Title
Planning for Change: The Implications of a Changing Climate for Ecological Conservation Planning

Author
Klausmeyer, Kirk

Publication Date
2005-12-01

PLANNING FOR CHANGE; THE IMPLICATIONS OF A CHANGING CLIMATE FOR ECOLOGICAL CONSERVATION PLANNING

KIRK KLAUSMEYER

PROFESSIONAL REPORT

Submitted in partial satisfaction of the requirements for the degree

of

MASTER OF CITY PLANNING

in the

Department of City and Regional Planning

of the

UNIVERSITY OF CALIFORNIA, BERKELEY

APPROVED

Timothy Duane, University of California at Berkeley
Maggi Kelly, University of California at Berkeley
Robin Cox, The Nature Conservancy

Date: Spring, 2005

Abstract:

The effects of current and future climate change on biological phenology, distribution, community composition, mortality, and extinction have been thoroughly analyzed. However, there has been little analysis of site-specific methods to preserve species and habitats faced with inevitable natural and anthropogenic climate change. The Nature Conservancy (TNC) is currently prioritizing parcels for protection within the Mount Hamilton region. This region contains oak woodlands, riparian habitats and rare and endangered species that are sensitive to the direct and indirect impacts of climate variation. Climate change predictions are based on a low to moderate emissions scenario and a global circulation model downscaled to a 40 kilometer horizontal resolution grid. Binary logistical regression is used to determine which climatic variables influence the distribution of habitat for six high priority species. Climate envelopes based on current and the predicted future climate are compared to determine the amount habitat lost due to climate change. Blue oak (*Quercus douglasii)* woodlands are the least impacted, but are still projected to lose up to 55% of their habitat. Bay Checkerspot Butterflies (*Euphydryas editha bayensis*) are the most impacted, and are projected to lose 100% of their habitat. Migration to areas of new habitat is restricted by elevation, low dispersal rates, and the lack of suitable habitat conditions. TNC and other organizations can help to avoid local extirpation of high priority species by preserving high elevation future habitat, migration corridors, and transplanting species upslope. With these efforts, the Mount Hamilton region could continue to support its rich biodiversity despite a rapidly changing climate.

Acknowledgements

Special thanks: To my committee, Tim Duane, Maggi Kelly, and Robin Cox, for their guidance, comments, and expertise; To Mark Snyder at University of California Santa Cruz and Edwin Maurer at Santa Clara University, for sharing the results of their downscaled climate change models; And to my wife Heather, for helping me with the biology research, for doing the dishes while I was in the computer lab, and for her loving support.

Table of Contents

Chapter 1: Introduction

Climate change or global warming is a serious environmental problem that all inhabitants of this planet must face. Much of the past and current research is focused on whether or not climate change is occurring, how much the climate will change, and how to avoid it. However, very little research has been done on ways to prepare for climate change and how to take actions now to mitigate the negative impacts of climate change. While it is essential to try to reduce the anthropogenic causes of climate change, the historical global climate record indicates that a changing climate is normal for the earth, and that long-term climate changes are likely regardless of human action. In addition, past human emissions will cause climate change in the near future regardless of actions taken now to reduce emissions. The question is not if climate change will occur, but what can we do now to prepare for when it does occur.

Preparing for climate change is especially important in the field of conservation planning. Many species and habitats are sensitive to changing climates through a myriad of complex feedback responses. Conservation planning involves the design of reserves that will ideally support species and their associated habitats in perpetuity. If these reserves do not allow the species to migrate and do not contain a diversity of habitat and climate types, they are unlikely to support the original species and habitats as the climate changes. Land use conversions to urban landscapes often make it impossible for the boundaries of reserves to change over time, so reserves need to be designed today that take future climate change into account.

While some research has been done on methods to preserve biodiversity in a changing climate on global (Hannah, 2002) and ecoregional scales (Pyke, 2004; Pyke and

Andelman, 2004; Bartlein, 1997), less research has been done at the site level. Site level planning can take specific migration corridors and barriers, topography, species distributions, and land ownership into account, and make specific recommendations for conservation design. Global and eco-regional studies can identify the problems, but site level analysis can identify methods to help solve these problems.

This analysis looks at the Mount Hamilton region; a topographically and biologically diverse landscape south and east of San Jose (see Figure 1-1). The Nature Conservancy (TNC) has been actively engaged in conservation in the region. TNC and their partners have purchased numerous key properties through fee acquisition and/or conservation easements. Conservation scientists have launched long-term research and monitoring programs to restore degraded ecological systems and to determine compatible rangeland management practices. TNC is currently prioritizing properties throughout the Mount Hamilton area for future protection based on biological criteria and land use patterns. TNC's goal is to establish a large conservation area that will help preserve the local species and habitats, while allowing for appropriate sustainable uses. This analysis is intended to aid their efforts by determining the predicted future climate for the area, investigating how certain target species will respond to future climate change, and recommending actions to take now to prepare for future climate change. Ideally, this information will aid TNC in determining reserve boundaries that will have a better chance at preserving rare and sensitive species long into the future.

1.1 Background Information

In order to study the impacts of future climate change, some understanding of past climate change is required. Several geological records provide information on the magnitude and rate of past climate fluctuations. Paleoecological records give insight to how different species responded to past climate changes. In addition to looking back in time, several researchers are working to predict future climate based on complex global and regional climate models. The output from these models is also being used to look at future ecological impacts of predicted climate change. These studies are summarized below.

1.1.1 History of Climate Change

Over the last 10,000 years, the global climate has been relatively steady, with few significant fluctuations. However, geological climate records indicate that this is an anomaly when compared to the climatic variability of the last 65 million years (see Figure 1-2). The magnitude and rate of climate change has varied over time, which has had significant impacts on all life on the planet.

Historical climate records come from a variety of sources. One of the most widely used is the ratio of oxygen isotopes (O^{18} and O^{16}) in layers of deep ocean sediments that have been accumulating for millions of years. Based on this record, the global climate 65 million years ago (near the end of the age of the dinosaurs) was significantly warmer than it is now (see Figure 1-3). Global temperatures continued to rise until 50 million years ago, roughly the time when mammals began dispersing and archaic whales appeared. The climate cooled from that point on until 26 million years ago, which was a relatively warm period. For the last 12 million years, the climate has continued to cool and become more variable (Zachos et. al., 2001).

Figure 1-4 shows the global climate variation from 3.2 million years ago to the present. This figure also shows a general cooling trend, but the amplitude of the variations has increased. According to the Milancovich theory, at least part of the regularity in these cycles can be explained by regular variations in the Earth's orbit and tilt relative to the Sun. Other factors believed to influence global climate include the position of the tectonic plates, the deep-sea ocean currents, and the extent of sea ice (Bloom, 1998).

