and abundant systems in the East (i.e., Yellow Pine–East Side) and West stratification units (i.e., Ponderosa Pine–Mixed Conifer).

NSP priority areas by themselves may not be large enough to capture landscape-level processes such as the range shifts of species in response to climate change. It is important for the Partnership to think about the larger landscape of which each priority area is a part. Many NSP priority areas are embedded within a larger matrix of public lands that afford more opportunity for landscape-scale conservation management than lands in private or commercial ownerships. Figures 2-17 and 2-18 illustrate the idea that lands outside of the NSP priority areas may be essential to the conservation of several major habitat types as climate change alters the suitability of the northern Sierra Nevada landscape. These figures clearly show that refugia areas for some major habitat types are located outside of the NSP priority areas. Public lands cover a much larger geography than the NSP priority areas, with significant representation of most conifer habitat types. Therefore, where public lands contain adequate biophysical refugia for habitat types that are poorly represented in NSP priority areas, there is an opportunity to apply restoration and management practices, such as mechanical thinning and controlled burns, to increase the health and resilience of these habitat types and thereby assist these habitat types in making a transition to a changing climate. More specifically, forecasts of vegetation shifts in the Northern Sierra Nevada reveal that Aspen Woodland and Aspen–Mixed Conifer Forest are most vulnerable to conversion to other habitat types of sagebrush, chaparral or conifer. We are fortunate that aspen groves are widely recognized as very important to the biodiversity of conifer forest landscapes, and the focus of numerous forest restoration projects. Aspen release is widely practiced, a technique to thin encroaching conifers and release aspen trees from competition. The results of forecasted vegetation shifts reveals that land managers must continue to pay special attention to aspen grove management and restoration if we are to maintain this habitat type under a changing climate.

For ecological systems that are found to be at risk from projected future climate changes, management strategies can be deployed to substantially abate future threats, improve ecological condition, and reduce undesirable vegetation conversions. These management strategies (e.g., stream and meadow restoration, forest thinning and prescribed fire) are not unconventional treatments; indeed, many of them are already being deployed by NSP and its partners within NSP priority landscapes, such as TNC’s forest thinning and restoration at Independence Lake, TPL’s and TDLT’s meadow and riparian restoration work on the Little Truckee River, and FRLT’s meadow and riparian restoration at Genesee Valley. However, the challenge will be to implement the successful strategies in early years at a sufficient scope and scale, given the financial costs and complex political environment. Our report relies heavily upon theory and assumptions to survey potential future climate risks, but the major outcomes seem reasonable: technically feasible management strategies can be deployed to increase the resilience of at-risk systems in a changing climate.

The departure of major habitat types from a natural range of variability affirms widely held views regarding the condition of natural habitats in the Sierra Nevada (see Table 3-1). The departure analysis reveals that many conifer forest types such as Lodgepole Pine, Red Fir – White Fir, and Ponderosa Pine–Mixed Conifer are significantly departed from a natural range of variability today. This departure is likely a reflection of altered stand conditions due to decades of fire suppression and incompatible timber harvest practices of the past. The departure analysis also revealed that riparian and meadow habitats are categorized as highly departed from a natural range of variability. This high departure level is consistent with field observations and other studies showing meadow and riparian systems are in poor condition in the Northern Sierra Nevada due to erosion, channel down-cutting, loss of stream-bank vegetation, de-watering of meadows, conversion of meadows, and other threats associated with development and intensive agriculture/ranching practices.

When climate change impacts were included in simulations for departure of major habitat types, a total of five systems are projected to depart highly from their natural range of variability, as compared to only two systems without climate change. The systems with the highest forecasted ecological departure are California Montane Riparian, Great Basin Riparian, Wet Meadow, Aspen Mixed Conifer, and Lodgepole Pine–Dry. Conversely, three systems showed predicted *improvement* in ecological departure as compared to scores with no climate change: Red Fir–Western White Pine, Red Fir–White Fir, and Serpentine Woodland and Chaparral.

The predicted ecological improvements of three habitat types in the absence of any active management despite climate impacts may seem counter-intuitive. The primary explanation for this result is the fact that the ecological models provided the “escape” of fires into the systems, even in the face of ongoing management for fire suppression. Moreover, for some systems the climate change impacts increased the frequency of fire. The return of fire allowed many fire-dependent systems to “reset” closer to the natural range of variability for a habitat type. The predicted high departures for riparian, wet meadow, aspen mixed conifer, and lodgepole pine highlight the vulnerability of freshwater habitats to the impacts of a changing climate. The Sierra Nevada Ecosystem Report of 1996 identified riparian and aquatic systems as the most damaged and impaired in the Sierra Nevada. It is not surprising then, that they would be most vulnerable to changing climatic conditions, particularly since a warming of the Sierra Nevada will alter hydrologic regimes and place particularly high stress upon systems so directly linked to water. Aspen groves are also linked to water in that they always occur in sites with high water availability. The forecasted departure of lodgepole pine is an interesting result, suggesting that this conifer type is more vulnerable to the impacts of climate change than other conifer habitat types.

The implication of forecasted departure models suggest that riparian and meadow habitats remain an important focus for conservation and stewardship by the Northern Sierra Partnership. These system types are forecasted to experience the highest levels of stress and departure from a natural range of variability. Conservation efforts to ensure riparian meadows are connected to the broader landscape and to other freshwater sites will be important. Acquisition, conservation easements and restoration are important tools to promote meadow resilience. In the face of a changing climate, these tools can be used to further several important objectives: maintain water rights and natural flow regimes; maintain connectivity between meadows and uplands; prevent habitat conversion of meadows; and, restore meadow hydro-geomorphology to optimize habitat conditions.

Another implication of the forecasted departure models is that lodgepole pine should receive additional scrutiny in the design and implementation of forest restoration projects. It may be warranted to place additional acreage of lodgepole pine into mechanical thinning and controlled burn projects, given their increasing departure levels from desired conditions in a changing climate.

Eight of the Northern Sierra's ecological systems are projected to experience increases in high-risk vegetation classes, and almost all of these increases occur with or without climate change (Table 3-4). The primary causes are: (1) increased cheatgrass in the understory of ponderosa pine, yellow pine, and three sagebrush systems; and (2) increases in exotic forbs in the wet meadow and riparian systems. Dramatic increases in exotic forbs are projected in California montane riparian systems. Climate change is predicted to exacerbate the high-risk classes in the wet meadow and riparian systems, by accelerating the rate of exotic forb invasion.

The forecasts of high risk vegetation classes indicate that a strong commitment to stewardship and land management will be necessary to combat the threat of invasive weeds in many major habitat types. This conclusion is challenging because today, elevation and cool temperature has been a natural barrier to many invasive plants. The future of terrestrial natural communities may come to resemble today's challenge of protecting aquatic natural communities. Aquatic invasive species are a major threat to lake and stream ecosystems and huge levels of resources are now being directed toward preventing and eradicating aquatic invasive species in places like Lake Tahoe and Independence Lake.

Forecasts of the aforementioned management strategies upon the highest at-risk major habitat types showed substantial improvements in projected habitat conditions under climate change for Aspen–Mixed Conifer Forest, Aspen Woodland, California Montane Riparian, and Lodgepole Pine–Dry. Continued use of traditional management strategies can have a dramatic impact in the ability of these at-risk habitat types to persist in the face of climate change. Traditional management includes mechanical thinning, controlled burns, weed prevention, weed control, floodplain restoration, habitat restoration, and livestock management. The cost of implementing these management strategies may be substantial over the vast geography of the Northern Sierra Nevada; streamlined meadow restoration was forecast at $100 million over 50 years. An important ongoing role for the Northern Sierra Partnership will be to highlight the importance of this region and to attract public and private dollars for acquisition, restoration, and management.

Finally, this study provides useful forecasts of terrestrial vegetation under a changing climate, however, important next steps must be considered in future studies if we are to fully understand and adapt to climate change. Aquatic systems and freshwater biodiversity urgently need climate change analyses. This study demonstrated that riparian and meadow systems are highly vulnerable to the effects of climate change. It is important to study and forecast how fishes, amphibians, insects, plants, mammals and birds that are associated with freshwater systems will respond to climate change. Independent of biomes, species are generally expected to respond to climate in unique ways, rather than tracking the responses of major habitat types; therefore, future studies of climate change should consider the individual responses of multiple (interacting) species across the landscape. Future comparisons between Sierra Nevada and surrounding ecoregions are needed to help identify the source of new species that may colonize the Sierra Nevada, as well as the potential destinations for species that need to migrate out of the Sierra Nevada because they can no longer tolerate climatic conditions. Additionally, as refinements to General Circulation Models (GCMs) eventually lead to consensus on the sign and magnitude of forecasted changes to precipitation, it will be important to revisit potential climate change impacts for the northern Sierra Nevada.

4.2 Short-Term Recommendations

The following major recommendations are offered to the Northern Sierra Partnership and The Nature Conservancy:

- The new NSP strategic plan should explicitly and prominently incorporate climate change adaptation within its priority goals and strategies. Our assessment suggests that *where* we work today in the project area is reasonably sufficient for addressing the threat of climate adaptation. *How* we work in these places may be as important to success.

- NSP Strategic Priority #1 should include conserving a network of functional landscapes that capture the region's notable diversity of terrain and vegetation types. A new assessment of connectivity may be warranted to ensure that select land acquisition provide connectivity among major habitat types and future climatic microrefugia.

- The NSP five-year goals should include refining, implementing and demonstrating climate-adapted strategies for long-term landscape and ecosystem protection.

- NSP should continue to engage with partners to demonstrate forest, riparian and wetland restoration strategies that measurably improve ecological condition of at-risk systems and increase their resilience to a changing climate – including focal efforts to restore Aspen-Mixed Conifer forests at Independence Lake and to restore meadows and riparian systems along the Little Truckee River, Genesee Valley, and Red Clover Valley. NSP should develop and implement these strategies in ways that can be replicated at a larger-scale and should monitor the outcomes.

- NSP should seek to engage with the U.S. Forest Service to promote landscape-scale forest, aspen, and meadow restoration.

5 Acknowledgements

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Appendix A

This Appendix explains the process of updating LANDFIRE vegetation geodata, calculating ecological departure, and simulating climate change effects using temporal multipliers in state-and-transition models.

Mapping Pre-settlement Vegetation and Current Vegetation

The foundation of ecological departure mapping is the stratification of a landscape via biophysical settings, or potential vegetation, as defined by LANDFIRE (www.landfire.gov; Rollins2009). Biophysical settings are conceptually similar to ecological sites from Natural Resource Conservation Service (NRCS) soil surveys, except the biophysical settings often represent groups of ecological sites dominated by the same upper-layer species. The NRCS defines ecological site as "a distinctive kind of land with specific physical characteristics that differs from other kinds on land in its ability to produce a distinctive kind and amount of vegetation." (*National Forestry Manual*, www.nrcs.usda.gov/technical/ECS/forest/2002_nfm_complete.pdf).

For each biophysical setting (a.k.a. ecological system), current vegetation was also mapped as the natural succession classes and any uncharacteristic classes. Natural succession classes typically were based on the standard LANDFIRE model of up to five classes ranging from early- to mid- to late-development; mid- and late-development classes may be expressed as open or closed canopy. Uncharacteristic classes included the presence of uncharacteristic native species (e.g. loss of aspen regeneration, loss of aspen clones, encroachment of pinyon or juniper into shrublands and wet meadows, loss of the herbaceous understory of shrublands, and entrenchment and drop of the water table in riparian systems and wet meadows) and uncharacteristic exotic species (e.g., invasion of cheatgrass into shrublands and woodlands, and invasion of exotic forbs in wet meadows and riparian systems).

The LANDFIRE program has developed maps of biophysical settings and current vegetation succession classes for the entire United States (Rollins 2009). LANDFIRE's remote sensing was based on multiple captures of Landsat imagery from the 1990s reflecting current land management practices. We clipped this GIS data to the ~5,000,000-acre project area. We refined the geodata using two major improvements: 1) replacing the LANDFIRE geodata covering National Forests with USFS's enhanced biophysical settings and current vegetation classes and 2) remapping the LANDFIRE riparian layers with National Wetland Inventory (NWI) geodata.

1) National Forest geodata. After LANDFIRE made geodata available for download in 2009, Dr. Hugh Safford, the USFS regional ecologist for Region 5, used historic USFS vegetation plot data and maps to remap the LANDFIRE geodata for Region 5 National Forests, along with revising reference VDDT models and recalculating NRV. USFS used LANDFIRE's definitions and standards. We used the new USFS geodata to replace the LANDFIRE geodata for approximately 70% of the study area (i.e., stamping new geodata over old geodata). The area outside National Forests was retained in their original LANDFIRE version.

2) Riparian geodata. LANDFIRE's biophysical setting map lacked Montane Wet Meadow, which is a critical ecological system for the Northern Sierra Partnership. LANDFIRE did not consider wet meadows as a distinct biophysical setting; therefore, they were not mapped. LANDFIRE mapped as agriculture (pasture), sagebrush, and riparian large areas we knew were large wet meadows. Without external geodata on wet meadows, it would not have been possible to map them. The NWI data were used to remedy biophysical setting shortcomings. Therefore, all NWI vegetation types that could be conceived as marsh, wet meadow, wetland, or naturally inundated lands were called montane wet meadow and replaced the LANDFIRE biophysical setting geodata. The new layer captured well known wet meadows. In a few very small cases, NWI mapped "forested coniferous swamp", which we lumped with lodgepole pine-wet (if LANDFIRE mapped forest types) or water (if LANDFIRE mapped water). The NWI geodata were limited to biophysical settings and could not provide any information for vegetation classes. The vegetation classes within each biophysical setting were obtained through a "coarse" crosswalk. Rules were:
    - If wet meadow biophysical setting in LANDFIRE, then we made no change to vegetation classes;
    - If sagebrush biophysical setting in LANDFIRE, then we changed the area to wet meadow class U (Uncharacteristic) *Desertification* (lowered water table or diverted water favoring subxeric shrubs);
    - If forest (usually conifers) biophysical setting in LANDFIRE, then we changed the area to wet meadow class U *Tree-Encroached* (conifer encroachment for usually lowered water table or diverted water);
    - If agriculture or pasture in LANDFIRE, then we changed the area to wet meadow class C *late-succession*.

Evaluating Current Ecological Condition

We assessed the condition of each major ecological system by mapping ecological departure (a.k.a., Fire Regime Condition or FRC) using the methodology developed under the U.S. interagency LANDFIRE program (Hann and Bunnell, 2001; Shlisky and Hann 2003; Rollins 2009; and adapted by Provencher et al. 2008). The fundamental elements of ecological departure analysis include mapping the distribution of ecological systems that existed prior to European settlement or are today naturally functioning, mapping current vegetation and succession classes, and calculating dissimilarity between current and pre-settlement (or naturally functioning) conditions. Ecological departure is an integrated, landscape-level measure of ecological condition that incorporates species composition, vegetation structure, and all significant disturbances (not only fire) for terrestrial and riparian ecological systems that would have occurred pre-settlement or in naturally functioning landscapes. This methodology determines the dissimilarity between an ecological system's current (or future simulated) condition and its natural range of variability (NRV). NRV reflects the distribution of vegetation classes that would be found under naturally functioning ecological processes, as predicted by field studies, expert opinion, and computer simulations. We calculated the ecological departure of each ecological system from new NRV using the grid data obtained from LANDFIRE, USFS geodata, and NWI. Ecological departure is scored on a scale of 0% to 100% departure from NRV using the standard LANDFIRE methodology: 0% represents NRV while 100% represents total departure from NRV (dissimilarity equation in Provencher et al. 2008).

Assessing Future Condition

Predictive Ecological Models

In order to forecast future condition with and without projected climate change effects (as well as to test alternative conservation strategies), one state-and-transition model was developed for each biophysical setting using Vegetation Dynamics Development tool (VDDT; Barrett 2001; Beukema et al. 2003) software. A state-and-transition model is a discrete, box-and-arrow representation of the continuous variation in vegetation composition and structure of an ecological system (Bestelmeyer et al., 2004). Different boxes either belong to different *phases* within a state or different *states*. States are formally defined in rangeland literature (Bestelmeyer et al., 2004) as: persistent vegetation and soil changes per potential ecological sites that can be represented in a diagram with two or more boxes (phases of the same state). Different states are separated by "thresholds." A threshold implies that substantial management action would be required to restore ecosystem structure and function. Relatively reversible changes (e.g., fire, flooding, drought, insect outbreaks, and others), unlike thresholds, operate between phases within a state. All ecological system models had at their core the LANDFIRE reference condition represented by some variation around the A-B-C-D-E succession classes, which are phases within the reference state. (Some USFS models had an F class representing an alternative early succession class.) The A-E class models typically represent succession from usually herbaceous vegetation (class A) to increasing woody species dominance where the dominant woody vegetation might be shrubs (class C) or trees (class E).

We used LANDFIRE-based descriptions and models as modified by Dr. Hugh Safford for the five predominant forest systems in the Sierra Nevada. For other systems, we used LANDFIRE descriptions and models or descriptions and models applied in the Bodie Hills in eastern California (Provencher et al., 2009; Low et al, 2010).

The models for many ecological systems included "uncharacteristic" (U) classes. Uncharacteristic classes are classes outside of reference conditions. Ecological departure calculations do not differentiate among the uncharacteristic classes – i.e., all U-classes are treated as equally outside of NRV. However, the cost and management urgency to restore different uncharacteristic classes varies greatly. TNC therefore previously developed and applied a separate designation and calculation of "high-risk" vegetation classes. A high-risk class was defined as an uncharacteristic vegetation class that met at least one out of three criteria: 1) ≥5% cover of invasive non-native species, 2) very expensive to restore, or 3) a direct pathway to one of these classes (invaded or very expensive to restore) (Low et al., 2010). We secured rates of conversion to uncharacteristic classes (e.g. the rate of cheatgrass invasion for ponderosa and Jeffrey pines) based on expert opinion and observational data (*personal communication*, Dr. Kyle Merriam, Plumas National Forest).

Accounting for Variability in Disturbances

The basic VDDT models incorporate stochastic disturbance rates that vary around a mean value for a particular disturbance associated with each ecological system. The default variability is relatively minor in magnitude. For example, fire is a major disturbance factor for most of the Northern Sierra's ecological systems, including replacement fire, mixed severity fire, and surface fire. These fire regimes have different rates or probabilities of occurrence in a given year (i.e., inverse of the mean fire return interval) that are incorporated into the models for each ecological system where they are relevant. However, in real-world conditions the disturbance rates are likely to vary appreciably over time. To simulate strong yearly variability for fire activity, drought-induced mortality, non-native species invasion rates, tree encroachment rate, loss of herbaceous understory, flooding, and so on, TNC incorporated temporal multipliers in the model run replicates. This approach was pioneered by TNC for the Bodie Hills project at the request of the Bureau of Land Management Bishop Field Office (Provencher et al., 2009).

A temporal multiplier is a number in a yearly time series that multiplies a base disturbance rate in the VDDT models: e.g., for a given year, a temporal multiplier of one implies no change in a disturbance rate, whereas a multiplier of zero is a complete suppression of the disturbance rate, and a multiplier of three triples the disturbance rate. A temporal multiplier can be obtained from time series data or theoretically derived.

We generated temporal multipliers for two different purposes: 1) to represent the reference condition and estimate new NRV (i.e., we did not use NRV provided by LANDFIRE) and 2) to represent the period of fire suppression and land management in the northern Sierra Nevada.