Climate records for the past 0.15 million or 150,000 years are more detailed and come from a variety of sources. All of these sources indicate two large peaks in global temperature, called interglacials. The first started roughly 127,000 years ago, and the most recent started 11,000 years ago. In between these two peaks, the temperatures show a general decreasing trend with several smaller peaks and valleys. These valleys correspond with the most recent ice-ages or glacial advances. Figure 1-5 shows an interesting record of this period from ice core records at Vostok, Antarctica. Based on this record, the temperature increased roughly 7° Celsius (C) over a period of 5,000 years at the end of the last ice age. The concentration of atmospheric carbon dioxide (CO_2) increased from 190 to almost 300 parts per million (ppm) over this same time period (Jouzel, 1993). Unfortunately, the record is not accurate enough to determine if the change in atmospheric CO_2 predates (and caused) the change in temperature, or vice-versa (Bloom, 1998). Regardless, this historical record indicates that large shifts in temperature have occurred in relatively short periods of geologic time.

One of the most interesting climatic events over the last 150,000 years it called the Younger-Dryas event. This event was named for the discovery of pollen from an Artic tundra plant called Dryas in a peat bog in northern Europe. The presence of a plant usually found in the Artic in Europe indicates the temperatures were significantly colder than they are today. This event occurred from 13,000 to 11,000 years ago during the most recent warming trend from the last ice-age. At the start of the Younger-Dryas, sea surface temperatures dropped by 7° C, which is roughly one third of the variation between ice-age and non-ice-age conditions. This 1,300 year cool period ended with a 7° C increase in temperature in an astonishing 10-20 years (Bloom, 1998). The causes for the Younger-Dryas are not well understood, but it indicates that severe changes in temperature can occur even within the time-scale of a human life-time.

Interestingly, the global climate over the last 10,000 years has been "mercifully tranquil" (Bloom, 1998, pg. 413). Ice cores in Greenland have shown variations in concentration of O^{18} isotopes ranging from -43‰ to -35‰ (a range of 8‰) between 80,000 and 10,000 years ago. However, over the last 10,000 years, the concentration has only varied between -34‰ and -36‰ (a range of 2‰). This period of climatic stability has in many ways shaped the world as we see it today. Human emissions of greenhouse gasses into the atmosphere are threatening that stability. But, as Bloom states, "…. although we now have the power to modify our environment both intentionally and unintentionally, it will also continue to change regardless of human activity" (pg. 413). The historical climate record indicates that even if all global greenhouse emissions stopped today, global temperatures could change drastically (either up or down) without any influence from humans.

1.1.2 History of Ecological Response to Climate Change

All life on earth is sensitive in one way or another to climatic conditions. Any persistent change in climate will have an effect on the ecosystem. Fossil and other evidence have preserved some of these ecological responses to historical climate changes. Unfortunately, matching global climate records and ecological records can be difficult because local climate does not always correlate with global climate. Also, techniques used to date both the climate records and the biological records may have errors. However, several researchers have uncovered relationships between climate change, extinction, migration, and other complex ecological responses.

Mass Extinctions

Fossil records indicate several mass extinctions have occurred over the course of Earth's history. Crowley and North (1988) found some correlation between major changes in climate and mass extinctions, but not a perfect one. The mass extinctions that occurred 440 and 365 million years ago coincide with glacial periods following long intervals of ice free conditions. Over the last 100 million years, Crowley and North found that extinction events occur approximately at the same time as major changes in the environment, but that the magnitude of the changes does not correlate well with the size of the extinction event (1988). In addition, the Cretaceous-Triassic (K-T) extinction (65 million years ago) is not correlated with any major climate shift, and no major extinctions are associated with late Carboniferous (330 million years ago) glaciations. This evidence suggests, "… the climate-life connection is intermittent and sometimes weak" (Crowley and North, 1988, pg. 1000). This study shows that climatic changes do play a significant role in mass extinctions, but that other factors are also likely to be important.

Crowley and North (1988) also found an interesting relationship between mass extinctions and the succession of climatic change. After a period of relative warm, the first cooling or ice age will tend to cause many of the temperature dependent species to go extinct. However, subsequent cooling periods (even if they are larger and longer than the initial period) will not have as large an effect because most of the temperature dependent species are already extinct. Thus, the response of a particular species to a change in climate depends on how much the climate varied as the species evolved. Many species extant today have endured significant climatic changes over the last 65 million years. However, the climate has changed little over the last 10,000. Thus certain species and populations alive today may be poorly equipped to deal with future climate changes.

Migration

Climate change does not always result in extinction of species. Some species are able to adapt to changing conditions by migrating up or down in latitude and/or in elevation. The ability of species to adapt to climate change depends on a variety of factors, including the mobility of individual animals, the dispersion of seeds, and the rate and extent of the climate change. In addition, almost all species depend on intricate webs of interaction with other species. If one species is able to migrate in response to a climate change, but a species it relies on for food or shelter is not, the species may not persist.

Several researchers have found some evidence of species migrations in response to historical climate changes.

Devender et. al. (1987) collected and analyzed the collections of packrats that have been preserved since the last ice age. The seeds and plants remnants in these collections indicate what plants were growing within 30-50 meters (m) of the rock shelter. Devender et. al. found collections that allowed them to reconstruct the species composition for a specific area in the Whipple Mountains in California over the last 14,000 years. This period corresponds to a global transition from ice age conditions to current conditions and it includes the Younger-Dryas from 13,000 to 11,700 years ago (Bloom, 1998). The general trend from this record shows a shift from foothill pine forests to desert shrub over roughly 3,000 years. Since the record only comes from one location, it is difficult to tell if the foothill pine population migrated upslope or became locally extirpated. However, it is clear that the desert shrub vegetation was able to colonize the area, migrating from elsewhere. One might expect to see some local extirpations associated with the rapid warming of 7° C following the Younger-Dryas event, but there is no indication of significant vegetation shifts during the Younger-Dryas in this record. However, there is a large drop in most species except California Juniper around 10,000 years ago. (Devender et. al., 1987).

Walther et. al., (2002) complied a series of studies that looked at the ecological responses of species to the global warming trend (an increase of 0.6° C) over the last 100 years. They found that migration rates are often episodic rather than gradual and vary greatly among species, reflecting different dispersal rates. Alpine plant species have been migrating at a rate that is slower than the loss of their habitat (they lag behind isothermal shifts by 8-10 m per decade). On the other hand, certain butterflies appear to track decadal warming quickly. The ranges of red fox (*Vulpes vulpes*) have been moving northward to fill in areas simultaneously vacated by the Arctic fox (*Alopex lagopus*) (Walther et. al., 2002). Recent evidence indicates that some species do migrate in response to climate changes, even during a relatively short period of 100 years, but the ability of these species to persist in a changed climate will depend on the amount of remaining habitat and the ability of other species to migrate with them.

Additional Ecological Responses to Climate Change

Species adapt to changing climates in other ways than going extinct and migrating away. Walther et. al., (2002) found that over the last 100 years of relatively mild warming some species exhibited phenological changes (timing of seasonal activities), some communities became more diverse due to varying rates of range shifts, and some ecosystems exhibited complex structural changes because key component species were affected by climate change in different ways.

Recent amphibian population declines in the western U.S. are a prime example of the complex interactions between climate and species. Kiesecker et. al., (2001) found that the recent global warming trend has elevated sea surface temperatures and intensified the El Nino/Southern Oscillation (ENSO) cycles. For areas in the western U.S., intensified ENSO cycles leads to less precipitation and thus less water in certain amphibian breeding ponds. The lower water depth increases exposure to UV-B radiation in embryos, which makes them more susceptible to infection from a pathogenic oomycete, *Saprolegnia ferax*. With fewer surviving embryos, the amphibian populations have been declining. This study highlights the complexity of linkages between a change in global climate and an impact to species.

These are just a few examples of how a changing climate has affected life on earth. From these examples it is clear that there is no direct relationship between mean annual temperature and the biodiversity of the planet. Complex environmental and ecologic interactions lead to extinctions, migrations, phenological changes, community shifts, and other impacts, many of which are not now understood. This uncertainty compounds the uncertainty associated with the magnitude and timing of future climate change. Regardless of these limitations, some researchers have attempted to predict future climatic conditions and the future ecological responses to these climate changes.

1.1.3 Future Climate Change in California

Predictions of global warming depend on a wide range of uncertain variables, including the future greenhouse gas emission rates, the effect of those gasses on trapping the sun’s radiation, the amount of clouds reflecting the sun’s light, and the complex positive and negative feedback loops between changes in temperature and changes in the geologic, ecological, hydrologic, and carbon cycles on Earth. Regardless of this complexity, scientists have been working for years to model the impacts of climate change using sophisticated general circulation models. Using additional spatial modeling, the results of these large scale models can be fine-tuned to predict climate changes at national, state, or regional levels. This analysis will focus on predictions for California’s future climate since the Mount Hamilton project area is near the center of the state (see Figure 1-1).

An articles was recently published in the Proceedings of the National Academy of Sciences (PNAS) that presents detailed predictions of the future climate of California (Hayhoe et. al., 2004). The PNAS article authors used two emission scenarios that bracket a large part of the range of the Intergovernmental Panel on Climate Change non-intervention emissions futures by assuming that atmospheric concentrations of CO_2 will range from 550 parts per million (ppm) to 970 ppm by 2100. These emission scenarios were then input into two state-of-the-art global climate models with low and medium sensitivity (Parallel Climate Model and Hadley Center Climate Model, version 3, respectively) to estimate the future global climate. The global model results were then downscaled to a 1/8° grid (approximately 10 kilometers (km) by 13 km) using the observed local precipitation and temperature from weather stations across the state from 1961-1990. The statewide results from this method include an increase from 2.3° C to 5.8° C by 2070-2099, with larger increases in the summer (see Figure 1-6). Annual precipitation predictions range from 38 millimeters (mm) increase to a 157 mm decrease for the same period, with the higher emission scenarios consistently predicting a decrease (see Figure 1-7).

Snyder et. al., (2002) used a similar approach as the researchers in the PNAS article to predict future climate in California. Snyder et. al. used an emission scenario of a doubling of atmospheric CO_2 from pre-industrial levels, or 560 ppm. This is close to the low end emission scenario used in the PNAS article. Snyder et. al. use the National Center for Atmospheric Research Community Climate Model (CCM) version 3.6.6 for the global climate predictions, and then downscaled the output to a smaller region including California using the RegCM2.5 regional climate model. The horizontal resolution of the RegCM2.5 model output was 40 km, which is slightly coarser than the PNAS model. Snyder et. al. found increases in temperature from 1.4° C to 3.8° C across the western US when compared with pre-industrial atmospheric CO_2 concentrations, with the greatest warming in the Sierra (see Figure 1-8). The researchers also found increases in precipitation across the state, with the northern half increasing the most (see Figure 1-9). Since Snyder et. al. used a different methodology and emission scenario than was used in the PNAS article, the results of the two studies are not directly comparable.

These two studies both show an increase in temperature and a change in precipitation in California over the next 50 to 100 years. The rate of warming is not as extreme as the warming following the Younger-Dryas event, but it certainly is significant. It is also important to note that current temperatures are at the top of a long-term spike, so many species extant today may not be adapted to additional warming. Some researchers have attempted to predict probable ecological responses to predicted future climate change. Several of these studies are reviewed below.

1.1.4 Predicted Ecological Responses to Future Climate Change

As mentioned above, the impacts of global climate change on species abundance and distribution depend on an enormous set of variables. However, with recent improvements in climatic and ecological modeling, some researchers have attempted to predict the effects of future climate change on species and habitats. One method is to determine the change in "climate envelopes" to see how reductions in habitats will impact species. Another method is to try to estimate migration rates and see how natural communities will change over time in response to climate change.

Extinction

Several researchers have used the climate envelope method to determine the impacts of climate change on species ranges. This method involves determining the correlation between the species' current range and certain environmental variables (temperature, precipitation, number of frost days, etc.). This is the climate envelope in which the species can survive in the face of competitors and natural enemies. A changing climate will alter the spatial location and perhaps size of the climate envelope (Thomas et. al., 2003). For example, an increase in average temperature on a mountain slope will increase the size of an envelope a species adapted to warmer temperatures and decrease the envelope of a species adapted to colder temperatures. If the decrease in size is large enough, the cold-adapted species will not have enough habitat to survive and could become extinct.

Current and future climate envelopes may be located in different spaces on the earth. For example, a future climate envelope may be higher in latitude than the current envelope, requiring the species to migrate from one envelope to the other. In topographically complex regions with natural barriers (e.g., waterways) and man-made barriers (e.g., roads, housing developments), a species may not be able to reach all or portions of the future climate envelope. The degree to which this will occur will depend in part on a species' ability to disperse and migrate, and on the length of time of the change in climate envelopes. In order to overcome this uncertainty, researchers typically assume two scenarios. One scenario assumes that the species can migrate quickly enough to fully utilize the entire future climate envelope, called universal dispersal. The other scenario, called no dispersal, assumes that the species cannot migrate at all outside of its current distribution and will be limited to the area of overlap between the current envelope and the future envelope, if any exists. The actual future course of events is likely to lie somewhere between these two extremes (Thomas, et. al., 2003).