NRV Estimation. The Palmer Drought Severity Index (PDSI) was used to create most temporal multipliers, including for fire. The PDSI (mean monthly November-April; raw numbers were not modified) for the region was used to create 100-year temporal multipliers to more accurately reflect annual variability in fire and other disturbance regimes. The PDSI period from 1896-2006 was obtained from the USFS (also: Data source from NOAA National Climate Data Center - http://www.ncdc.noaa.gov/oa/mpp/). Taylor and Beaty (2005) showed that the PDSI is highly negatively correlated to fire frequency and total area burned for forest types during pre-settlement: more fire was observed during increasingly drier years. The same relationship holds for average temperature (Westerling et al. 2006). This, however, does not apply to shrublands that must first experience consecutive wetter than average years to accumulate fine fuels that will more likely burn in a dry year immediately following the wet year sequence (Westerling and Bryant 2008; Westerling, *in press*). The first replicate of the PDSI time series was obtained from the 1896 to 1995 period. The next four replicates were randomly resampled with replacement from the full 111-year time series with MS Excel's VLOOKUP function; they conserved the original time series' number of high and lows, and magnitude of area burned per year. Cyclical behavior, such as caused by climate forcing factors, will not be preserved by this approach.

By trial-and-error, we fitted equations that converted the PDSI time series values into temporal multipliers of fire and other mortality sources that had to satisfy one important condition: the results of NRV simulations with their imbedded temporal multipliers had to reproduce USFS data-supported estimated fire and insect/disease rates (probability per year) when simulated to equilibrium in each of five VDDT major forest model developed by

Safford. In other words, fire and insect/disease rates in the VDDT models were "true" because USFS staff had estimated them from field data, whereas the PDSI variability we were introducing as an external forcing factor had never been used for simulations. Therefore, simulations with PDSI had to yield realized rates for fire and insect/disease that approximately equaled the field estimates, which in turn required transformation of the yearly PDSI values for each temporal multiplier series. Different negative exponential equations were used because the general form of the negative exponential appropriately damped the effects of wet and average years (positive PDSI) but magnified the effects of truly dry years (negative PDSI) (Table A-1; Figure A-1 except intraspecific competition). Obtaining the best fitting negative exponential equation for each simulation type was an incremental trial-and-error process in parameter fitting. Using temporal multipliers from Table A-1, simulations were run for 100 years to obtain equilibrium values for vegetation classes. If equilibrium was not achieved after 100 years, the previous run's end values became the initial conditions for the next 100 years and repeated until equilibrium was reached. Equilibrium values were the NRV.

Table A-1. Temporal multipliers fitting equations for biophysical settings developed by USFS R5. Legend: RF = replacement fire, MF = mixed severity Fire, SF = surface fire, and I/D = insect & disease.

Biophysical setting	RF	MF	SF	I/D	Intra-specific Competition[#]
Red Fir-White Pine	$0.5474e^{-0.4938PDSI}$	$0.0364e^{-1.5PDSI}$	$0.5202e^{-0.7177PDSI}$	$0.5474e^{-0.4938PDSI}$	
Red Fir-White Fir	$0.5474e^{-0.4938PDSI}$	$0.0364e^{-1.5PDSI}$	$0.5202e^{-0.7177PDSI}$	$0.194e^{-0.8056PDSI}$	
Mixed Conifer	$0.5474e^{-0.4938PDSI}$	$0.0364e^{-1.5PDSI}$	$0.5652e^{-0.5664PDSI}$	$0.5474e^{-0.4938PDSI}$	$e^{-(PDSI+abs(min[PDSI]))} / e^{-abs(min[PDSI])}$
Ponderosa Pine	$0.5474e^{-0.4938PDSI}$	$0.0364e^{-1.5PDSI}$	$0.5202e^{-0.7177PDSI}$	$0.5652e^{-0.5664PDSI}$	$e^{-(PDSI+abs(min[PDSI]))} / e^{-abs(min[PDSI])}$
Jeffrey Pine	$0.5474e^{-0.4938PDSI}$	$0.194e^{-0.8056PDSI}$	$0.5652e^{-0.5664PDSI}$	$0.5652e^{-0.5664PDSI}$	$e^{-(PDSI+abs(min[PDSI]))} / e^{-abs(min[PDSI])}$

[#]Intra-specific competition among early-succession saplings was included in USFS models, but a field-estimated was not provided; therefore, we could not fit an equation. We developed a plausible equation that caused wetter than average years to suppress intra-specific competition.

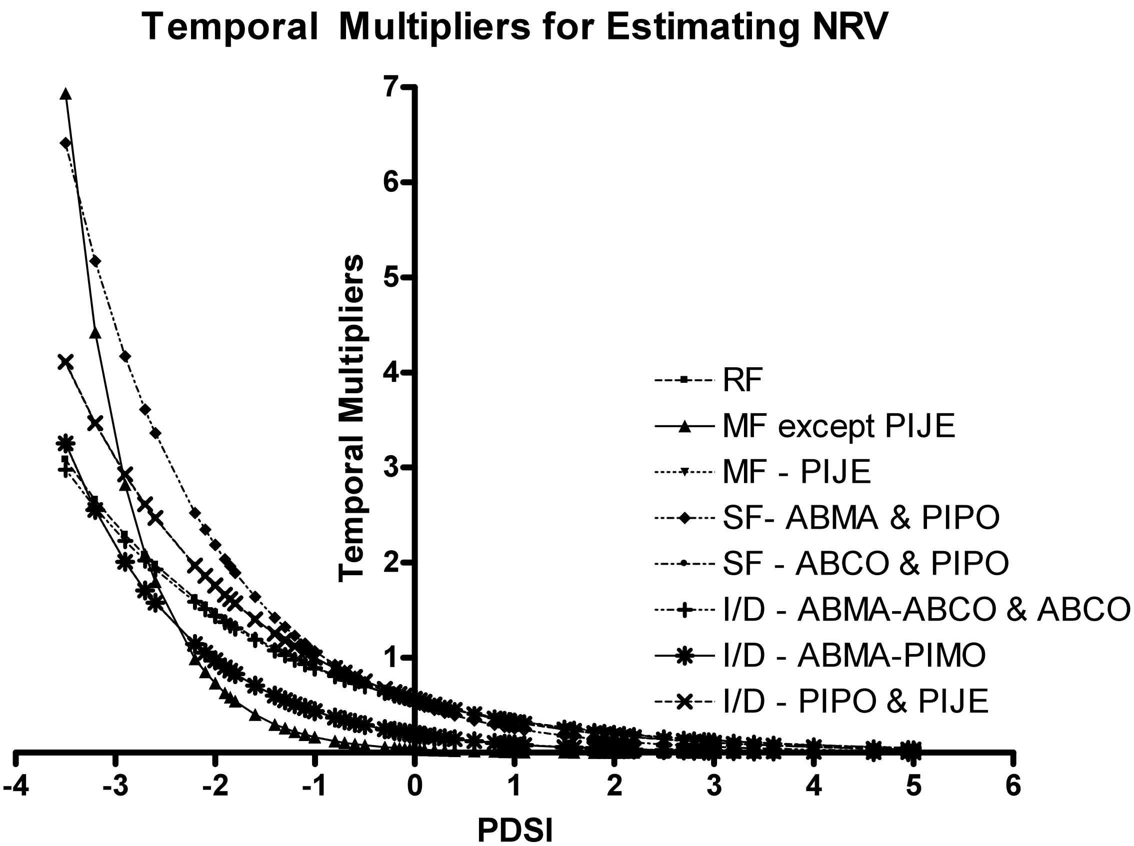


Figure A-1. Temporal multipliers based on the Palmer Drought Severity Index (PDSI) for biophysical settings developed by USFS R5. Legend: RF = replacement fire, MF = mixed severity Fire, SF = surface fire, and I/D = insect & disease, PIJE = Jeffrey pine, ABMA = California red fir, PIPO = ponderosa pine, ABCO = white fir, and PIMO = western white pine.

Temporal multiplier equations in Table A-1 applied to Safford's five models. There were, however, 20 other biophysical settings that also needed temporal multipliers based on PDSI for consistency in methods. "Thematic" temporal multipliers were developed by which similar biophysical settings were grouped: i) shrublands - subxeric woodlands, ii) alpine – subalpine – wet systems (including aspen), and iii) low- and mid-elevation forests. These are shown in Table A-2. The low- and mid-elevation forest group essentially shared ponderosa pine's temporal multipliers. The shrubland - subxeric woodland group was based on our work in the Bodie Hills of eastern California for big sagebrush (Provencher et al., 2009). The temporal multiplier equation for fire in shrublands reflects the fact that moisture and fine fuels have to build up with above average moisture before fire can spread in these subxeric systems (Westerling, *in press*): it is the only equation that considers PDSI over two consecutive years. The alpine-subalpine-wet system group included all systems that are not water limited, except during droughts.

Table A-2. Temporal multiplier fitting equations for biophysical settings not developed by USFS R5. Legend: RF = replacement fire, MF = mixed severity Fire, SF = surface fire, and I/D = insect & disease.

Biophysical setting	RF	MF	SF	I/D	Drought	Snow-Deposition	Very-Wet-Year
Alpine-Subalpine-Wet Systems (including Aspen)	$0.5474 \times e^{-0.4938PDSI}$	$0.0364 \times e^{-1.5PDSI}$		$0.5474 \times e^{-0.4938PDSI}$	$0.5474 \times e^{-0.4938PDSI}$	if(PDSI < -2.5 then =0 else =0.9334 + 0.3338PDSI)	
Low &Mid-Elevation Forest	$0.5474 \times e^{-0.4938PDSI}$	$0.0364 \times e^{-1.5PDSI}$	$0.5652 \times e^{-0.5664PDSI}$	$0.5652 \times e^{-0.5664PDSI}$			
Shrubland-Subxeric Woodland	$e^{0.5(PDSI_t - PDSI_{t+1} - 1)} \times e^{-0.1PDSI_{t+1}}$		$e^{0.5(PDSI_t - PDSI_{t+1} - 1)} \times e^{-0.1PDSI_{t+1}}$		$0.5474 \times e^{-0.4938PDSI}$		If(PDSI >2, then =PDSI else =0)

Temporal multipliers for montane-subalpine riparian systems (not shown in Table A-2) were strongly dependent on flow variations (Rood et al., 2003; McBride and Strahan, 1984). We had recently developed long term flow temporal multipliers for the lower Truckee River (USGS Sparks Truckee River gage), which is highly influenced by the Pacific Ocean and representative of the whole northern Sierra Nevada. Variability of the 7-year, 20-year, and 100-year flood events used in the models were all based on filtering the full time series for increasingly higher values of annual peak flow that correspond to these flood events. The three levels of flooding corresponded to 7-year events that killed or removed only herbaceous vegetation; 20-year events that killed or removed shrubs and young trees; and 100-year events that top-killed larger trees (i.e., these are three distinct disturbances in the riparian VDDT models). All temporal multipliers were obtained by dividing peak flow from each year by the temporal average of peak flow. Based on known flood events for the Truckee River, the 7-yrear, 20-year and 100-year flood events, respectively, corresponded to ~0.8, ~1 and ~3.69 of the flood temporal multiplier series: All values less, respectively, than the thresholds of 1 and 3.69 for the 20-year and 100-year flood events were zero because they did not have enough force to destroy class-dependent vegetation (i.e., had no effect on vegetation in the class), whereas all values above the flood event thresholds were used directly as a temporal multiplier (Figure A-2). The 7-year flood events encompass the full time series of peak flow because few peak flows were below the 7-year event threshold and those that were below actually suppressed the model's disturbance rate.

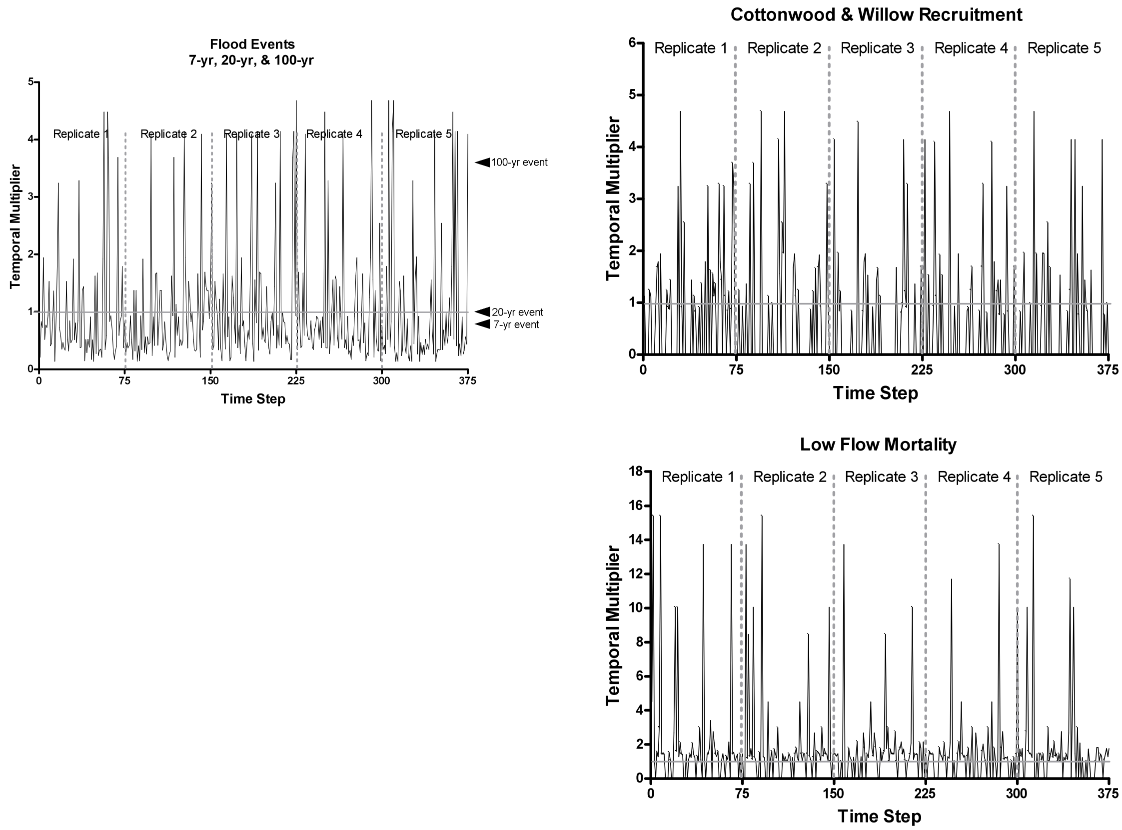


Figure A-2. Riparian temporal multipliers a) for 7-year, 20-year, and 100-year flood events, b) for cottonwood and willow recruitment, and c) for low average August and September flows that kill cottonwood and willow seedlings. For the 20-year and 100-year flood events, respectively, all values below their threshold were zero. Data obtained from the Sparks Truckee River U.S. Geological Survey gage. The gray line for temporal multiplier = 1 represented the "no-change" or neutral parameter line.

Two other riparian disturbances were used during the first two years of succession: *cottonwood-willow recruitment* and *low-flow-kill*. Each had a temporal multiplier based on different flow data. *Cottonwood-willow recruitment* depends on flood stage and recession rate (Rood et al., 2003; McBride and Strahan, 1984), which do not translate nicely into the yearly time step of VDDT models. To imitate the effect of stage and recession on *Cottonwood-willow recruitment*, two dependent components that had to be met for successful recruitment:

1. Recruitment was more successful as peak flows increased in a given year for various reasons, including scouring and creation of wetted mineral surface. The temporal multiplier (yearly peak flow divided by the temporal average of peak plow) contributed to recruitment if it was > 0.77 or a 5-year flood event, which is a typical minimum overbank flow value; (Figure A-2); and

2. Given peak flows were sufficient for recruitment, sometimes recruitment failed for purely random reasons in a year due to various factors including the shape of the hydrograph (appropriate recession rate) and weather. We assigned an arbitrary 5% rate of failure of cottonwood and willow germination (i.e., 95% of times germination would succeed). The 5% rate of failure to germinate was randomly drawn from a uniform distribution in MS Excel (RAND() function).

After recession of spring flows, low-flow-kill was a source of mortality applied to the established cottonwood and willow seedlings (i.e., successfully germinated in June and July) that was caused by desiccation of seedlings from prolonged lower summer flows. The lowest water months of the year causing this mortality were August and September. We summed August and September flows in a year and then divided them by the temporal average of this sum to obtain the temporal multiplier time series. If the low-flow temporal multiplier was >1 (i.e., more water than average), *low-flow-kill* was zero (i.e., no desiccation), otherwise *low-flow-kill* was the inverse of the low flow temporal multiplier (i.e., greater mortality for lower summer flows; Figure A-2).

We used PDSI to calculate NRV because PDSI captured the high variability of dry and wet years, and fire activity in the northern Sierra Nevada (Taylor and Beaty 2005). However, we do not necessarily recommend the approach of incorporating more realistic levels of variability to estimate NRV as a general practice for other projects because significant changes in the PDSI or any critical time series data (spatially or duration) can lead to a different recalibration of the models parameters and NRV. Our approach was very time-consuming. The accepted standard method for NRV estimation — LANDFIRE's — does not use any external source of variability (i.e., no temporal multipliers) other than the default variability of VDDT and is far less arduous.

<u>Incorporating Fire and Land Management into Models</u>. Different fire temporal multipliers were used for post-settlement models than for NRV models. We secured fire history geodata for the northern Sierra Nevada from federal and state sources to more accurately reflect the actual annual variability in fire activity in the forest ecosystems during the XXth century and early XXIst century — including fire suppression and wildfires escaping suppression efforts. The temporal multipliers used for this phase of modeling were based on total area burned geodata from federal, state, and private lands over ~107 years. Three steps were involved:

1. <u>Partition area burned</u>: Using GIS, we clipped the fire area geodata to the east and west sides of the Sierra Nevada, and further separated those areas by biophysical settings, to create 100-year (the full time series was 107 years long) fire time series per biophysical setting.
2. <u>Sum area burned by major biophysical setting groups</u>: The area burned by biophysical setting was pooled (summed) into five major functional groups and fire temporal multipliers (area burned in a year divided by the temporal average of area burned) were calculated for these groups to avoid tedious and possibly sized-bias temporal multiplier calculations, especially for small systems (Table A-3).

3. Partition by fire severity: Total are burned by major biophysical setting group was partitioned among the three fire severity types (replacement = high, mixed = intermediate, and surface = low); otherwise the variability of replacement fire would equal that of surface fire and lead to intense and unrealistic fire activity in forests and rangelands that are currently fire suppressed. To obtain the severity type proportions, VDDT models of the most dominant biophysical settings were inventoried for their realized disturbance rates (result of simulations). We then averaged these rates across biophysical settings by fire type. These rates were divided by their total (of the three types) to guarantee a total proportion of one (Table A-4). As a final result, fifteen time series (i.e., three time series per each of five replicates, one each for replacement, mixed severity, and surface fire) were uploaded into the appropriate VDDT models, and yearly probability multiplier values multiplied the average wildfire rate in the models. All replicates had differing peaks and lows of fire activity. Importantly, the temporal multipliers reflected fire suppression practices and human activity of the last century and were considered the "no-climate change" version for all simulations.

Table A-3. Biophysical settings by functional groups.

Functional Group	Biophysical Setting
Alpine & Subalpine	
	Subalpine meadow
	Alpine Shrubland
	Lodgepole Pine-dry
	Lodgepole Pine-wet
	Subalpine Woodland
	Red Fir-Western White Pine
	Red Fir-White Fir
Mid-Elevation Forest	
	Mixed Conifer-Mesic
	Yellow Pine East Side
	Ponderosa Pine-Mixed Conifer
	California Oak-Pine Forest
	Wet Meadow
	California Montane Riparian
	Great Basin Montane Riparian
Mid-Elevation Eastern Shrubland	
	Montane sagebrush Steppe
	Big Sagebrush Shrubland
	Low Sagebrush
	Pinyon-Juniper Woodland
	Curlleaf Mountain Mahogany

	Aspen Woodland Aspen-Mixed Conifer Forest
Xeric-Shrubland	
	Ultramafic Woodland and Chaparral Montane Chaparral
Lower-Elevation-Western Forest & Woodland	
	California Mixed Evergreen Forest Blue Oak-Pine Foothill Woodland

Table A-4. Relative proportions of fire severity types.

Functional Group	Fire Type	Relative Proportion
Alpine & Subalpine		
	surface fire	0.73
	mixed fire	0.19
	replacement fire	0.07
Mid-Elevation Forest		
	surface fire	0.35
	mixed fire	0.39
	replacement fire	0.26
Mid-Elevation Eastern Shrubland[&]		
	surface fire	0.01
	mixed fire	0.01
	replacement fire	0.98
Xeric-Shrubland[&]		
	surface fire	0.01
	mixed fire	0.01
	replacement fire	0.98
Lower-Elevation Western Forest & Woodland [#]		
	surface fire	0.35
	mixed fire	0.46
	replacement fire	0.19

[&] These types generally only have replacement fire; however 1% each for mixed severity and surface fire were allowed for a few exceptions.
[#] Based on ponderosa pine VDDT data

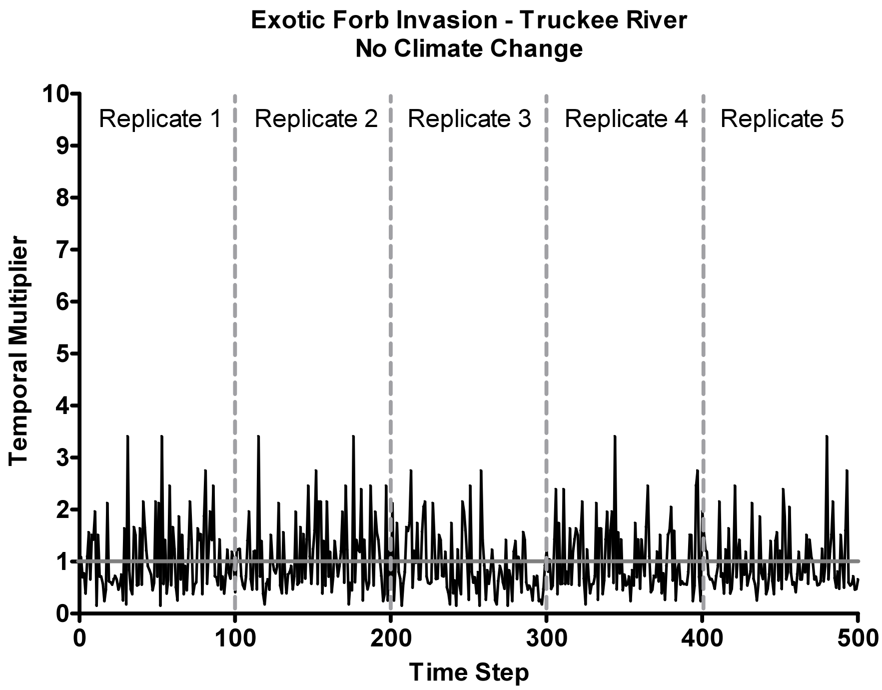
Temporal multipliers for drought-induced mortality, insects and disease, snow deposition, very-wet-year, flooding, cottonwood-willow-recruitment, and low-flow-kill that were shown above for NRV estimation were also used in management models. The Truckee River flow temporal multipliers were kept to represent the east side; however, new USGS gage data were obtained from the Feather River at Oroville to calculate west side 7-, 20-, and 100-year flood events, cottonwood-willow recruitment, and low-flow-kill temporal multipliers.

New temporal multipliers were needed, however, for tree (singleleaf pinyon and Utah or western juniper) encroachment into shrublands and non-native species invasions. We assumed that the rate of annual grass-invasion was greatest in wetter years and least in drier years (Table A-5). Tree encroachment similarly responded to PDSI, but we assumed a much slower process (Table A-5). Both temporal multiplier equations were linear for the non-null portion of the relationship. Linearity was chosen as the simplest assumption because Dr. Robert Nowak at University of Nevada, Reno indicated that he was not aware of any published data to inform our pixel-based modeling.

Table A-5. Temporal multipliers fitting equations by biophysical setting. Legend: AG-Invasion = annual-grass invasion.

Biophysical setting	Tree-Invasion	AG-Invasion
Ponderosa Pine & Jeffrey Pine		f(PDSI < -2.5 then 0 else 1.8+0.7156PDSI)
Sagebrush shrubland, Pinyon-Juniper & Mountain Mahogany Woodland	if(PDSI < -2.5 then 0 else 0.9334+0.3338PDSI)	if(PDSI < -2.5 then 0 else 1.8+0.7156PDSI)

A final parameter was exotic forb-invasion in montane-subalpine riparian and wet meadow. We assumed that years of greater average annual flows would favor the invasion of exotic forbs. The exotic forb invasion temporal multiplier was the only one based on average annual flow because we assumed that year-round flows provided the soil moisture to promote weed growth. The rate of exotic forb invasion was, therefore, multiplied by the annual flow temporal multiplier (Figure A-3).



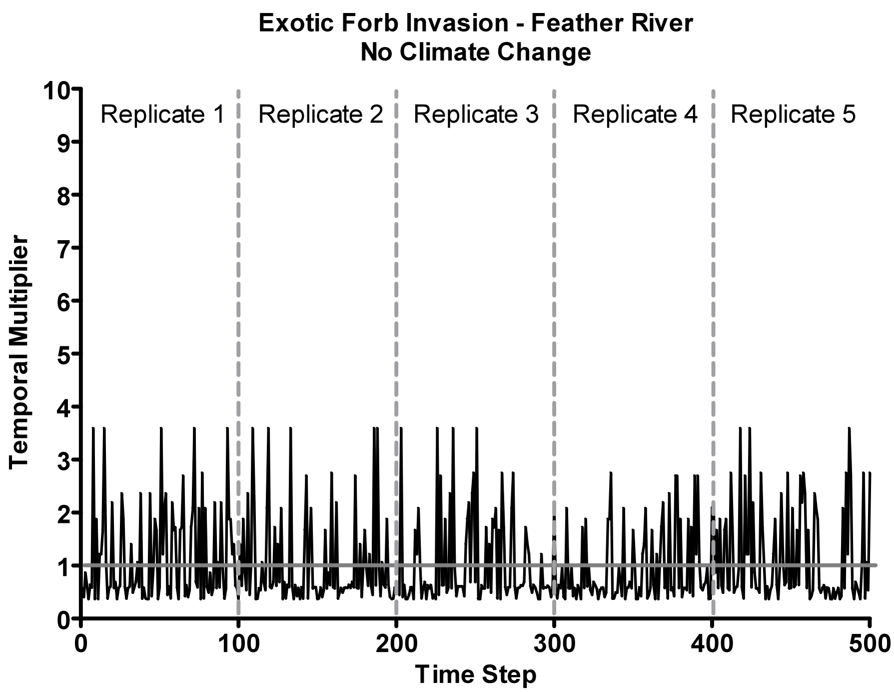


Figure A-3. Temporal multipliers for exotic fob invasion for the Truckee River (east side, upper graph) and Feather River (west side; lower graph). Under the no-climate change scenario, the exotic forb invasion temporal multiplier is equal to the annual flow temporal multiplier. The y-axis was set high to facilitate the comparison to the climate change scenario presented below.

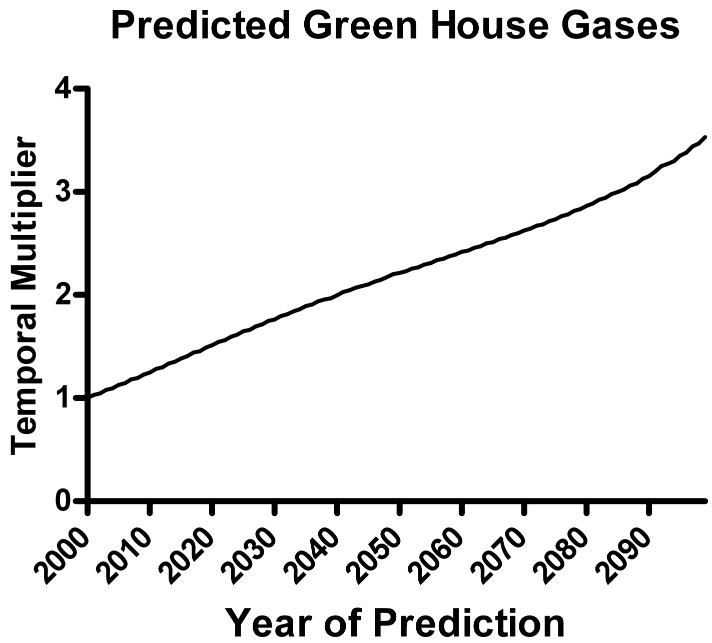
Modifications of Temporal Multipliers to Reflect Future Climate Change

Fire Temporal Multipliers

We modified several replicate temporal multipliers from the east and west sides to simulate future fires assuming increasingly higher temperatures and about the same total precipitation (Parallel Climate Model with the business-as-usual B066.44 scenario from Dettinger et al., 2004; Figure A-4), and increasing green house gases (Figure A-4; IPCC 2007). The temperature, precipitation, and GHG multipliers were calculated differently than other temporal multipliers (the precipitation temporal was not needed): The temperature and GHG temporal multiplier time series were, respectively, obtained by dividing each year's value (in degree Celsius for temperature) by the value of temperature and GHG of the first year of the time series. We chose this different calculation of temporal multipliers under the assumption of increasing temperature and GHG would increasingly affect model parameters and that the beginning of the simulation is not affected by climate change factors (thus, temporal multiplier of the first year = 1). In retrospect, however, we recommend the standard division by the time series' temporal average to minimize, but not remove problems with unit conversions (e.g., Fahrenheit versus Celsius), but then adding a constant to all transformed values such that the first temporal multiplier at the beginning of the series is equal to one.

The simplest, most generic modification of historic fire temporal multiplier was to multiply year for year each historic replicate fire temporal multiplier for each of the five vegetation groups by the predicted temperature temporal multiplier (Figure A-4). This assumed that higher temperature caused more forest fire activity in a linear manner. The assumption of higher temperature or greater PDSI causing more fire activity is highly supported for forested systems (Taylor and Beaty 2005; Westerling et al. 2006; Westerling and Bryant 2008; Westerling *in press*). Westerling and Bryant (2008) showed nonlinearities between area burned and maximum temperature; however, their predictions under the A2 emissions scenario showed a nearly linear relationship between percent change in number of voxels (i.e., unit of lat × long × month) burned with fires >200 ha and future years of simulation. This bulk update of future fire activity resulted in 15 new temporal multipliers (5 groups × 3 fire severities) for each of the east and west sides representing climate change.

Temporal multipliers for fire, with and without climate change, are depicted in Figures A-5 to A-14. Every 100-year segment of the x-axis is a replicate.



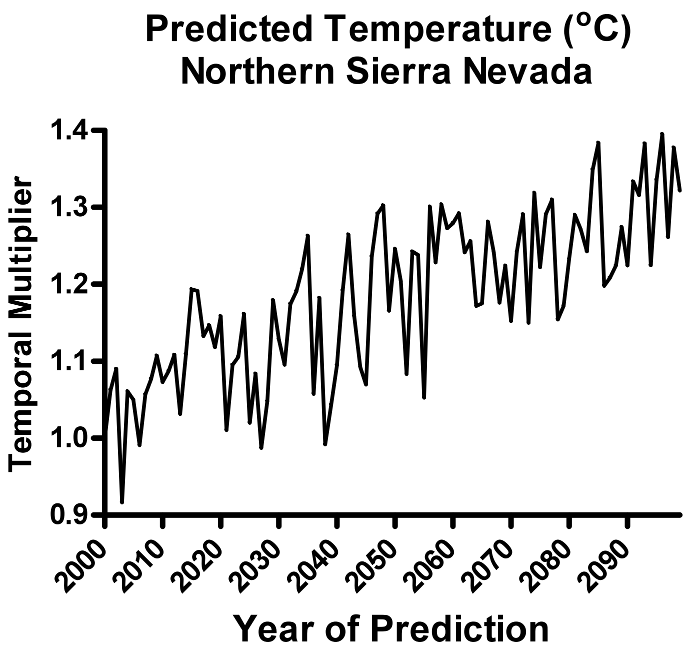


Figure A-4. Temporal multiplier of temperature for the Northern Sierra Nevada (based on Dettinger et al. 2004) and global green house gases (based on IPCC 2007) under the "business-as-usual" (A2) climate change scenario. Temperature raw data obtained from Dr. M. Dettinger, USGS, 2009 based on the PCM simulations. The green house gases and temperature temporal multipliers were each calculated by dividing each yearly value by the value of the first year of the time series.

East Side - Low-Elevation Forest Fire Multipliers

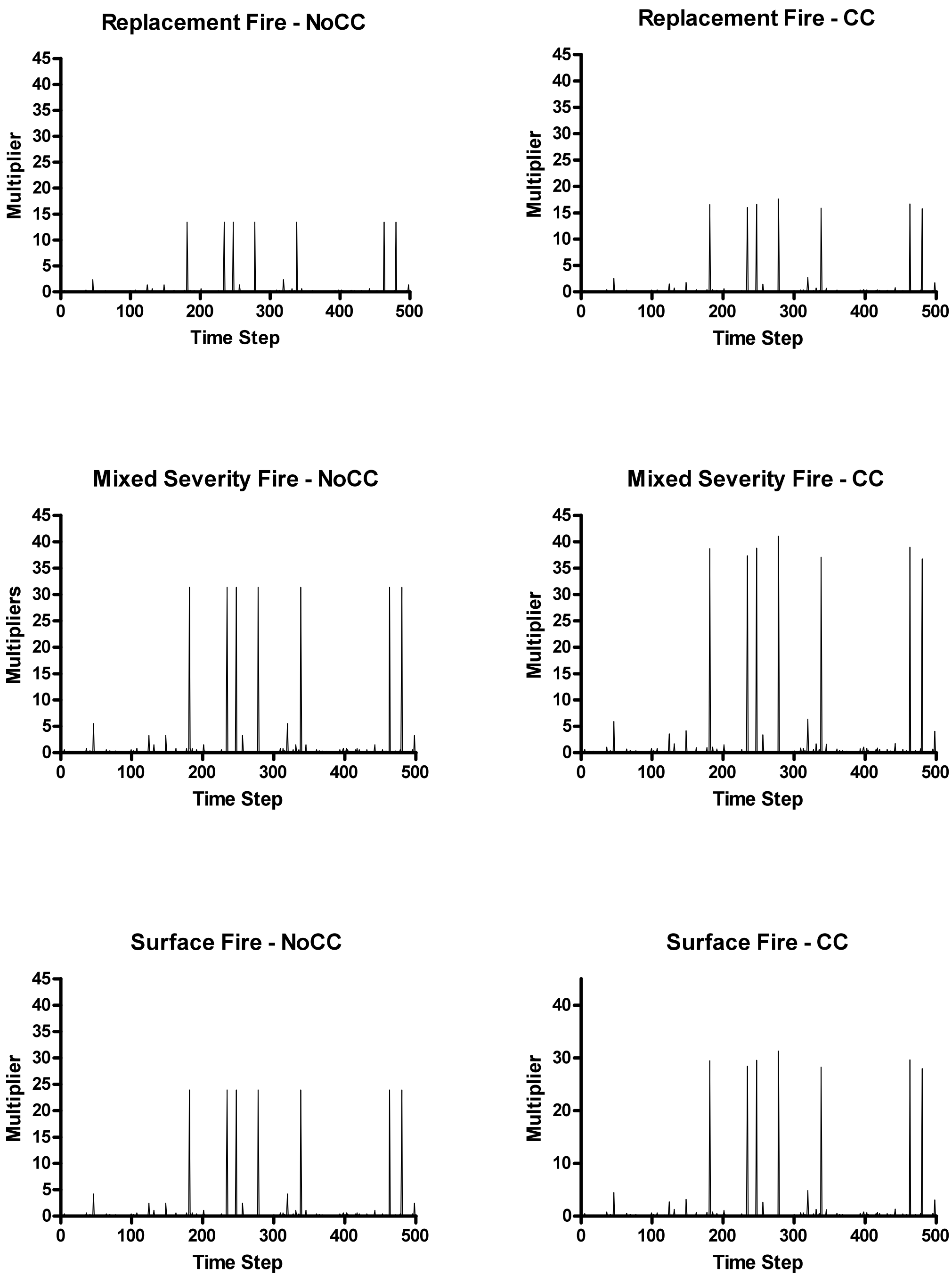


Figure A-5. Temporal multipliers of fire severity types for low elevation forest types on the east side of the Sierra Nevada.

East Side - Mid-Elevation Forest & Meadow Fire Multipliers

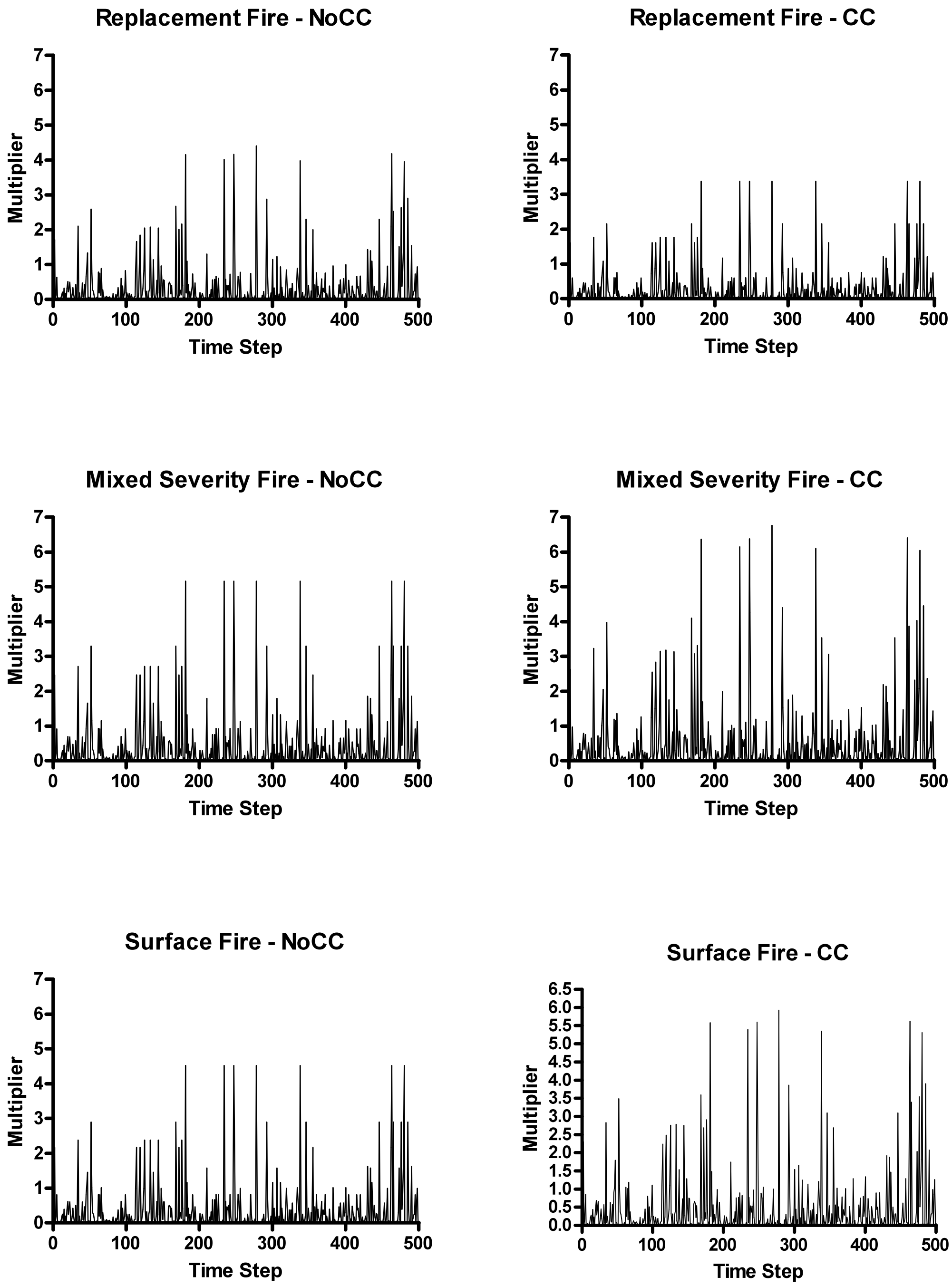


Figure A-6. Temporal multipliers of fire severity types for mid- elevation forest types on the east side of the Sierra Nevada.