Thomas et. al., (2003) used a global data set of 1,103 species ranges and several global warming predictions to calculate the extinction rates due to climate change. Assuming universal dispersal and mid-range global warming, they found that by 2050, 15 to 20% of the species in study regions world wide will lose enough suitable habitat that they will become extinct. Assuming no dispersal, the percentage of species that will eventually become extinct jumps to 26 to 31%. While this was a relatively coarse-grained global study, the results are nonetheless alarming.

Harte et. al., (2004) present a critique to the method used by Thomas et. al., (2003). Harte et. al. posited that certain individuals or populations *within* a species may have different tolerances for climate change. In essence, each population within a species has its own climate envelopes that may be smaller than the aggregate climate envelope for the entire species. A change in climate could cause conditions to change for one population that is still within the range of tolerances for the entire species, but it is not in the range of tolerances for that population. If this occurs, this population could become extinct, even though the habitat is still in the climate envelope for the entire species. If population specific adaptations to climate are common, the extinction levels estimated by Thomas et. al. (2003) could be significantly understated. However, as stated in Harte et. al., “the prevalence of such genetic adaptation to climate at the population level is unknown" (2004). Regardless, the climate adaptations and envelopes at a population level should be compared with the species-wide adaptations and envelopes.

McBride and Mossadegh, (1990) conducted a similar climate envelope analysis for the endemic oak trees in California. They used several climate change models available at the time that predicted an increase in temperature from 2.3°C to 4.7°C and a decrease in annual precipitation from 0.5mm to 7mm in California (which are similar to the results from the more recent models mentioned above). McBride and Mossadegh found that the predicted climate change is not likely to have an impact on the distribution or persistence of California blue oaks (*Quercus douglasii*). They found a low correlation between the location of the species and the temperature and precipitation of the area. Thus, the species is adapted to endure an increase in temperature and a variation in precipitation. One critique of this analysis was similar to the critique raised by Harte et. al. (2004). It stated that certain oak populations in the state may have smaller climate envelopes than the species as a whole. If migration is limited (as is likely over a short time scale), individuals from the more tolerant populations may not be able to migrate to fill in the areas vacant by the less tolerant populations (McBride, personal communication, 2004). In order to resolve this debate, more research must be done on the genetic variation and climate tolerances between various oak populations.

Distribution Changes and Migration Rates

Several researchers have taken a different approach to studying the ecological response to future climate change. These studies do not look at species specific climate envelopes, but attempt to determine migration rates and shifts in community composition using sophisticated vegetation models. These vegetation models are unable to predict species specific impacts, but are able to determine changes in the spatial distribution of habitat types.

Malcolm et. al., (2002) used two global vegetation models (BIOME3 and MAPSS) and several global circulation models to look at migration rates of large habitat types or biomes. They found high migration rates for the various biomes (>1 km per year) in all of the different models they used. However, these rates were significantly higher than the observed migration rates for spruce when it followed the retreating North American glacier at the end of the last ice age. In order to get their model to replicate these slower migration rates, Malcolm et. al. had to increase the period of warming from the currently predicted 100 years to greater than 1,000 years. Based on current emission rates and climate modeling, this longer period to reach the same level of warming is not likely. The authors conclude that "global warming may require migration rates much faster than those observed during post-glacial times and hence has the potential to reduce biodiversity by selecting for highly mobile and opportunistic species" (Malcolm et. al., 2002, pg. 835). Man-made barriers to migration are also likely to enhance this selection effect.

Diffenbaugh et. al., (2003) conducted a similar analysis to Malcolm et. al., (2002) but focused on the western US, centered on California. Diffenbaugh et. al. used a vegetation model (BIOME4) and a regional climate model (RegCM2.5) to look at vegetation changes in the topographically diverse region. They found that the predicted changes in climate caused significant vegetation changes, especially at high elevations, due primarily to warming and decreased precipitation in the Sierra. The main climate impacts statewide included contractions of high elevation forests and the overall conversion of forest vegetation to non-forest woodland, shrubland, and grassland.

Diffenbaugh et. al. took their analysis one step further than Malcolm et. al. by modeling the impacts of predicted increases in atmospheric CO_2 concentrations on vegetation types. Several studies have found that changes in CO_2 concentrations can lead to changes in plant biomass, distribution, and community structure (e.g., Gill et. al., 2002; Smith et. al., 2000 and Joos et. al., 2002). Increased CO_2 also improves efficiency of water use in plants by reducing the amount of transpiration per unit area of leaf surface (McBride and Mossadegh, 1990). Diffenbaugh et. al. found that increases in CO_2 concentration resulted in woody biome types replacing less woody types. When both climate and CO_2 impacts were included, the climate effect dominated in some areas and the CO_2 effect dominated in others. But in many cases, the result was different than either alone, indicating the importance of including CO_2 impacts in determining the ecological responses to future climate change.

1.1.5 Conclusions from Existing Research

The review of existing literature indicates that the Earth's climate has gone through significant changes over the last 100 million years, and although the climate has tended to get colder and more variable, the last 10,000 years have been relatively warm and stable. There is some evidence linking historical mass extinctions to climate change, but other factors are also important. Additional historical ecological responses to climate change include migrations, changes in phenology, and changes in community composition and function.

Looking toward the future requires many assumptions and sophisticated modeling. Two recent regional climate change studies for California indicate the temperature will increase over the next century, and the amount of precipitation is likely to drop. These climate changes may alter the geographic distribution of species climate envelopes, which could result in species extinctions, especially if species are unable to freely migrate and if local populations have adapted separately to specific climatic conditions. In addition to changing the climate, increases in atmospheric CO_2 concentrations will directly impact some species in either positive or negative ways. This analysis builds on these findings and focus on the likely impacts of climate change on the biodiversity of a specific region in California; the Mount Hamilton range.

1.2 Mount Hamilton Study Site

The Mount Hamilton study site is located east of San Jose, California, between the Santa Clara valley and the Central Valley (see Figure 1-1). The boundaries of the study site were defined by TNC as the Mount Hamilton "project area." TNC project areas are vast, landscape-scale conservation implementation or action units, embracing particularly rich and intact systems. The TNC "project area" terminology will be used throughout this analysis to refer to the Mount Hamilton study site.