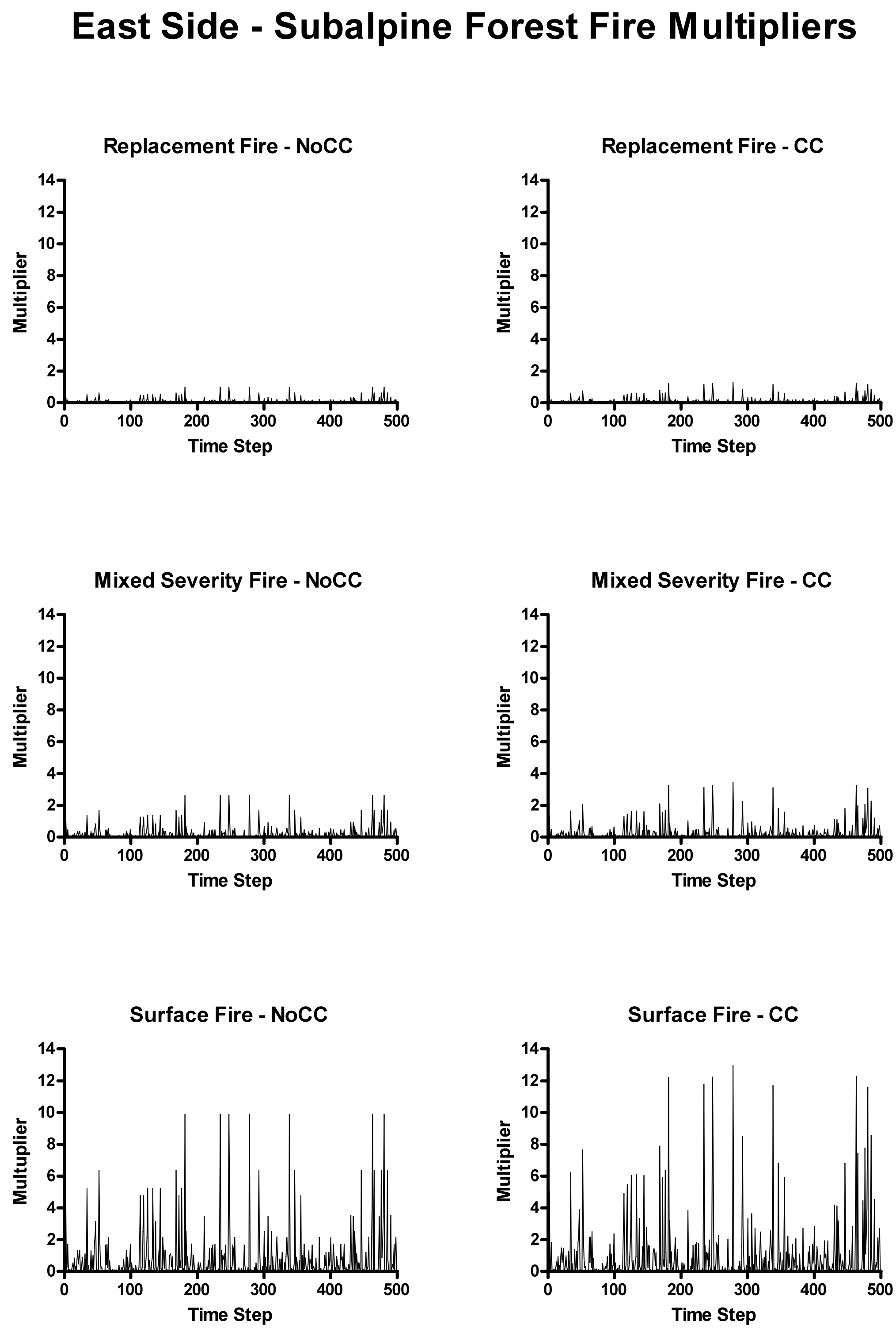
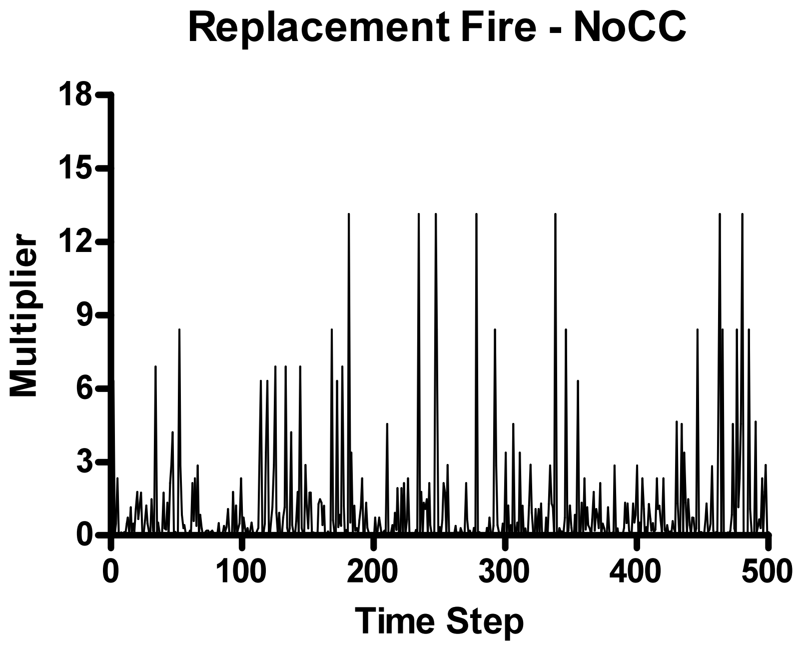


Figure A-7. Temporal multipliers of fire severity types for subalpine forest types and alpine systems on the east side of the Sierra Nevada.

East Side - Mid-Elevation Shrubland Multipliers



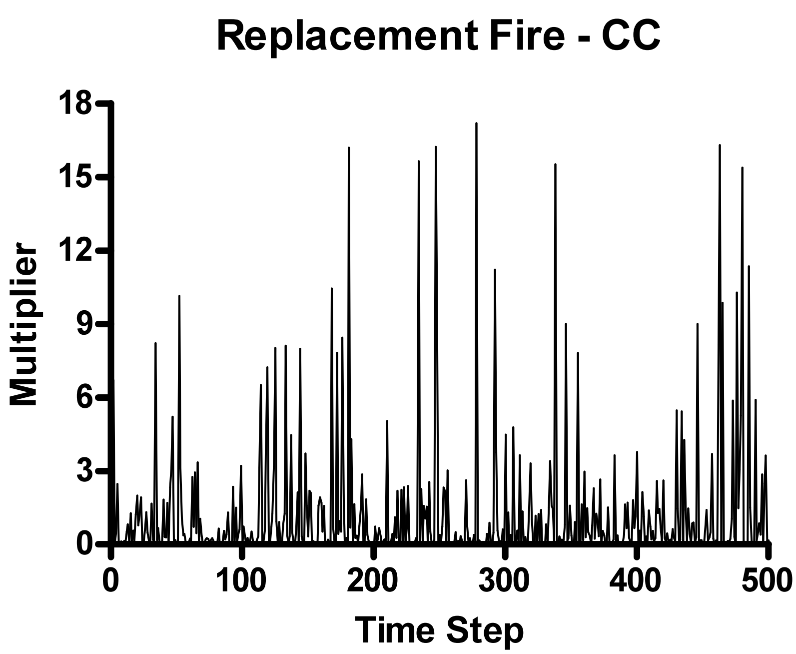


Figure A-8. Temporal multipliers of fire severity types for mid-elevation shrublands and woodlands on the east side of the Sierra Nevada.

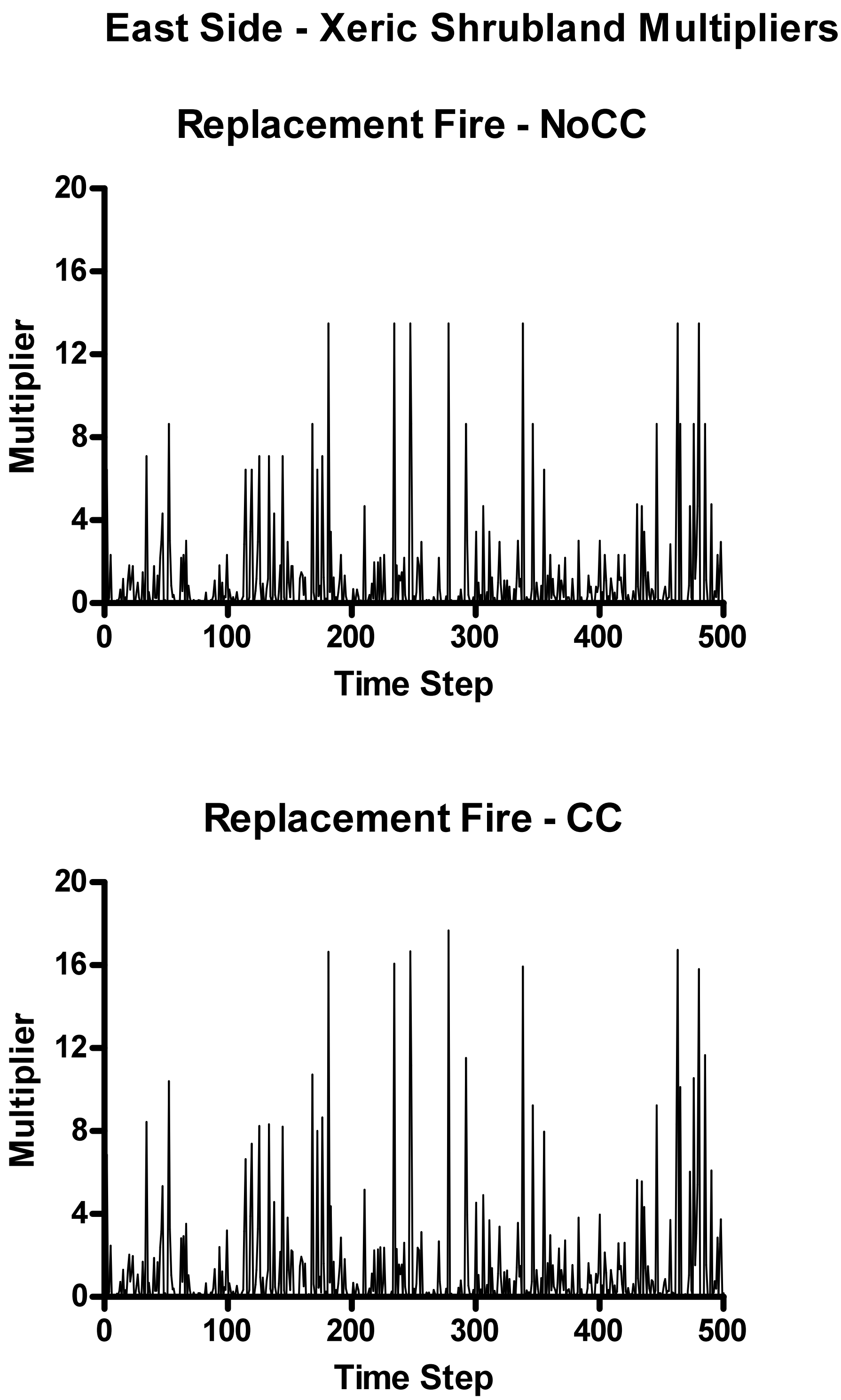


Figure A-9. Temporal multipliers of fire severity types for xeric shrublands on the east side of the Sierra Nevada.

West Side - Low Elevation Forest Fire Multipliers

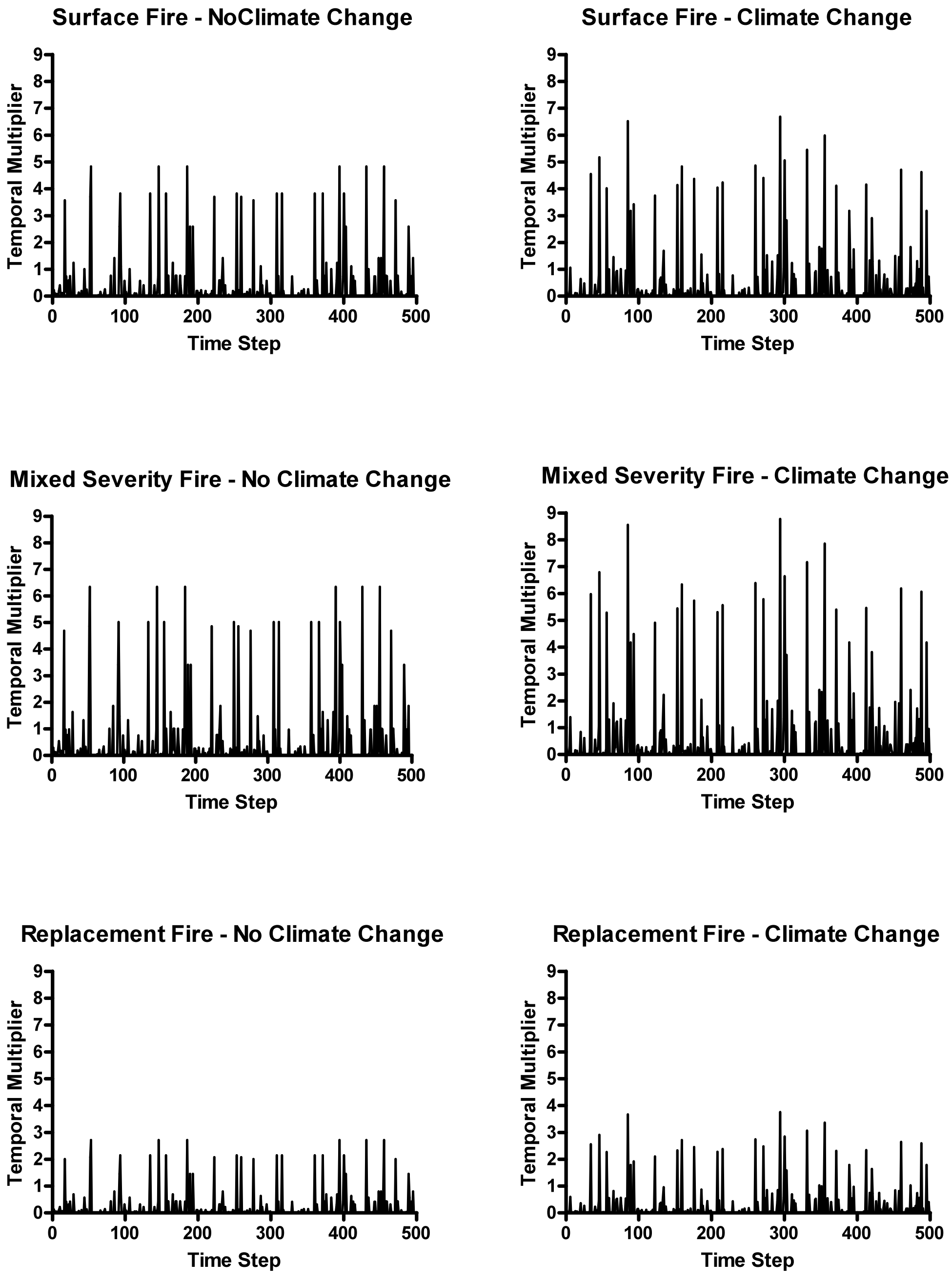


Figure A-10. Temporal multipliers of fire severity types for low-elevation forests on the west side of the Sierra Nevada.

West Side - Mid-Elevation Forest & Meadow Fire Multipliers

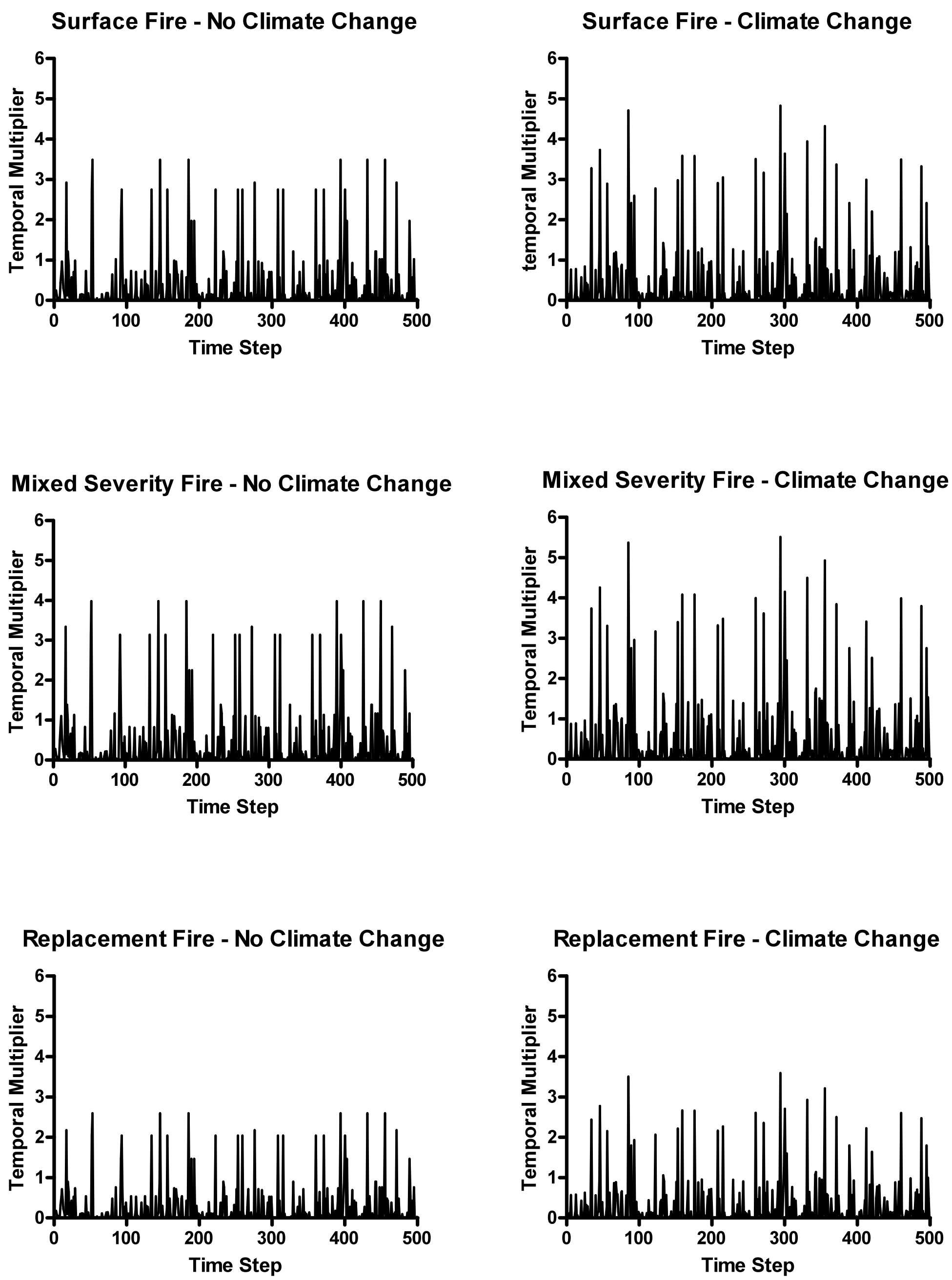


Figure A-11. Temporal multipliers of fire severity types for mid-elevation forests on the west side of the Sierra Nevada.