The Mount Hamilton project area and associated 1.6 km (1 mile (mi)) buffer covers roughly 6,200 square km (or roughly 1.5 million acres). The area is characterized by steep topography, with elevation ranging from 1271 m (4,170 feet (ft)) at the top of Mount Hamilton to just above sea level near the southern extent of the San Francisco Bay (see Figure 1-10). The climate is classified as Mediterranean, with hot dry summers and cool wet winters. The vegetation of the area consists of a complex mosaic of open grasslands, oak savannas and forests, mixed evergreen forests, chaparral, and coastal sage scrub. While the climate is generally mild, the upper elevations do receive frost and occasional snows (see Figure 1-11).

1.2.1 Biodiversity

The Mount Hamilton range has long been noted for its rich collection of biodiversity. About 47% of the plants in the range are endemic to California (Sharsmith, 1982). TNC identified the Mount Hamilton project area as a key conservation area in part due to its biodiversity. According to TNC,

> [The Mount Hamilton project] area encompasses a mosaic of many of California's most urgently threatened systems, including outstanding examples of once widespread valley oak, blue oak, coast live oak and black oak woodlands, as well as rare systems including sycamore alluvial woodlands, serpentine grasslands, wildflower fields, Coast Range ponderosa pine forests and seasonal wetlands. The region is drained by streams critical to the survival of unique native fishes, amphibians and reptiles once abundant in California, but now endangered throughout their ranges (Cox et. al., 2004, pg. 3)

TNC has identified and ranked several natural communities within the Mount Hamilton project area as those in greatest need of immediate conservation. A list of these "priority" natural systems and TNC's reasoning for their ranks are provided below:

Table 1-1: TNC Priority Natural Systems

System	Rank
Sycamore alluvial woodland	Very High
Valley Oak Woodland/Savanna	Very High
Serpentine Grasslands & Wildflower Fields	High – Very High
Black oak	High – Very High
“Sky Islands” (any native conifer except grey pine)	High – Very High
Coast Range Ponderosa Pine Forest	High
Blue Oak Woodland/Savanna	High
Large-area-dependent species - Mountain lion - San Joaquin kit fox	High
Burrowing Owls	High
Ponds	High
Rivers & Streams	High
Riparian Corridors	High
Freshwater wetlands (sag ponds, lake edges, etc.)	High
Coast Live Oak Woodland	Medium
Coast Range Ponderosa Pine Forest	Medium
Diablo Sage Scrub/Chaparral	Medium
Annual Grasslands	Medium

Two systems, sycamore alluvial woodlands and valley oak woodlands, received the highest rank due to their extremely reduced distributions, escalating disappearance due to incompatible land practices, and lack of juvenile recruitment. The Project Area encompasses over half the remaining, documented 2,000 acres of rare California Central Coast sycamore alluvial woodland habitat, including some of the best and largest occurrences. Valley oak woodlands, already reduced to less than 10% of their original extent, are considered especially vulnerable to continued land use conversion in California and the project area supports outstanding examples.

Serpentine habitats host a rich ensemble of endemic plant and wildlife species, such as the endangered Bay checkerspot butterfly, and are highly threatened by development, occurring adjacent to major transportation corridors within the Project Area. Annual grasslands and wildflower fields also are critically important as they serve as essential habitat for sensitive species including the San Joaquin kit fox, burrowing owl, and golden eagle, and encompass rapidly vanishing native grassland patches. Blue oak woodlands and savanna, endemic to California, are ranked high since they are one of the least protected natural communities in the state, despite their widespread distribution in California’s foothills. Aquatic communities provide critical habitat for at least five different threatened native fish assemblages and steelhead, and, along with nearby ponds, provide essential habitat for threatened and endangered amphibian and reptile

> species including California tiger salamanders, California red-legged and foothill yellow-legged frogs.
>
> Other important natural community systems that ranked medium include coast live oak woodland, coast range ponderosa pine forest, and Diablo sage scrub/chaparral. Coast live oak woodland, although highly representative of the Mount Hamilton Project area and the Central Coast ecoregion, is more widespread and not currently in severe decline. Coast range ponderosa pine forest was ranked as medium because while extremely limited in distribution (only one occurrence) in the Project Area, significant stands are protected within Henry Coe State Park. Chaparral was ranked as medium due to its widespread occurrence throughout the Project Area and its relative lack of immediate irreversible threats compared to systems associated with more moderate and hence, developable terrain.
>
> Finally, the distribution of large-area-dependent mammals was used as an indicator of the existence of important linkages that maintain the functionality and viability of the terrestrial landscape and therefore received a high ranking (Cox et. al., 2004, pgs 6-7).

This list of high priority natural systems provides an indication of the rich biodiversity of the project area, as well as some of the threats to the region.

1.2.2 Threats and Existing Protections

According to TNC, the most serious stresses to the high priority natural systems listed above include habitat destruction and fragmentation, lack of recruitment, and competition with invasive species. The most significant sources of these stresses are caused by urban and rural development, agricultural conversions, incompatible cattle grazing practices, and invasive species. The Mount Hamilton area is directly adjacent to the rapidly growing South Bay region, and large portions of land within the project area have been converted to large-lot rural residential developments. Certain cattle grazing practices, which have occurred over the last 200 years, can lead to loss of oak and riparian seedlings, altered community structure, and increased erosion and sedimentation in the waterways. Invasive species compete directly with many native species for resources. Key invasive species include prolific feral pigs, bullfrogs, and exotic fish. Other threats to the area include conversion of land to agricultural uses, dam development, road and other infrastructure construction and maintenance, and mining (Cox et. al., 2004).

Fortunately, as of May 2001, a significant portion (1,250 km^2 (308,000 acres) or 20%) of the Mount Hamilton project area was already protected through State, regional and county parks, water departments, the University of California, and TNC lands and conservation easements (Cox et. al., 2004). Figure 1-12 shows the type, location and extent of these protected lands. The portions of the Mount Hamilton Project area within Santa Clara County are also protected by a “greenline” which limits urban growth along the base of the foothills. Above the greenline, lots are limited to 20-160 acres depending on slope. The northern portions of the project area in Alameda County are zoned for rural agricultural uses with 320-acre minimum lot sizes (Cox et. al., 1998).

TNC is currently updating the conservation plan for the Mount Hamilton project area in order to refine and update site-specific conservation strategies and partnerships and prioritize the remaining unprotected 80% for protection. This climate analysis is intended to enhance TNC’s conservation planning efforts by identifying potential threats due to climate change, as well as possible methods to prepare for future climate scenarios.

Chapter 2: Methods

In order to predict the impacts of future climate change on the biodiversity of the Mount Hamilton project area, the following basic methodology was used:

- Review the high priority natural systems, communities, and species identified by TNC and select a subset based on data availability and priority level
- Research existing literature on these communities and species to determine the process by which climate affects their viability
- Determine which key climatic variables have the greatest impact on these communities and species
- Determine how those climatic variables will change in the future in the region
- Model how those changes will affect the future location of climatically suitable habitat
- Compare the future climatically suitable habitat locations with current habitat ranges and with TNC target areas for conservation

This basic methodology was followed by conducting preliminary research, assembling a GIS database, modeling impacts to specific communities and species, and comparing the results with the current habitat and TNC target conservation areas.

2.1 Preliminary Research

Preliminary research was conducted on the high priority natural systems identified by TNC, as well as the federally listed threatened and endangered species found in the Mount Hamilton project area. Detailed data on the location of only a subset of the communities and species was readily available. After conferring with TNC, a subset of these communities and species were chosen for detailed research, based on degree of threat, availability and quality of data, and potential susceptibility to climate change. These communities and species are listed below:

- Endemic California oak woodlands, including:
  - Blue oak woodland
  - Coast live oak woodland
  - Valley oak woodland
- California tiger salamander (*Ambystoma californiense*)
- California red-legged frog (*Rana aurora draytonii*)
- Bay checkerspot butterfly (*Euphydryas editha bayensis*)

Additional research was conducted for all of these species using the internet, TNC resources, journal articles, and personal communications. This research attempted to answer the following questions:

- How does climate affect these communities and species?
- What is the extent of their current range?
- What climatic conditions adversely affect these communities and species?
- How long must these conditions persist to induce the adverse impacts?
- What are some secondary threats (or benefits) that could be influenced by climate change (e.g., fire, invasive species, CO_2 fertilization)?

Answers to many of these questions are presented in Results chapter.

2.2 GIS Database and Modeling

A GIS database was constructed to geographically relate current climate conditions, future climate conditions, the spatial extent of the selected communities and species, potential migration corridors, and TNC conservation targets. Data viewing and analysis was conducted with ESRI ArcGIS version 9 and ArcInfo version 8.3 (www.esri.com).

Information on current climate conditions was derived from raster grids produced by the Daymet model that was developed by the Numerical Terradynamic Simulation Group at the University of Montana (www.daymet.com). Daymet uses digital elevation data and daily weather observations from various weather stations to interpolate a continuous surface for a variety of climatic variables (e.g. mean annual temperature, mean annual precipitation, mean maximum daily temperature, etc). The climate layers are based on 18 years of weather data (from 1980 to 1997) and are produced in 1 km^2 grid cells.

Predictions for future climate were obtained from Mark Snyder at the University of California Santa Cruz from the regional climate modeling effort described in Snyder et. al., 2002. The data consists of a recent climate scenario (a 20-year average from 1980 to 1999) and a future climate scenario (a 20-year average from 2080 to 2099). The assumed atmospheric CO_2 concentration for the future scenario starts at 635 ppm in 2080, rising to 688 ppm by 2099. These CO_2 levels are well within the range used in the PNAS article mentioned in Chapter 1 of 550 to 970 ppm by 2100 (Hayhoe, et. al., 2004). The data provided included annual and seasonal averages of temperature and precipitation.

All of the future climate data was provided in ASCII text files with each row representing a temperature or precipitation reading for a particular location in a 40 km (horizontal) grid covering much of the western US. These text files were converted to point shapefiles using ArcGIS. Using the spline interpolation method provided with the spatial analyst extension, the point files were converted to continuous raster grids with the same spatial resolution and extent as the Daymet climate layers (1 km^2). For each climate variable, the future scenario was subtracted from the modern scenario using the raster calculator in ArcGIS. This provided a 1 km^2 grid of the predicted change for temperature and precipitation over the next 100 years. These change layers were added to the Daymet climate layers to get finer resolution grids of current and future climatic conditions.

Initial research indicated that the different natural communities and species were sensitive to different climatic variables, and thus some would require separate modeling efforts. Descriptions of the species specific impact modeling are provided below.

2.2.1 Endemic Oak Woodlands

GIS Habitat Data

The spatial extent of the endemic oak woodlands in California was obtained from the California Department of Forestry and Fire Protection (CDF) Fire and Resource Assessment Program (FRAP) (www.frap.cdf.ca.gov). The GIS raster layer is called the "Hardwood Rangeland Vegetation (pixels)" layer and was derived from the hardwood maps delineated by Dr. Norm Pillsbury from black and white aerial photos taken in 1981. These maps were digitized and updated using 1990 LANDSAT TM satellite imagery. The layer contains all of the oak woodlands below 5,000 feet statewide and has a very detailed resolution (25 meters). FRAP also provides a polygon layer that generalizes the high-resolution grid data into larger polygons.

Climatic Variables

As will be discussed in the Results chapter, initial research indicates that oak species are affected most by the following climatic variables: Annual precipitation (P); average of the daily highs for the hottest month (M); and average of the daily lows for the coldest month (m). These three variables can be combined to create the Emberger's pluviothermic index (Q) with the following equation:

$$Q = P * 2000 / (M^2 – m^2)$$

In order to test if other climatic variables were important, a spatial logit regression model was used with the presence of the various oak woodland types used as the binary dependent variable. In order to create the dataset for the regression model, the FRAP hardwoods polygon layer was converted to a 1 km^2 grid that matched all of the climate variable grids. Using the "sample" command under the Grid prompt in ArcInfo, a text file was created that contained one record for each of the 1 km^2 grid cells in the hardwoods layer. Each record contained the values for all of the climatic variables (annual temperature, annual precipitation, etc.) and the type of oak woodland present. This text file was imported into SPSS for statistical analysis.

A variable for the average daily maximum and minimum temperatures, as called for in the Emberger's index, was not available by month. However, the average temperature for the hottest and coldest months was available, so this was used as a proxy. After running several different logit regression models for the various oak woodland types, it became clear that including the three variables separately (annual precipitation, average temperature of the hottest month, average temperature of the coldest month), explained more of the variation in the location of the various oak species than the

Emberger's index alone. The amount of variation in the dependent variable explained by the variables in a model is expressed by a pseudo R^2 in logit analysis. The Nagelkerke R^2 is the pseudo R^2 reported in this analysis. For example, the Nagelkerke R^2 for the model with only the Emberger's index was 0.288 for blue oak woodland, 0.160 for coast live oak woodland, and .001 for valley oak woodlands. However, when annual precipitation and the average temperatures for the hottest and coldest months were included and the Emberger's index removed from the model, the Nagelkerke R^2 increased to 0.314 for blue oak, 0.488 for coast live oak, and 0.162 for valley oak. While these R^2 values are still relatively low (an R^2 of 1 would mean the variables included in the model explain all of the variation in the location of the various oak woodland types), some important variable are missing, such as soil type and depth, proximity to other similar oak stands, land use, etc. These variables are less likely to change as a result of climate change, so they were not included in the model.