West Side - Subalpine Forest Fire Multipliers

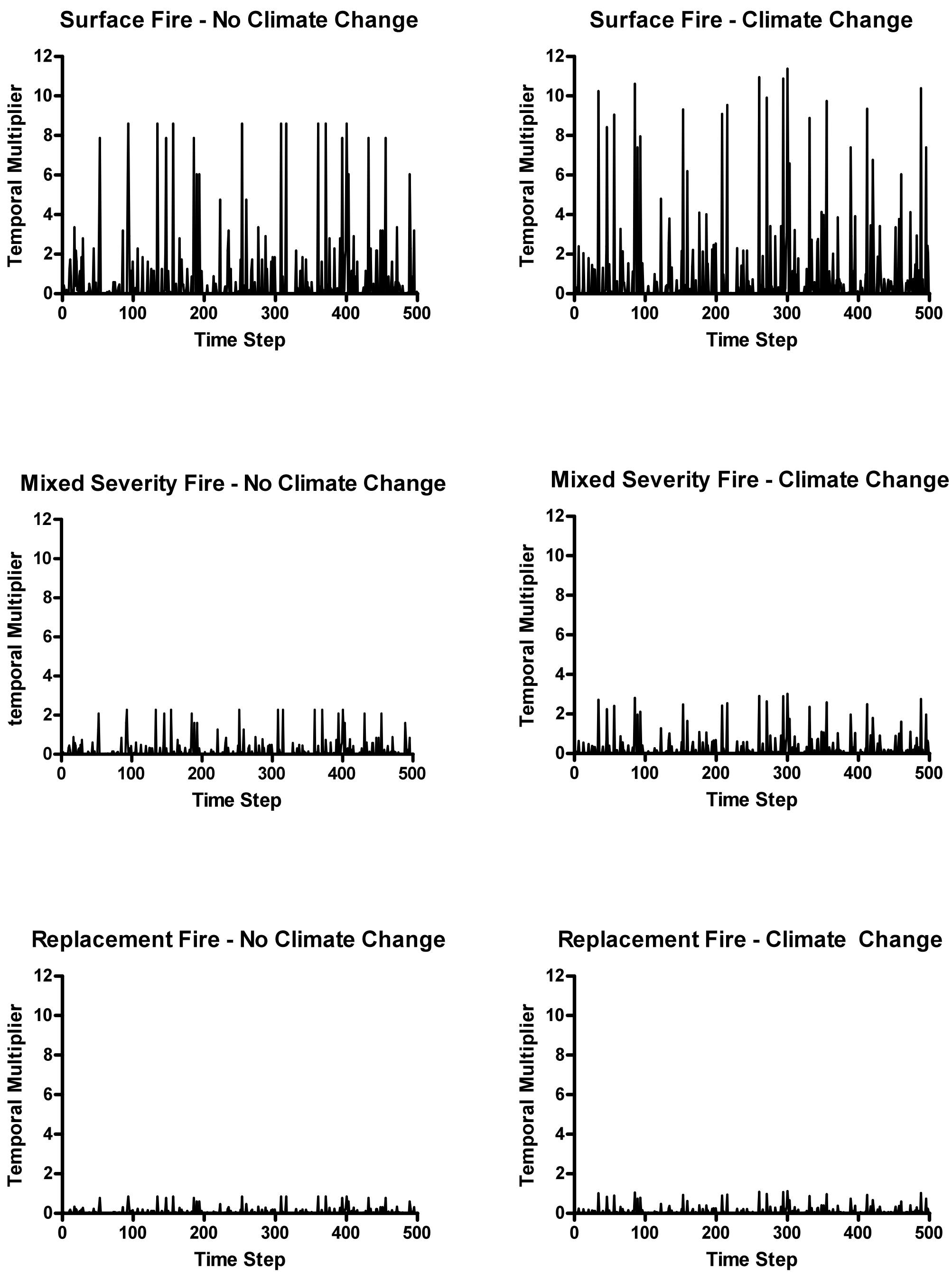
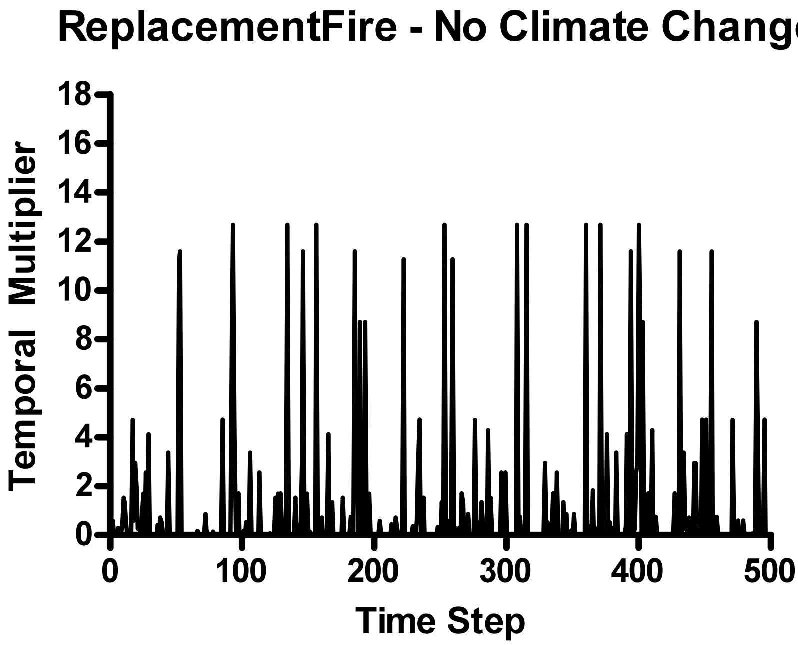


Figure A-12. Temporal multipliers of fire severity types for subalpine forests and alpine systems forests on the west side of the Sierra Nevada.

West Side - Mid-Elevation Shrubland Fire Multipliers



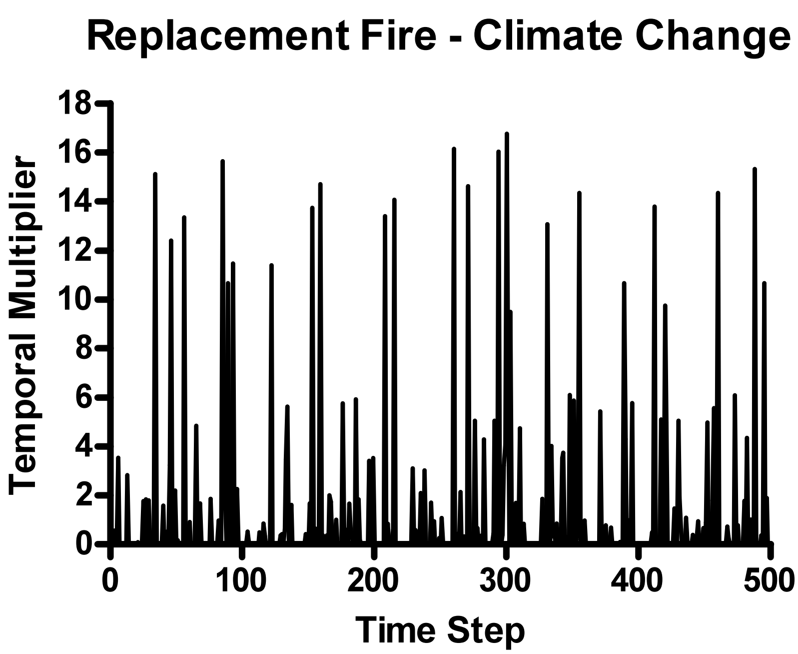


Figure A-13. Temporal multipliers of fire severity types for mid-elevation shrublands on the west side of the Sierra Nevada.

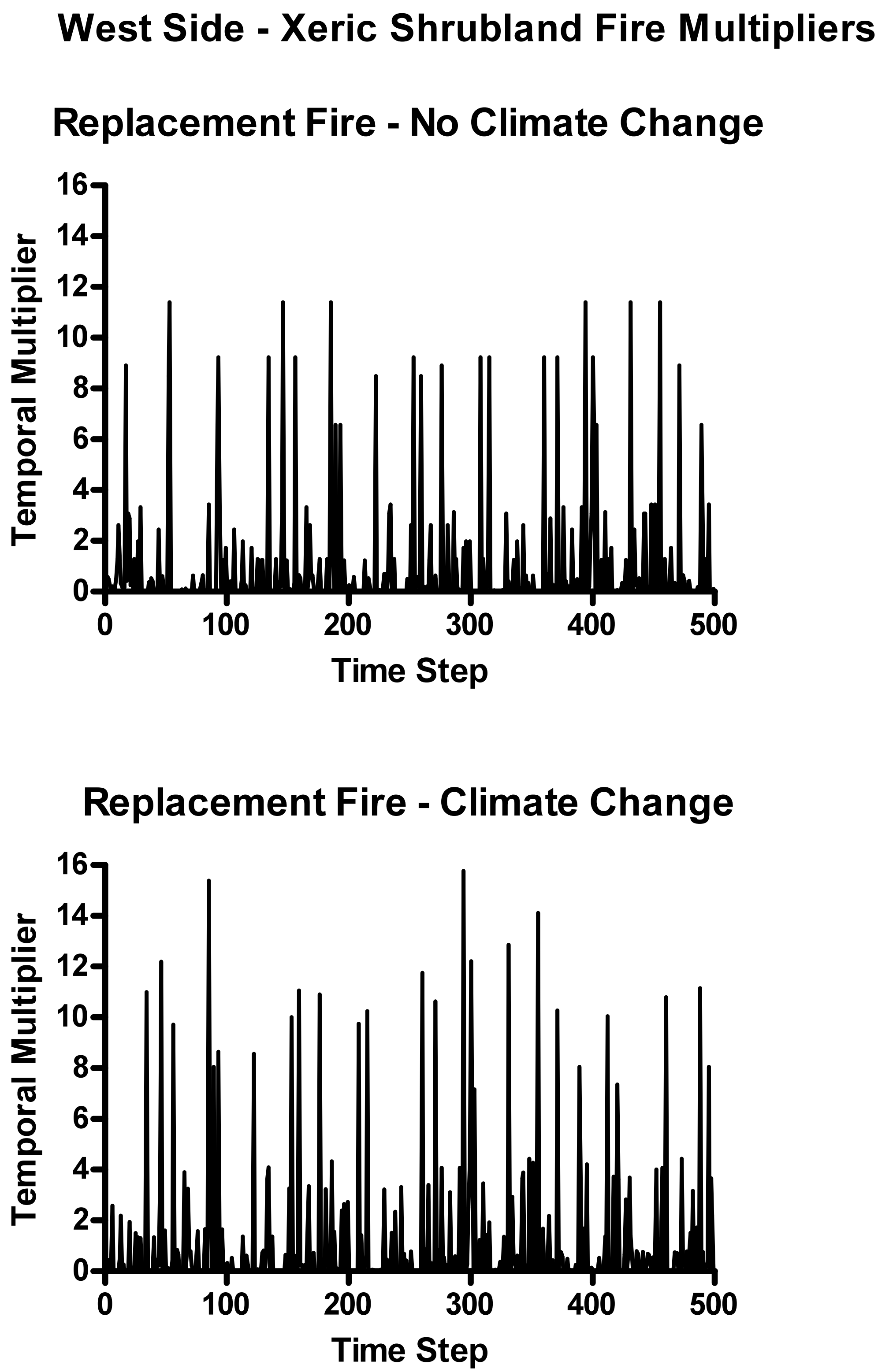


Figure A-14. Temporal multipliers of fire severity types for xeric shrublands on the west side of the Sierra Nevada.

Non-Fire Temporal Multipliers

All other temporal multipliers involved modifications to drought, invasion rates, soil moisture, and flows. Drought related temporal multipliers were the same on the east and west sides. We assumed that the new PDSI under climate change would show drier (higher temperature, less precipitation, or more evapotranspiration) conditions, which means that positive PDSI values would become smaller and that negative values would become even more negative. Although this assumption was conceptually true, the mathematical implementation of the modification is not straightforward, in part because several variables enter into the computation of PDSI (not just temperature) and its time step is monthly, not yearly (yearly PDSI is obtained through averaging) (Heddinghaus and Sabol 1991). Therefore, we arbitrarily chose to multiply yearly original PDSI values <0 (dry years) by the temperature temporal multipliers to make them more negative or drier, whereas values ≥0 (wet years) were divided by temporal multipliers keeping them positive but reduced (Figure A-15). This heuristic linear modification was not too unreasonable given that the real PDSI equation is also a linear formula based on past values of PDSI:

$$\mathrm{PDSI}_t = 0.897 \times \mathrm{PDSI}_{t-1} + \text{calibrated change in soil moisture}_t$$

where t is the month and the calibrated change in moisture can be ≥ or < zero (Heddinghaus and Sabol 1991).

All non-fire equations developed above (Tables A-1, A-2, and A-5) used the new PDSI for climate change simulations. One exception was the intra-specific competition equation that became:

$$= e^{-\mathrm{TempCC} \times (\mathrm{PDSI} + \mathrm{abs}(\min[\mathrm{PDSI}]))} \,/\, e^{-\mathrm{abs}(\min[\mathrm{PDSI}])},$$

where PDSI is the original time series from 1896 to 2006 and TempCC is the temperature temporal multiplier assuming climate warming. Under future drier conditions, we heuristically assumed that intra-specific competition will be more intense.

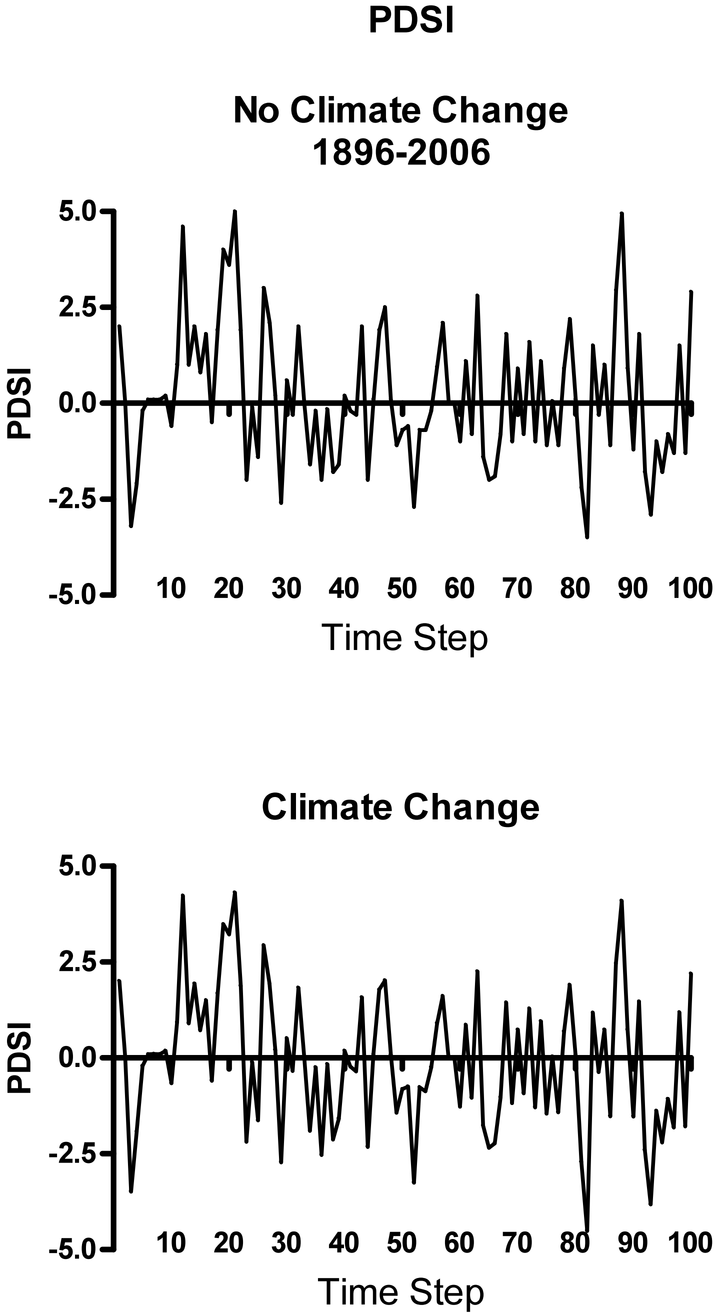


Figure A-15. PDSI for the northern Sierra Nevada from 1896 to 2006 (upper graph) and modified PDSI assuming temperatures increasing by +3^{o}C (lower graph).

As before, flow temporal multipliers were generated with gage data from the Truckee River and Feather River. The peak flow temporal multiplier (-CC for no climate change) was modified for climate change (+CC) under the simple assumptions that peak flows and their variability increase with time due to more frequent rain-on-snow events and early snow melt.

A heuristic relationship was built in the absence of more mechanistic flow modification equation:

Peak Flow_{+CC} temporal multiplier

$$= \text{Peak Flow}_{-CC} \text{ temporal multiplier} \times (1+U \times U \times \log_{10}[\text{time-step}]),$$

where U is a random number drawn ($0 \leq U < 1$) from a uniform distribution. In this equation, peak flow increases by nearly twice over 100 years as both drawn random numbers are closer to one. The multiplication of the two independently drawn random numbers insures a highly variable time series (Figure A-16). The new time series was used to obtain 7-year, 20-year, and 100-year flood events using the same rules as described above.