As mentioned above, the variables provided by Mark Snyder for predicted future climate contained seasonal temperature averages instead of monthly averages. Two additional regression models were run to see if substituting average summer and winter temperatures for the average temperature of the hottest and coldest month reduced the predictive capability of the model. Using seasonal averages had little effect on the coefficients and actually increased the R^2 for some of the models. For example, the Nagelkerke R^2 decreased from .314 (monthly) to .313 (seasonal) for blue oak woodlands, but it increased from .488 (monthly) to .490 (seasonal) for valley oak woodlands, and increased from .162 (monthly) to .165 (seasonal) for valley oak woodlands. Since there were insignificant changes in the Nagelkerke R^2, seasonal averages are used instead of monthly averages for this analysis.

Climate Envelopes

In order to construct climate envelopes for the various oak woodland types, it was necessary to determine the range of climatic conditions the woodlands currently tolerate. This was achieved by estimating the average annual precipitation, winter temperature and summer temperature for all of the land of each of the oak woodland types using the zonal statistics command in the spatial analyst extension of ArcGIS 9. The 25 m resolution hardwoods grid layer was used for the zone data set because it is more accurate than the polygon layer. The output tables from the zonal statistics command were imported into Microsoft Excel for additional calculations.

The zonal climate statistics were calculated twice; once for the full extent of the woodlands statewide, and once for the extent of the woodlands within the Mount Hamilton project area. As discussed in Chapter 1, Harte et. al., (2004) critiqued the climate envelope method because certain populations within a species may have different climatic tolerances than the species as a whole. Since oak woodlands cannot migrate long distances, the individuals of the local population may be the only available individuals to be able to adapt to climate change. However, the research of McBride and Mossadegh (1990) suggests that genetic variation in blue oaks is minimal and that one local population is likely to be as tolerant to climate change as any other population. In order to get a range of tolerance, climate envelopes were constructed based on both the extent of the woodland types statewide (assuming there is little genetic variation within the species), and for the local populations in the Mount Hamilton project area (assuming these populations have unique climate tolerances).

The climate envelopes for both the statewide and local woodland types were generated in Excel by adding and subtracting 2 times the standard deviation to the mean of each climate variable. If the climatic variable were normally distributed, this range would encompass roughly 95% of the climate tolerated by this woodland type. For example, 95% of the blue oak woodlands would be located in areas that experience temperature within the high and low ranges. Histograms constructed for a sample of the woodland types and climate variables indicate that while some are normally distributed (see Figure 2-1), some are not (Figure 2-2). However, the bulk of the observations are within two standard deviations of the mean.

The climate envelopes were generated using the raster calculator in ArcGIS 9. The raster calculator generated a new 1 km^2 resolution raster layer for each woodland type. Each raster cell was given a value of 1 if the cell was within the range for annual precipitation, summer temperature, and winter temperature. If the cell did not meet all three conditions, it was given a zero. All of the cells with a value of 1 are the climate envelope for that woodland type. An example of the script used to create the climate envelope for blue oak woodlands is shown below:

```
bow_spdj_n = [mtham 1k precip] > 13.9975427058674 & [mtham 1k precip] <
135.041198387831 & [mh1kt_djf_n] > 2.1502933738948 & [mh1kt_djf_n] <
12.1788998599793 & [mh1kt_jja_n] > 14.9552936731145 & [mh1kt_jja_n] <
27.3632577082067
```

The first term is the name of the blue oak woodland (bow) climate envelope based on current conditions (_n). The terms in brackets refer to climate layers ([mtham 1k precip] is the current average annual precipitation in cm; [mh1kt_djf_n] is the current average winter temperature, and [mh1kt_jja_n] is the current average summer temperature). The numbers represent the ranges of temperature and precipitation observed statewide for blue oak woodlands.

Climate envelopes were constructed for each woodland type for statewide and local observed climatic conditions. A second set of climate envelopes was also constructed based on the estimated future climate conditions using the using the modeled results generated by Snyder et. al. (2002). The current and future climate envelopes were combined for each species. These layers were then combined with the current extent of each woodland type. The resulting maps are shown in the Results chapter.

2.2.2 Threatened and Endangered Animal Species

The Mount Hamilton project area supports habitat for several animal species that are listed by the US Fish and Wildlife Service (USFWS) as threatened and endangered (T&E) species. This analysis focuses on three of these T&E species: California red-legged frog (*Rana aurora draytonii*) (CRLF); California tiger salamander (*Ambystoma californiense*) (CTS); and the bay checkerspot butterfly (*Euphydryas editha bayensis*) (BCB).

GIS Habitat Data

The USFWS has designated proposed or final critical habitat for all three of these species. The Endangered Species Act of 1973 defines critical habitat as the areas essential to the conservation of the species. Critical habitat is used to delineate the extent of the habitat for the T&E species in this analysis for several reasons. First, the critical habitat is based in part on the historical habitat for the species. As such, it includes both areas that are currently occupied by the species as well as areas that were once occupied by the species and could be occupied again. Second, critical habitat does not include all areas where the species is found, especially if the area is marginal habitat. This means that the critical habitat only includes the areas with relatively large populations of the subject species. These factors make critical habitat a good indicator of the best habitat that was once and is now occupied by the species.

After the USFWS proposes critical habitat, the public has a chance to comment on the designation, and an economic analysis is completed. The USFWS can remove areas from the proposed critical habitat if the economic benefits of exclusion outweigh the benefits of inclusion. However, the critical habitat is not yet finalized for the CTS or CRLF, so no areas have been removed for economic reasons. The critical habitat for the BCB is final, but no areas were removed from the proposed habitat for economic reasons (USFWS, 2001).

Climatic Variables

The key climatic variables that influence the vitality of the T&E species were chosen using a methodology very similar to the one used for the oak woodlands. First, existing literature was reviewed to determine the life history of the species, the climatic and habitat requirements, and the timing of key events, such as breeding and hatching. This research indicated that each T&E species has different life histories and is sensitive to different climatic variables during different seasons. For example, a wet winter improves the survival rate of juvenile CTS because it allows them to feed longer in seasonal ponds. Hot summers affect CRLF because they will die if they must live in pools of water that have a temperature of 29° C or more for an extended period of time. More information on these sensitivities to climate is presented in the Results chapter.