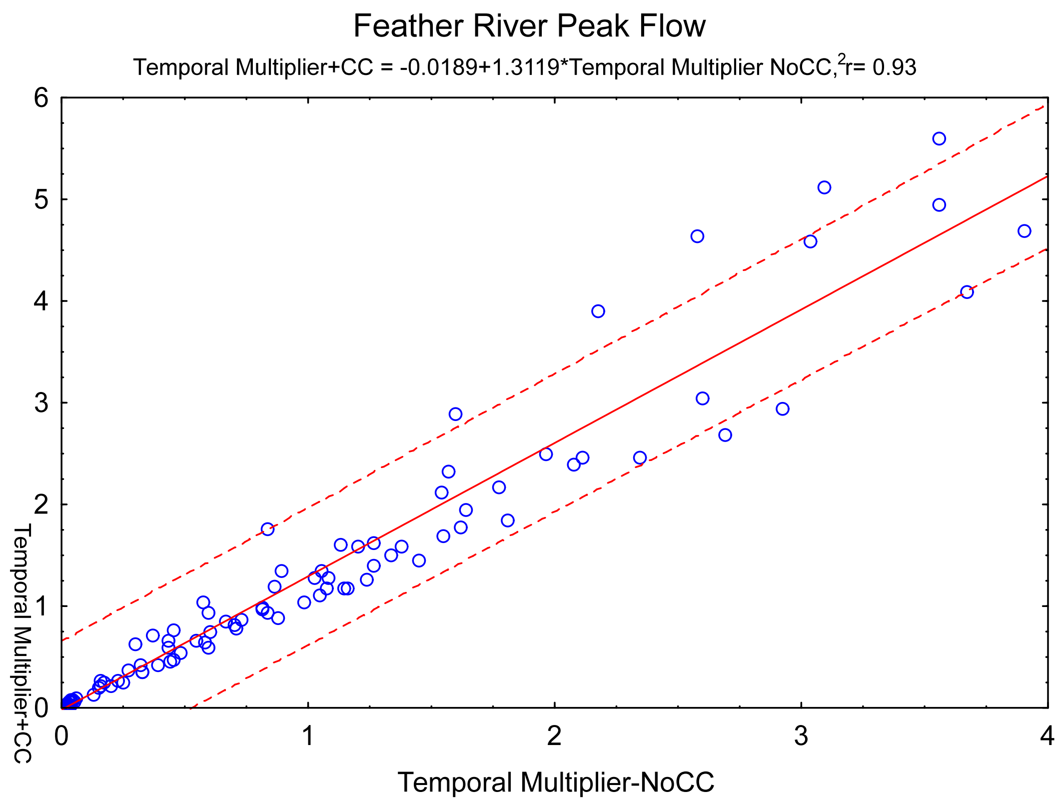


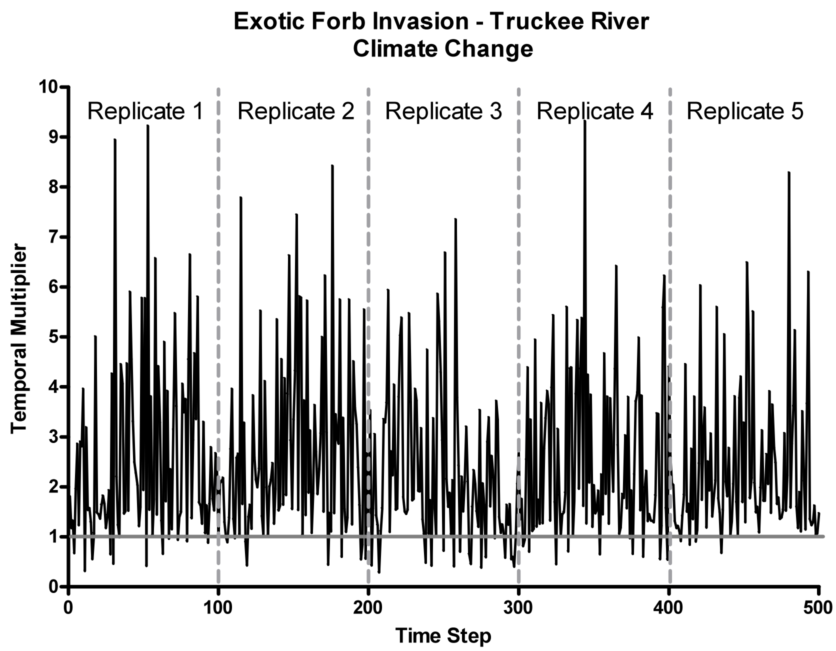
Figure A-16. Peak flow temporal multipliers without climate change versus climate change effects used to illustrate heuristic transformation using gage data from Feather River. Regression bands are ±95% confidence intervals. Note the slope > 1 and increasing variability with higher values.

The cottonwood and willow recruitment temporal multiplier used the new temporal multiplier for peak flow; however, the rules for successful recruitment were modified under the climate change scenario. As before, a 5% failure rate was assumed: 5% of years were randomly chosen for completely failed recruitment. For the no-climate change scenario, we had assumed that the level of peak flow during a year was the only datum that determined if enough river scouring, deposition, and wetting permitted recruitment. With climate change, however, peak flow was predicted to occur increasingly earlier (Maurer 2007) and before flowering and seed deposition of cottonwood and willow. (We also assumed that cottonwood and willow flowering would not "catch up" with earlier flows because of potential genetic constraints and persistent cold air drafting in drainages.) Therefore, recruitment was increasingly uncertain with time due to the mismatch of peak flow and flowering. Maurer's (2007) estimates of uncertainty (of earlier flow occurring) for periods of 30 years under the "business-as-usual" scenario of the PCM model were used to reduce recruitment success: 87% for years 1 to 30; 74% for years 31 to 60; and 61% for years 61 to 100. To determine successful recruitment the product of this uncertainty (as a proportion) and the peak flow temporal multiplier with climate change needed to be >0.77 (as before without climate change); otherwise the resulting temporal multiplier was zero. In summary, the onset of future peak flow will always have a depressing effect on cottonwood and willow recruitment, but future peak flow can be higher and more variable and compensate for loss of recruitment success.

The *low-flow-kill* temporal multiplier shared a similar heuristic equation as that of peak flow, with the exception that the temporal multiplier was the inverse of the average August and September flow (= low flow) multiplied by the correction factor for climate change:

Low-flow-kill $_{+CC}$ temporal multiplier
= 1/{low flows $_{-CC}$ temporal multiplier × (1+U × U × $\log_{10}$[time-step])} > 1;
= 0 if 1/{low flows $_{-CC}$ temporal multiplier × (1+U × U × $\log_{10}$[time-step])} ≤ 1.

We hypothesized that carbon from enhanced atmospheric green house gases would fertilize exotic forb species growth, seed or root production, and invasion of uninfested areas if the floodplain was sufficiently wetted by annual (not peak) flows (Bradley 2009; Smith et al., 2000). The temporal multiplier for exotic forb invasion was simply the year by year multiplication of the green house gases temporal multiplier and the annual flow temporal multiplier (i.e., more infestation during years of higher annual flows and more atmospheric carbon), divided by 0.6, which is about the annual flow realized on the Truckee during a year with a 5-year flow (Figure A-17). This correction factor insured that only the lowest annual flow depressed exotic forb invasion.



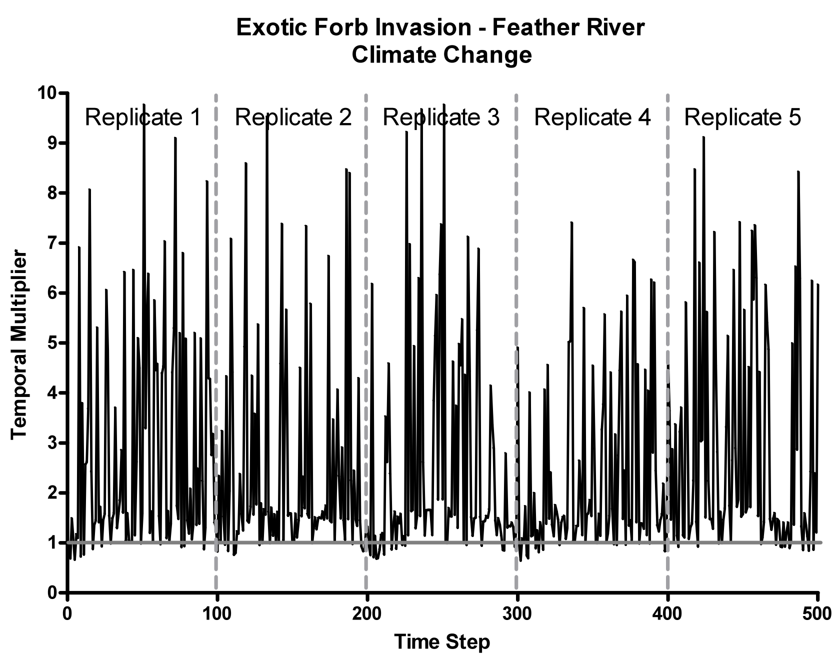


Figure A-17. Temporal multipliers for exotic forb invasion under a climate change scenario of increasing green house gases.

Using VDDT to Simulate Vegetation Conversions

To simulate potential future shifts in biophysical settings, we first determined the *rate* of projected shift, and then determined the *type* of projected vegetation shift.

As described in Section 3, we used future "climate envelope" projections for major tree and shrub species to show predicted *rates* of stress over the next 80 years for the associated biophysical settings. The rate of stress in the VDDT models was the proportion of a biophysical setting experiencing stress as calculated in Section 3 divided by the number of years projected (i.e., 80 years). Projected stress areas for a given species were assumed to equate with likely conversion because the species would not reproduce under the new climatic conditions. It was realized that a biophysical setting might persist beyond the 80 years of predicted stress because adult trees can survive although their offspring fail to establish. To minimize this problem, biophysical setting conversion in the models only occurred when a stand replacing disturbance killed adults; in other words, a biophysical setting could persist for longer than predicted if it did not experience significant stand replacing events, even assuming increased disturbance rates with climate change. This adjustment led to another problem: some subalpine and aspen biophysical settings that were predicted to experience very high levels of stress did not experience vegetation shifts rapid enough to "keep up" with predicted stress over 80 years because the natural disturbance rates are too slow (for example, a long mean fire return interval). In these cases, 100% of all stand replacing events caused a vegetation shift, although conversion was still not "fast enough."

To forecast the *type* of biophysical settings that would replace a stressed one, we used Dr. Jim Thorne's data on actual vegetation conversions based on the analysis of Wieslander Vegetation Type data for the Sierra Nevada. The critical assumption made here was that vegetation transitions from the last 80 years were the best guess to future transitions for our VDDT simulations with climate change effects. Moreover, no other data were available. The conversion first required a crosswalk between the California Wildlife Habitat Relationship classification (WHR) used by Thorne et al. (2008) and biophysical settings (Table A-6).

Table A-6. Biophysical settings and California Wildlife Habitat Relationship classification (WHR) crosswalk.

Functional Group	Biophysical Setting	WHR
Alpine & Subalpine		
	Subalpine meadow	WTM
	Alpine Shrubland	ADS
	Lodgepole Pine-dry	LPN
	Lodgepole Pine-wet	LPN
	Subalpine Woodland	SCN
	Red Fir-Western White Pine	RFR
	Red Fir-White Fir	RFR
Mid-Elevation Forest		

	Mixed Conifer-Mesic	WFR, SMC, DFR
	Yellow Pine East Side	EPN, JPN
	Ponderosa Pine-Mixed Conifer	PPN
	California Oak-Pine Forest	MHC, MHW
	Wet Meadow	WTM
	California Montane Riparian	MRI
	Great Basin Montane Riparian	MRI
Mid-Elevation Eastern Shrubland		
	Montane sagebrush Steppe	SGB, BBR
	Big Sagebrush Shrubland	SGB, BBR
	Low Sagebrush	LSG
	Pinyon-Juniper Woodland	PJN
	Curlleaf Mountain Mahogany	PJN
	Aspen Woodland	ASP
	Aspen-Mixed Conifer Forest	ASP
Xeric-Shrubland		
	Ultramafic Woodland and Chaparral	MCH, MCP
	Montane Chaparral	MCH, MCP
Lower-Elevation-Western Forest & Woodland		
	California Mixed Evergreen Forest	MHC, MHW
	Blue Oak-Pine Foothill Woodland	BOP, BOW

Thorne's matrix of type conversions allowed us to convert VDDT virtual pixels from an original type to new types over time (~80 years) as dictated by the recalculated proportions (i.e., after elimination of "false" conversions) in the conversion matrix. (See main text Section 5 for the distinction between true and false vegetation shifts.)

The data for true conversion when more than one transition pathways were documented were used to split proportionally the rate of transition (previous paragraph) using proportions calculated from the Thorne data. Several steps were involved in the calculations of vegetation shifts:

1. <u>Calculate the total rate of replacement events</u>: Obtain the realized rate (probability/year) of each replacement disturbance from the *non-climate change* simulation (assuming *minimum management*) for the out-going biophysical setting. The rates of different disturbance types (for example, replacement fire and mixed severity fire) are summed according to their contributions to the early succession class. For example, replacement fire had a rate 0.0026/yr and mixed severity fire of 0.0148/yr in ponderosa pine; however mixed severity fire contributed only 25% to the

early succession class, whereas replacement fire fully contributed to this class. Therefore, the weighted sum of replacement events = $0.25 \times 0.0148 + 1 \times 0.0026 = 0.0063$.

2. Calculate total loss of "virtual pixels" from originating biophysical setting: During the 80-year period of simulation, a certain proportion of a biophysical setting's area per year flows away from the out-going vegetation. This value is determined by the division of the percentage of the area of the biophysical setting stressed (as calculated in Section 3 of main text) by the total rate of replacement events. To continue the example, approximately 6.6% of the ponderosa pine biophysical setting of today will be stressed during the next 80 years; as a result the realized loss of this biophysical setting will be 0.131 or 0.066 divided by 80 years and divided by 0.0063, which is the magnitude of realized replacement events.
3. Split the loss to recipient biophysical setting(s) (i.e., vegetation shift): The loss per year of area (or virtual pixels) was allocated according to Thorne's recalculated proportions to in-coming biophysical settings (i.e., biophysical settings that received pixels from out-going biophysical setting). To complete the example, approximately 85.3% of stressed ponderosa pine being lost at the above rate of 0.131 will convert to California mixed evergreen and 14.7% to chaparral.
4. Split the disturbance rates in the losing biophysical setting: To simulate this calculated outcome, split all replacement disturbances in the original biophysical setting model. In the ponderosa pine example, the original replacement rates are split in three proportions for each of replacement fire and mixed fire:
    a. No conversion = $1 - 0.131 = 0.869$ for replacement fire
    b. Conversion to California mixed evergreen = $85.3\% \times 0.131 = 0.112$ for replacement fire
    c. Conversion to chaparral = $14.7\% \times 0.131 = 0.019$ for replacement fire
    d. The three rates above are each multiplied by 0.25 to obtain the conversion proportion based on the contribution of mixed severity fire, which was 25% top-kill.
5. These proportions are implemented in every model's appropriate pathways.

Simulations will generate new pixels for in-coming biophysical settings in the model of the out-going one. In the final accounting of area for ecological departure calculation, the new pixels must be added to the results of another independent model representing the recipient biophysical setting. Ideally, all inter-connected models should be simulated in a single "Uber" model, which is the more recent modeling approach we use.

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Appendix B

Historical climate and projected future climate changes

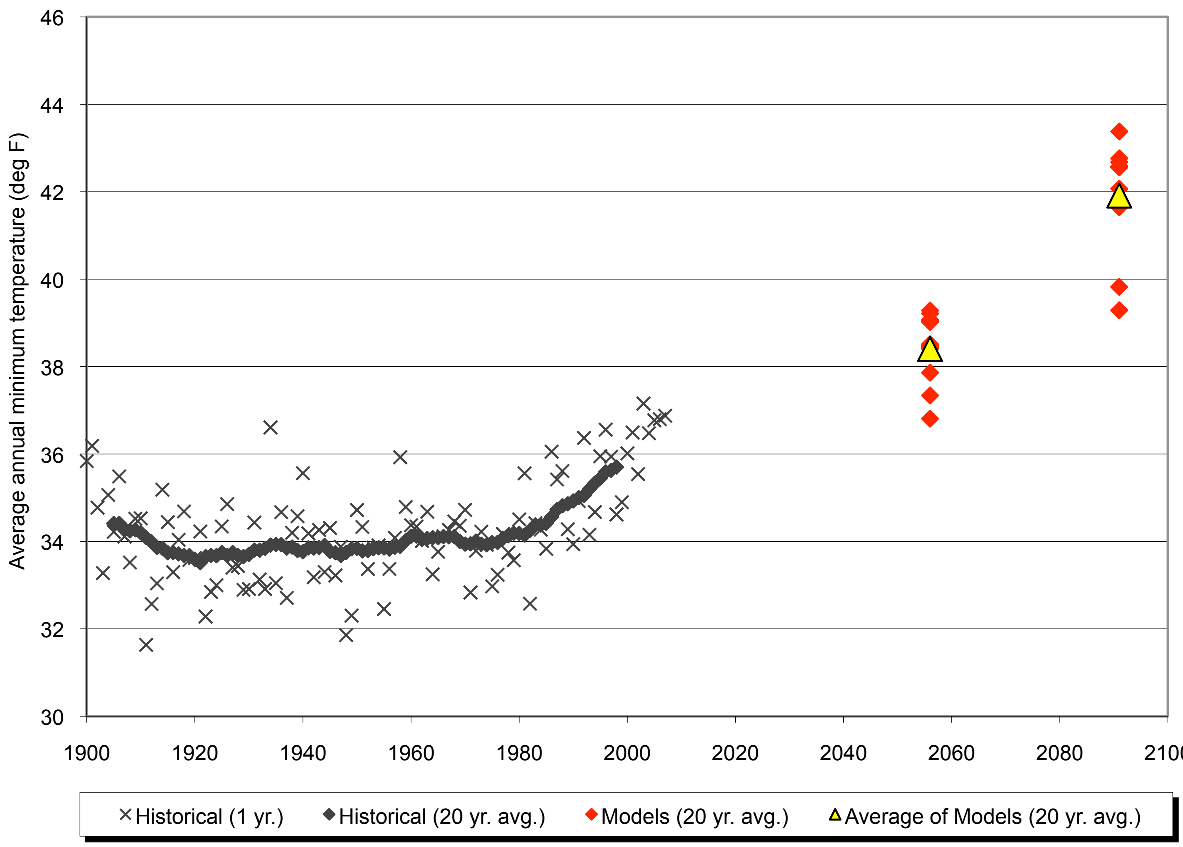

Figure B1: Historical and projected future average annual minimum temperatures for the Northern Sierra Partnership (NSP) region.

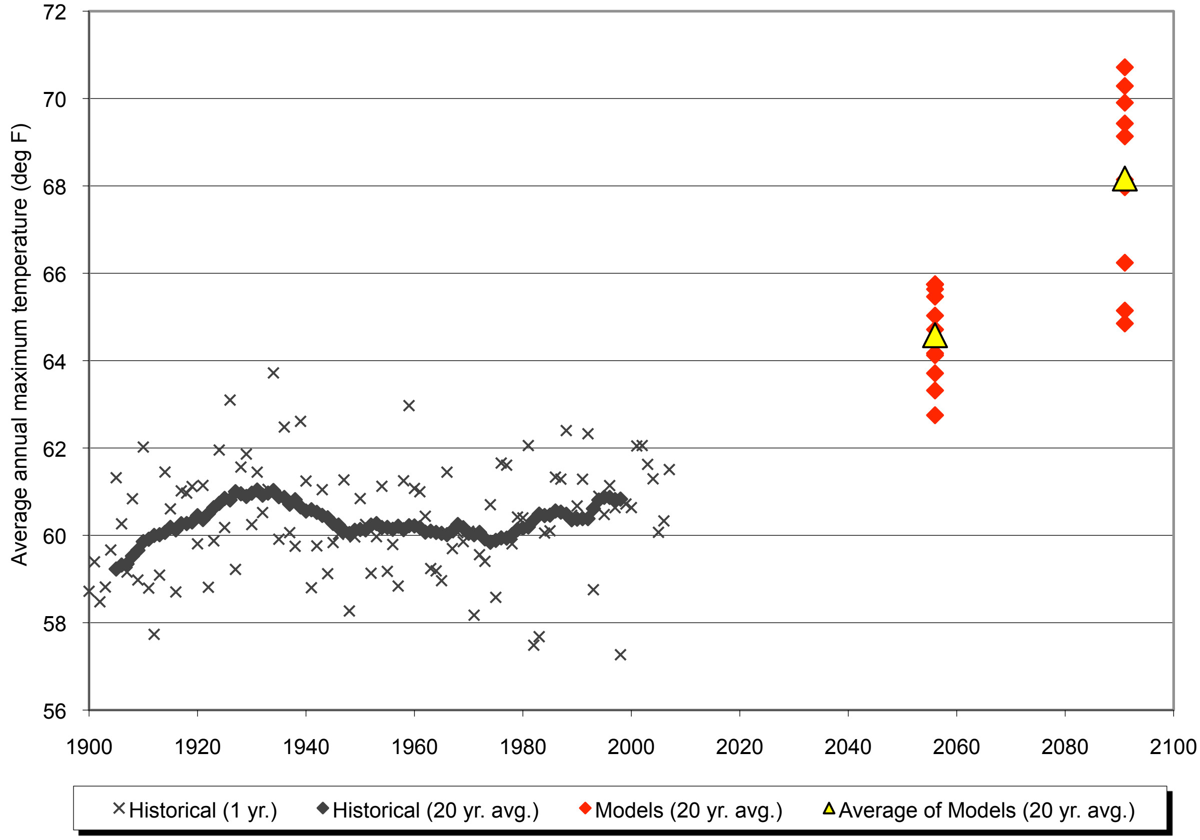

Figure B2: Historical and projected future average annual maximum temperatures for the Northern Sierra Partnership (NSP) region.

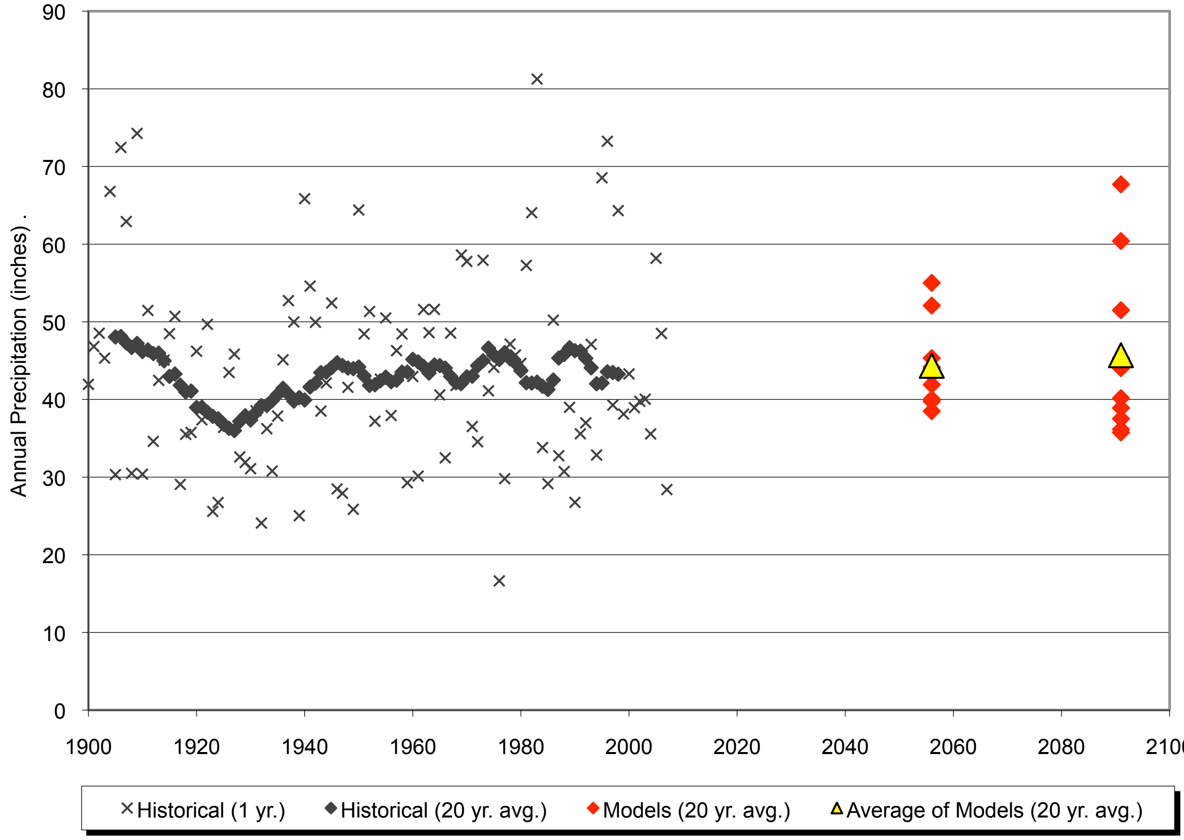

Figure B3: Historical and projected future annual precipitation for the Northern Sierra Partnership (NSP) region.

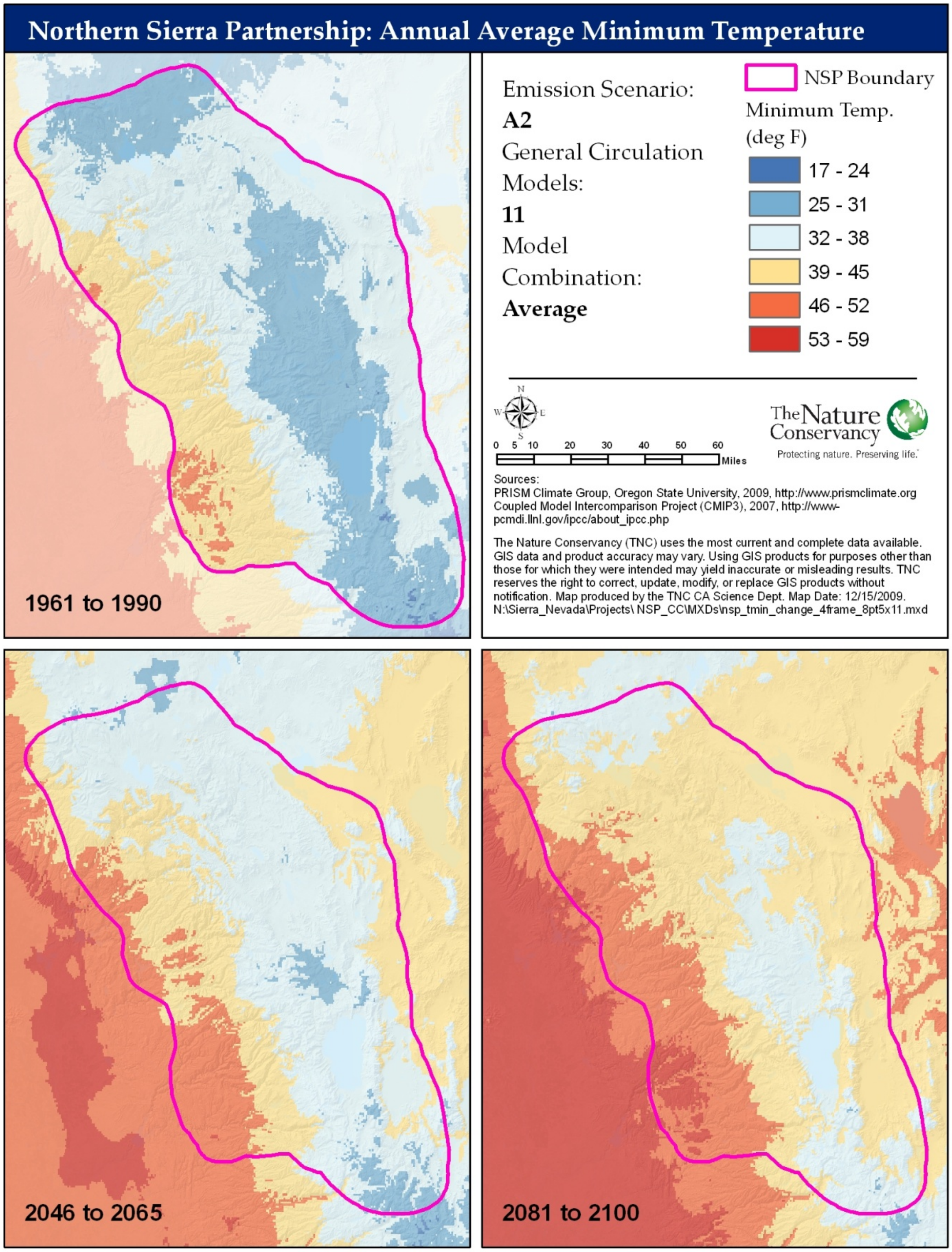

Figure B4: Maps of average annual minimum temperature change across the NSP region

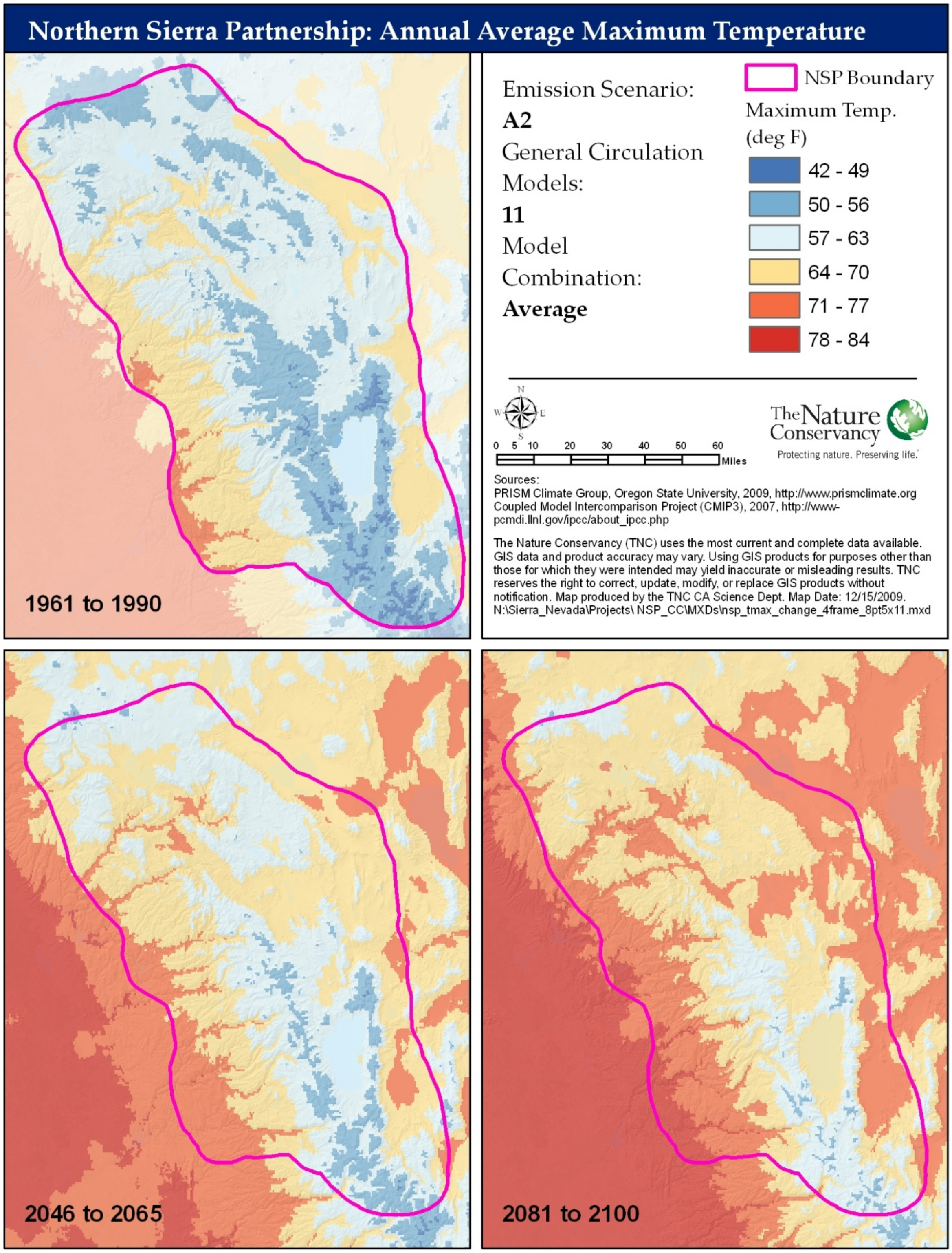

Figure B5: Maps of average annual maximum temperature change across the NSP region

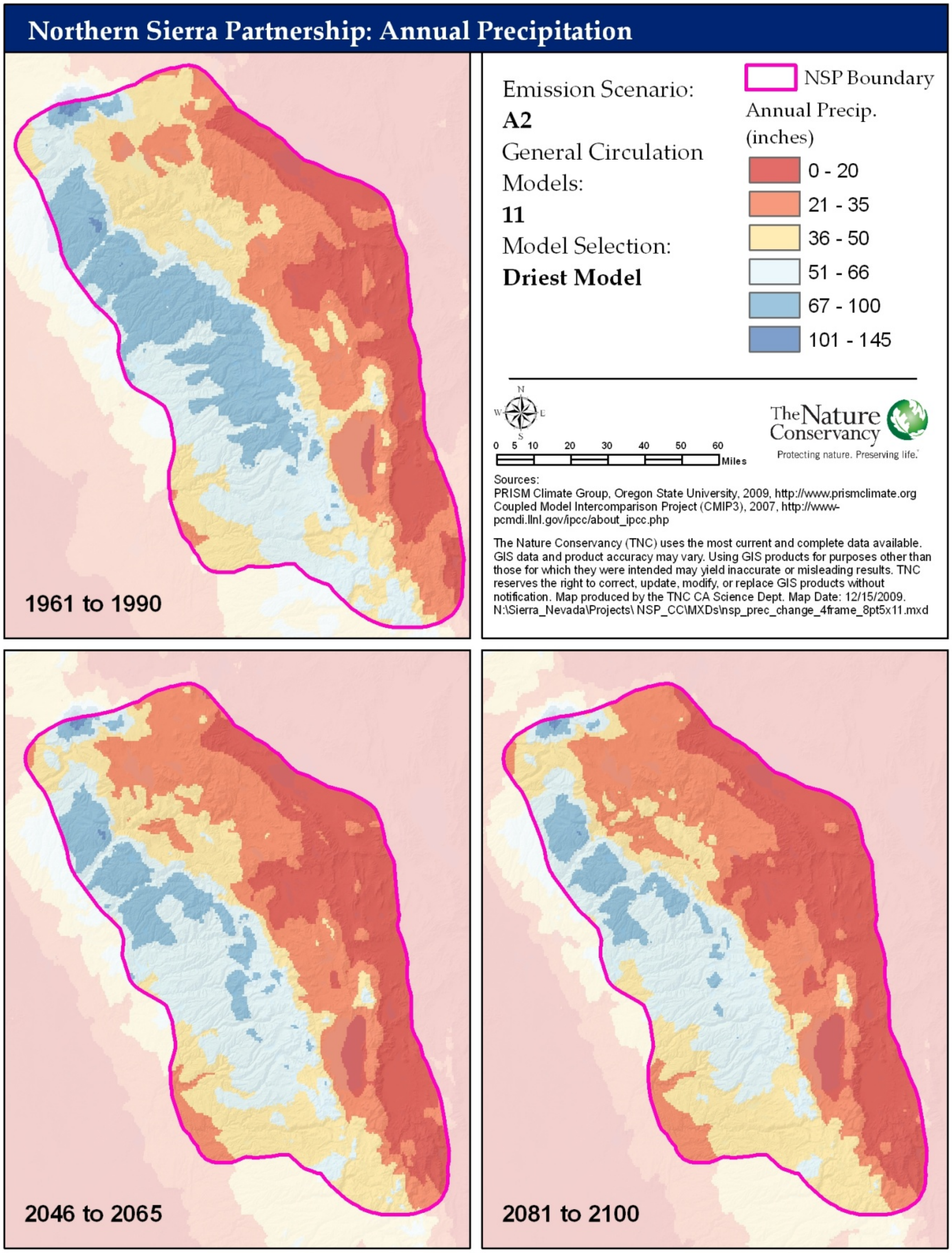

Figure B6: Maps of annual precipitation change as forecast by the driest model across the NSP region

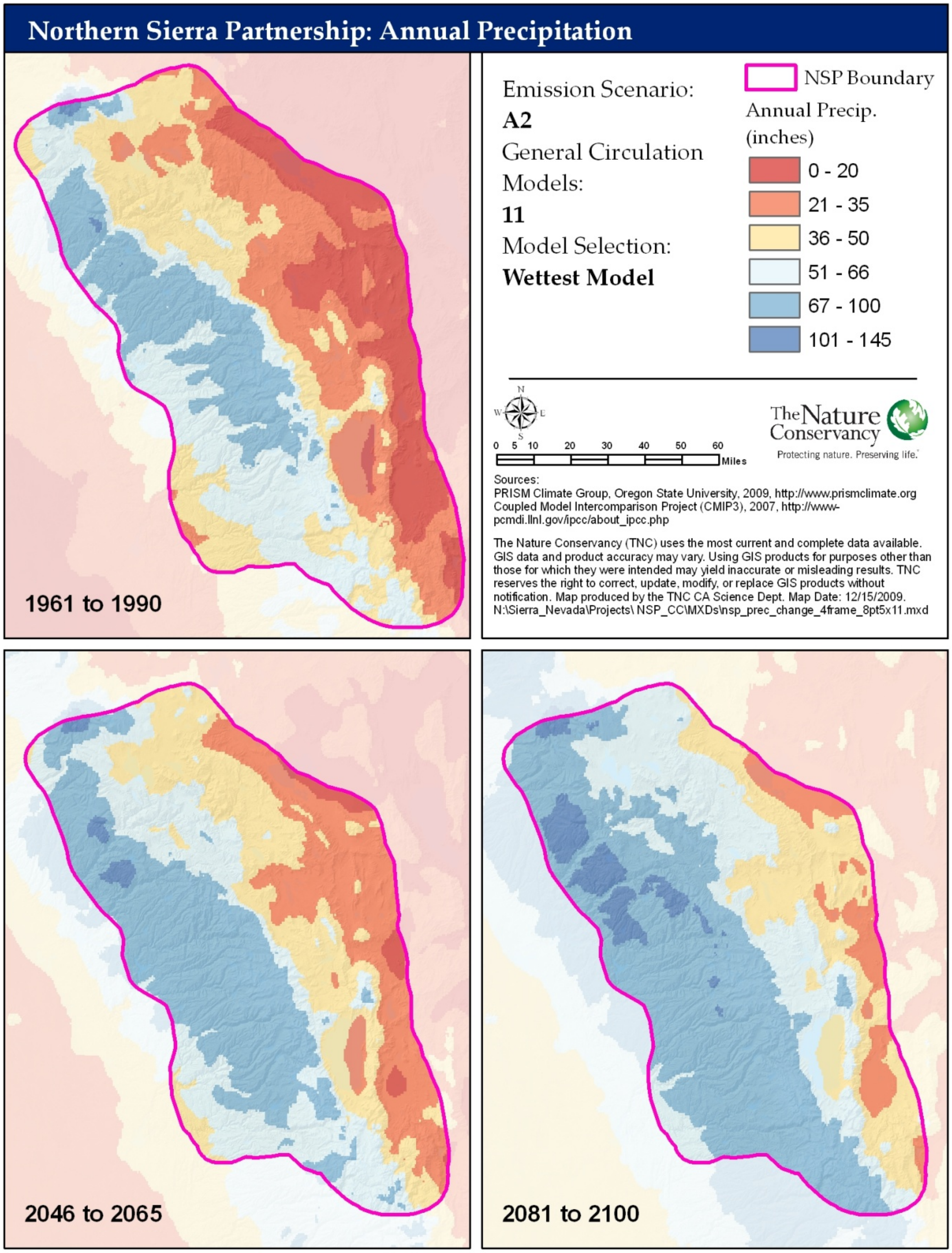

Figure B7: Maps of annual precipitation change as forecast by the wetest model across the NSP region

Appendix C
Descriptive Summary of Ecological Departure for 25 Northern Sierra Ecological Systems

Summary

Ecological departure measures an ecological system's departure from its natural range of variability (NRV). It is an integrated, landscape-scale metric that takes into account species composition, seral structure, and all relevant disturbances. Scores are graded on a scale of 0 to 100. The higher the score, the more the ecosystem is "out of whack."

Ecological departure was assessed using LANDFIRE satellite imagery, supplemented by other data, for 25 Northern Sierra ecological systems over an area of approximately 5,000,000 acres. Northern Sierra ecological systems range from good to poor current condition. All occurrences under 500 acres were not scored, size per LANDFIRE recommendations.

- Ten ecological systems are currently in good condition (i.e., low departure), including the region's largest forest system and the three smallest systems:
  - Alpine shrubland
  - Aspen woodland
  - California mixed evergreen
  - Low sagebrush
  - Mixed conifer-mesic
  - Montane chaparral
  - Montane sagebrush steppe
  - Pinyon-juniper woodlands
  - Subalpine meadow
  - Subalpine woodland

- Three ecological systems are in poor condition (i.e., high departure). Two of these are attributable to uncharacteristic native species -- Great Basin riparian (uncharacteristic native species) and wet meadows (conversion to pastureland).

- Twelve (12) other ecological systems are moderately departed from NRV, including four other large-scale conifer forest systems. The current departure for most of these ecosystems can likely be largely attributed to fire suppression or invasive species.

Ecological System Assessment

In general, the overall Eastside & Westside departure scores are more accurate than scores that were calculated for the 10 individual watersheds, due to larger sample sizes. Conditions for individual watersheds will be noted only when there is a substantial variance from the mean and sufficient acres in the occurrence.

- Alpine Shrubland rates as good condition. It is a simple system with only two vegetation classes, with almost all found in the dominant class with low-growing perennials. It is the second-smallest ecosystem in the region (1,600 acres).

- Aspen-Mixed Conifer Forests are generally lacking early succession vegetation and have too much conifer-dominated late succession. They are in better shape in the Truckee River and Middle Fork Feather River watersheds than elsewhere.

- Aspen Woodland is found almost exclusively on the eastside, and is generally in good condition. However, it also has too much senescing clones in the late succession class that are opening up and a shortage of early succession vegetation.

- Big Sagebrush Shrubland is found 99% on the eastside, where it is in fair condition due to virtually no early succession classes as well as the presence of invasive species. (It shows as good condition on the westside, but with only a small acreage in the North Fork Feather River watershed.)

- Blue Oak-Pine Foothill Woodland is found exclusively on the Westside (with only 4,700 acres in the project area), where it is in fair condition due largely to an overabundance of late succession class with woody understory encroachment.

- California Mixed Evergreen is found over 95% on the Westside, in good condition.

- California Montane Riparian is in fair condition on both sides, with an overabundance of the late succession class.

- California Oak Pine Forest, which is 90% on the Westside, is in fair condition on both sides. It shows as good condition in the North Fork Feather River, due to presence of both early succession and late succession classes, which are scarce elsewhere.

- Curleaf Mountain Mahogany is found exclusively on the Eastside, in fair condition.

- Great Basin Riparian is found 95% on the Eastside, in poor condition, due to over 50% in uncharacteristic native species (Wood's rose, basin big sagebrush, irises), plus no early succession class.

- Lodgepole Pine-Dry shows as poor (just barely) on the Eastside and fair on the Westside. The Eastside condition is due to an overabundance of the open late succession class; however, this may not be problematic, in that LANDFIRE shows this as the dominant class vs. our calculations of NRV based on Sierra climate.

- Lodgepole Pine-Wet shows as fair condition on both sides, due to the same overabundance of the open late succession class.

- Low Sagebrush is found solely on the Eastside, in good condition.

- Mixed Conifer-Mesic Forest is the largest ecosystem and comprises 22% of the project area – over 800,000 acres in the Westside and over 200,000 acres Eastside. It is generally in good condition, and may have been favored by fire suppression compared to the more fire dependent major forest systems.

- Montane Chaparral is found on both sides, overall in good condition. However, more than any other system, the scores for montane chaparral vary greatly across the ten watersheds. However, like alpine shrubland, this is a very simple ecosystem with only two succession classes. The variances are probably explained by recent fires that temporarily shift large chaparral patches into early succession in some watersheds.

- Montane Sagebrush Steppe is found 98% on the eastside, generally in good condition. The East Branch of the North Fork occurrence, which is actually on the eastside of the project area, is an outlier with an 83% departure score, with almost all of its 35,000 acres in the closed late succession class. Unlike in many areas of the Great Basin with limited conifer seed sources, conifer encroachment is a powerful process in the Sierra Nevada where conifer seed source is abundant. Conifer encroachment is also favored under condition of fire suppression.

- Pinyon-Juniper Woodland is found solely on the Eastside, in good condition.

- Ponderosa Pine – Mixed Conifer is the 3rd largest ecosystem and comprises 16% of the project area – almost 600,000 acres in the Westside and almost 200,000 acres Eastside. It is generally in fair condition, with an overabundance of the closed mid succession class. The good occurrence in the Hone-Eagle Lake watershed is relatively small acreage.

- Red Fir – Western White Pine is abundant and generally in fair condition on both sides.

- Red Fir – White Fir is also abundant and generally in fair condition on both sides due to overabundance of the closed mid-succession class; however, it is in good condition in the Upper Yuba and North Fork American watersheds.

- Subalpine Meadow, the smallest ecosystem (1,300 acres), is in good condition on both sides.

- Subalpine Woodland is generally in good condition on both sides, except for fair condition the Upper Carson and Lake Tahoe watersheds.

- Ultramafic Woodland and Chaparral is found on thin, often serpentine soils, and shows as being in poor condition on both sides, due to an overabundance of the mid succession class. However, this departure score may be explained by the difficulty of remote sensing interpretation of the succession classes for this system.

- Wet Meadow is in poor condition everwhere due to uncharacteristic native species, which exist in different forms. In the Sierra Nevada, lodgepole pine and fir encroachment is common at the edge of wet meadows. This encroachment increases during periods of dry years and fire suppression. Dominance of wet meadows by silver sage, Wood’s rose, irises, and big sagebrush is also frequent and a consequence of intense historic grazing or poor current grazing management.

- Yellow Pine is the 2nd largest system in the project area at 890,000 acres, with over 90% located on the eastside. It generally is in fair condition everywhere due to overabundance of the closed mid succession class. Many stands of yellow pine are still young because they are recovering from heavy logging that happened during the mining era of the 19th century.

Appendix D – Ecological Departure Worksheets (Eastside and Westside)

The following worksheets show the departure from the natural range of variability (NRV) for each Northern Sierra biophysical setting/ecological system, by Eastside and Westside. For each system, the tables display the following information by row:

- Name of biophysical setting
- Class: vegetation succession classes (per LANDFIRE model descriptions or Safford adaptations)
- Acres in Class: number of acres currently in each vegetation class, and total acres (last column)
- NRV: NRV percentage in each vegetation class
- Current % in Class: current percentage in each vegetation class
- Ecological Departure: departure from NRV (last column)

Eastside

Class	A	B	C	D	E	F	UE	UN	Total
Alpine Shrubland									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	-	1,027	-	-	-	-	-	5	1,032
NRV	13	87	0	0	0	0	0	0	100
Current % in Class	0	100	0	0	0	0	0	0	100
Ecological Departure									**13**
Aspen - Mixed Conifer Forest									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	156	2,859	3,012	619	4,627	-	-	158	11,431
NRV	34	54	11	1	0	0	0	0	100
Current % in Class	1	25	26	5	40	0	0	1	100
Ecological Departure									**62**
Aspen Woodland									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	165	786	3,790	1,616	-	-	-	7	6,365
NRV	10	32	57	0	0	0	0	0	99
Current % in Class	3	12	60	25	0	0	0	0	100
Ecological Departure									**28**
Big Sagebrush Shrubland									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	-	147,145	8,655	142	113	-	26,009	475	182,540
NRV	24	49	26	0	1	0	0	0	100
Current % in Class	0	81	5	0	0	0	14	0	100
Ecological Departure									**46**
California Mixed Evergreen Forest									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	857	73	1,295	59	-	-	-	-	2,284
NRV	4	38	58	0	0	0	0	0	100
Current % in Class	38	3	57	3	0	0	0	0	100
Ecological Departure									**36**
California Montane Riparian									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	512	5,179	20,363	-	-	-	-	2,043	28,098
NRV	10	45	45	0	0	0	0	0	100
Current % in Class	2	18	72	0	0	0	0	7	100
Ecological Departure									**35**
California Oak-Pine Forest									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	254	2,077	3,011	219	133	-	1	38	5,734
NRV	15	19	15	35	16	0	0	0	100
Current % in Class	4	36	53	4	2	0	0	1	100
Ecological Departure									**55**
Curleaf Mountain Mahogany									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	2,667	216	971	6,873	1,596	-	195	88	12,606
NRV	10	17	18	19	36	0	0	0	100
Current % in Class	21	2	8	55	13	0	2	1	100
Ecological Departure									**49**

Great Basin Riparian									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	159	359	10,499	-	-	-	159	14,822	25,999
NRV	29	44	27	0	0	0	0	0	100
Current % in Class	1	1	40	0	0	0	1	57	100
Ecological Departure									**71**

Lodgepole Pine - Dry									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	28	194	206	4,895	1,202	-	17	2	6,543
NRV	20	0	50	26	4	0	0	0	100
Current % in Class	0	3	3	75	18	0	0	0	100
Ecological Departure									**66**

Lodgepole Pine - Wet									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	133	659	1,051	6,737	5,433	-	7	68	14,089
NRV	17	36	13	2	32	0	0	0	100
Current % in Class	1	5	7	48	39	0	0	0	100
Ecological Departure									**53**

Low Sagebrush									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	3,817	6,321	52	5,047	-	-	979	304	16,521
NRV	17	51	32	0	0	0	0	0	100
Current % in Class	23	38	31	0	0	0	6	2	100
Ecological Departure									**14**

Mixed Conifer - Mesic									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	6,571	84,651	64,028	20,827	30,980	6,571	5	102	213,734
NRV	14	23	18	20	21	4	0	0	100
Current % in Class	3	40	30	10	14	3	0	0	100
Ecological Departure									**29**

Montane Chaparral									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	11,852	61,320	1,659	956	101	-	681	1,822	78,391
NRV	10	90	0	0	0	0	0	0	100
Current % in Class	15	78	2	1	0	0	1	2	100
Ecological Departure									**12**

Montane Sagebrush Steppe									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	7,683	99,804	71,744	9,161	459	-	11,841	1,526	202,217
NRV	32	47	16	3	2	0	0	0	100
Current % in Class	4	49	35	5	0	0	6	1	100
Ecological Departure									**30**

Pinyon-Juniper Woodland									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	-	95	2,063	9,675	6,423	-	579	265	19,100
NRV	5	9	29	57	0	0	0	0	100
Current % in Class	0	0	11	51	34	0	3	1	100
Ecological Departure									**38**

Ponderosa Pine - Mixed Conifer									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	3,873	92,172	40,913	3,753	46,477	3,873	0	10	191,071
NRV	10	14	30	31	8	7	0	0	100
Current % in Class	2	48	21	2	24	2	0	0	100
Ecological Departure									**51**
Red Fir - Western White Pine									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	14,748	71,730	59,388	17,471	18,230	-	320	50	181,937
NRV	11	12	21	32	24	0	0	0	100
Current % in Class	8	39	33	10	10	0	0	0	100
Ecological Departure									**39**
Red Fir - White Fir									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	4,877	57,142	51,425	20,289	19,689	4,877	1	16	158,316
NRV	8	16	17	22	34	3	0	0	100
Current % in Class	3	36	32	13	12	3	0	0	100
Ecological Departure									**36**
Subalpine Meadow									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	194	319	0	-	-	-	-	3	517
NRV	13	61	26	0	0	0	0	0	100
Current % in Class	38	62	0	0	0	0	0	1	100
Ecological Departure									**26**
Subalpine Woodland									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	1,413	1,662	11,106	13,982	5,562	-	1	8	33,734
NRV	9	12	27	28	24	0	0	0	100
Current % in Class	4	5	33	41	16	0	0	0	100
Ecological Departure									**19**
Ultramafic Woodland and Chaparral									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	-	4,948	352	-	-	-	1	-	5,301
NRV	31	26	43	0	0	0	0	0	100
Current % in Class	0	93	7	0	0	0	0	0	100
Ecological Departure									**67**
Wet Meadow									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	39	23	26,616	-	-	-	5	53,594	80,277
NRV	7	73	20	0	0	0	0	0	100
Current % in Class	0	0	33	0	0	0	0	67	100
Ecological Departure									**80**
Yellow Pine East Side									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	54,281	386,653	234,311	11,762	60,601	54,281	230	17,237	819,355
NRV	8	8	23	54	4	3	0	0	100
Current % in Class	7	47	29	1	7	7	0	2	100
Ecological Departure									**54**

Westside

Alpine Shrubland									
Class	A	B	C	D	E	F	UE	UN	Total
Acres in Class	-	592	-	-	-	-	-	2	594
NRV	13	87	0	0	0	0	0	0	100
Current % in Class	0	100	0	0	0	0	0	0	100
Ecological Departure									**13**

Aspen - Mixed Conifer Forest									
Class	A	B	C	D	E	F	UE	UN	Total
Acres in Class	52	172	51	50	389	-	-	-	714
NRV	34	54	11	1	0	0	0	0	100
Current % in Class	7	24	7	7	54	0	0	0	100
Ecological Departure									**61**

Aspen Woodland									
Class	A	B	C	D	E	F	UE	UN	Total
Acres in Class	2	1	1	2	-	-	-	-	6
NRV	10	32	57	0	0	0	0	0	99
Current % in Class	35	23	12	31	0	0	0	0	100
Ecological Departure									**55**

Big Sagebrush Shrubland									
Class	A	B	C	D	E	F	UE	UN	Total
Acres in Class	-	1,498	388	-	-	-	-	-	1,885
NRV	24	49	26	0	1	0	0	0	100
Current % in Class	0	79	21	0	0	0	0	0	100
Ecological Departure									**30**

Blue Oak-Pine Foothill Woodland									
Class	A	B	C	D	E	F	UE	UN	Total
Acres in Class	5	179	1,887	2,345	-	-	-	312	4,728
NRV	15	25	53	7	0	0	0	0	100
Current % in Class	0	4	40	50	0	0	0	7	100
Ecological Departure									**49**

California Mixed Evergreen Forest									
Class	A	B	C	D	E	F	UE	UN	Total
Acres in Class	9,161	16,470	20,095	7,383	10,890	-	-	31	64,030
NRV	4	38	58	0	0	0	0	0	100
Current % in Class	14	26	31	12	17	0	0	0	100
Ecological Departure									**39**

California Montane Riparian									
Class	A	B	C	D	E	F	UE	UN	Total
Acres in Class	50	5,410	23,334	-	-	-	-	1,238	30,032
NRV	10	45	45	0	0	0	0	0	100
Current % in Class	0	18	78	0	0	0	0	4	100
Ecological Departure									**37**

California Oak-Pine Forest									
Class	A	B	C	D	E	F	UE	UN	Total
Acres in Class	2,858	34,513	13,551	1,546	5,114	-	1	43	57,626
NRV	15	19	15	35	16	0	0	0	100
Current % in Class	5	60	24	3	9	0	0	0	100
Ecological Departure									**49**

Great Basin Riparian									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	4	7	757	-	-	-	-	533	1,301
NRV	29	44	27	0	0	0	0	0	100
Current % in Class	0	1	58	0	0	0	0	41	100
Ecological Departure									**72**

Lodgepole Pine - Dry									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	53	101	778	1,359	71	-	12	-	2,373
NRV	20	0	50	26	4	0	0	0	100
Current % in Class	2	4	33	57	3	0	0	0	100
Ecological Departure									**36**

Lodgepole Pine - Wet									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	153	397	1,074	4,166	1,905	-	0	7	7,702
NRV	17	36	13	2	32	0	0	0	100
Current % in Class	2	5	14	54	25	0	0	0	100
Ecological Departure									**53**

Mixed Conifer - Mesic									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	30,050	340,662	236,859	57,961	190,501	30,050	-	427	886,509
NRV	14	23	18	20	21	4	0	0	100
Current % in Class	3	38	27	7	21	3	0	0	100
Ecological Departure									**25**

Montane Chaparral									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	16,473	67,957	19,463	1,587	3,099	-	9	196	108,784
NRV	10	90	0	0	0	0	0	0	100
Current % in Class	15	62	18	1	3	0	0	0	100
Ecological Departure									**28**

Montane Sagebrush Steppe									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	272	2,265	1,124	222	117	-	1	0	4,001
NRV	32	47	16	3	2	0	0	0	100
Current % in Class	7	57	28	6	3	0	0	0	100
Ecological Departure									**25**

Pinyon-Juniper Woodland									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	-	-	-	0	89	-	-	-	90
NRV	5	9	29	57	0	0	0	0	100
Current % in Class	0	0	0	0	100	0	0	0	100
Ecological Departure									**100**

Ponderosa Pine - Mixed Conifer									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	26,855	235,272	157,369	28,097	118,026	26,855	-	61	592,535
NRV	10	14	30	31	8	7	0	0	100
Current % in Class	5	40	27	5	20	5	0	0	100
Ecological Departure									**38**

Red Fir - Western White Pine									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	12,479	39,084	96,842	15,711	32,867	-	46	58	197,087
NRV	11	12	21	32	24	0	0	0	100
Current % in Class	6	20	49	8	17	0	0	0	100
Ecological Departure									**36**
Red Fir - White Fir									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	9,103	84,167	53,814	20,297	35,809	9,103	-	16	212,309
NRV	8	16	17	22	34	3	0	0	100
Current % in Class	4	40	25	10	17	4	0	0	100
Ecological Departure									**33**
Subalpine Meadow									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	345	485	-	-	-	-	-	-	830
NRV	13	61	26	0	0	0	0	0	100
Current % in Class	42	58	0	0	0	0	0	0	100
Ecological Departure									**29**
Subalpine Woodland									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	3,568	1,564	5,009	11,928	10,304	-	2	10	32,384
NRV	9	12	27	28	24	0	0	0	100
Current % in Class	11	5	15	37	32	0	0	0	100
Ecological Departure									**19**
Ultramafic Woodland and Chaparral									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	-	2,688	145	-	-	-	-	0	2,833
NRV	31	26	43	0	0	0	0	0	100
Current % in Class	0	95	5	0	0	0	0	0	100
Ecological Departure									**69**
Wet Meadow									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	27	4	2,492	-	-	-	0	25,605	28,128
NRV	7	73	20	0	0	0	0	0	100
Current % in Class	0	0	9	0	0	0	0	91	100
Ecological Departure									**91**
Yellow Pine East Side									
Class	**A**	**B**	**C**	**D**	**E**	**F**	**UE**	**UN**	**Total**
Acres in Class	4,307	38,911	15,101	1,252	6,579	4,307	-	27	70,484
NRV	8	8	23	54	4	3	0	0	100
Current % in Class	6	55	21	2	9	6	0	0	100
Ecological Departure									**56**

Appendix E - Acronyms

BLM	Bureau of Land Management
BpS	Biophysical Settings
BpS refugia	Biophysical Settings refugia
CMIP	Coupled Model Intercomparison Project
CWHR	California Wildlife Habitat Relationships
FRLT	Feather River Land Trust
GCMs	General Circulation Models
IPCC	International Panel on Climate Change
NPS	National Park Service
NRV	Natural range of variability
NSP	Northern Sierra Partnership
PCM	Parallel Climate Model
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PDSI	Palmer Drought Severity Index
PRISM	Parameter-elevation Relationships on Independent Slopes Model
SBC	Sierra Business Council
TDLT	Truckee Donner Land Trust
TNC	The Nature Conservancy
TPL	Trust for Public Land
US EPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey
VDDT	Vegetation Dynamics Development Tool
WCRP	World Climate Research Programme
WGCM	Working Group on Coupled Modeling