Existing research on the sensitivity of T&E species to climatic extremes is limited due to their rarity and protected status. In order to determine additional climatic variables that will affect these species, a spatial regression analysis was conducted in a manner very similar to the oak woodland data. All of the critical habitat GIS layers were converted to a 1 km^2 resolution grid file in ArcGIS to match the current climate layers. Additional layers were included to exclude parts of the state that could not support the T&E species. The Multi-source Land Cover Data (v2.2) from FRAP was included to identify and exclude urban and agricultural land. The Bioregion data from FRAP was also included to exclude certain regions in the State that are inaccessible to the species. These layers were also converted to a 1 km^2 grid. The data from all of the grids were exported to a text file using the “sample” command in ArcInfo and then imported into SPSS for the regression analysis.

Before conducting regression analysis, the statewide data was winnowed down to include only the areas that could possibly be habitat for the T&E species. Urban land, agricultural land, and large water bodies were excluded from the data set. Certain bioregions were also excluded or included as follows:

- CRLF: Mohave and Colorado Desert bioregions **excluded**
- CTS: Mohave, Colorado Desert, South Coast, Klamath/ North Coast, and Modoc bioregions **excluded**

- BCB: Bay Area/ Delta and South Central Coast **included**

These bioregion-based restrictions on the data were chosen based on the extent of the critical habitat and what areas could possibly support the species based on topography and distance from the core populations. This was done to reduce the sample size from the entire state to just the potential habitat. Excluding areas that are clearly not habitat improves the validity of the regression model and the accuracy of the results. The results from the logistic regression models are included in the Results chapter.

Climate Envelopes

After choosing the relevant climatic variables based on the review of existing literature and the results of the regression analysis, climate envelopes for each of the three species were constructed. Using SPSS, a data set was created that included only the areas covered by the critical habitat for each species. Next the 2.5 and 97.5 percentile for each relevant climatic variable was calculated using these datasets. This technique provides a maximum and minimum range that incorporates 95% of the variability observed in the habitat for each species. This method is also more accurate that the standard deviation method used for the oak woodlands because the data does not have to be normally distributed. (Note: This percentile technique was not used with the oak woodland data because it has a much higher resolution (25 m^2 compared to 1 km^2) so the ability to export all of these data points into SPSS was limited by computer processing power).

Another difference with the T&E species methodology and the oak woodland methodology was the area used to create the climate envelopes. With the oak woodlands, a statewide and local method was used to calculate two separate climate envelopes for each climate variable and each woodland type in order to account for the fact that separate populations may have different genetic codes and thus separate tolerances for climatic variability. For the T&E species, only the statewide dataset is used. This is because the individual T&E animals have more mobility than the oaks and thus the genetic variability is likely to be less between populations. In addition, the USFWS has already separated the T&E species into sub-species (CRLF, BCB) and distinction population segments (CTS). The BCB populations are also so geographically limited that there would be little difference between a statewide and local climate envelope.

After the ranges for each climate variable and each species were calculated, scripts were generated in Excel to be used in the raster calculator in ArcGIS, as with the oak woodlands. Separate envelopes were generated based on current climate conditions and future climate conditions. These two envelopes were combined for each species to compare the results and determine which areas of habitat will be lost. Finally, these combined envelopes were compared with the critical habitat for the species to determine which areas of future climatically suitable habitat will be accessible for each species. The resulting maps and tables are presented in the Results chapter.

Chapter 3: Results

Based on the methods described above, this chapter presents the primary results of the analysis. First, data on the current and predicted future climate of the Mount Hamilton project area is presented. This is followed by research on the target species' and communities' ecological sensitivities. Next, the results of the climate envelope analysis indicates how much current habitat will become unsuitable due to climate change. Finally, several other impacts of climate change are discussed, including CO_2 fertilization, fire, and invasive species. Discussion and analysis of these results is primarily reserved for the following Discussion chapter.

3.1 Climate of the Mount Hamilton Project Area

The Mount Hamilton project area is characterized by a Mediterranean climate with generally mild temperature fluctuations and highly seasonal rainfall patterns. This general climate regime is not likely to change significantly over the next 100 years, but the average temperature is predicted to increase and total annual precipitation may go down.

3.1.1 Current Climate

The annual average temperature and total precipitation for the Mount Hamilton project area are shown in Figure 3-1. This figure displays two histograms. Each data point used to make the histogram represents the climatic conditions for a 1 km^2 area within the project area. This data is based on the Daymet climatological summaries for 1980 to 1997 that are described in Chapter 2. The mean annual temperature for the entire project area is 14.2° C (57.6° F) with a standard deviation of 1.24° C (2.23° F). Based on the histogram, the mean annual temperatures range from 10° C (50° F) to 16.5° C (61.7° F). The mean total annual precipitation for the project area is 48 cm (18.9 in) with a standard deviation of 9.2 cm (3.6 in). The precipitation ranges from 28 cm (11 in) to about 75 cm (30 in), although some areas receive more precipitation. These ranges represent the varied topography of the Mount Hamilton project area, with the higher elevations generally bearing the cooler temperatures and receiving more precipitation.

The seasonal variations in current climate can be seen in Figures 3-2 and 3-3. These figures show histograms for Winter (December, January, and February), Spring (March, April, May), Summer (June, July, August), and Fall (September, October, November). The monthly temperatures in Figure 3-2 are averaged by season, while the monthly precipitation figures in Figure 3-3 are totaled. The current average winter temperature in the project area is 7.9 °C (46.2° F) while the average summer temperature is 20.3 °C (68.5° F), for a total seasonal range in average temperatures of 12.4° C (22.3° F). Of course, daily temperatures fluctuate much more than this, but these figures are provided to indicate the longer-term climatic trends.

Mount Hamilton gets almost all of is precipitation in late fall, winter, and early spring. The total average precipitation for winter is 25 cm (9.8 in), while only 0.52 cm (0.2 in) of rain falls during the dry summer months. During fall, the project area gets 10 cm (3.9 in) and another 13 cm (5.1 in) falls in the spring. As will be discussed below, the various plants and animals that live in the Mount Hamilton project area have developed interesting adaptations to survive in this variable precipitation climate.

3.1.2 Future Climate

As discussed in Chapter 1, several researchers have modeled the regional impacts of increased human emissions on the future climate of California. The maps presented in Figures 1-6 and 1-7 show the output of several different modeling efforts presented in the 2004 PNAS article. Based on these maps, the winter temperatures for the Mount Hamilton project area is projected to increase from 2° C to 5° C (3.6° F to 9° F) and the summer temperatures will increase from 2° C to 8° C (3.6° F to 14.4° F). The winter precipitation will either increase by 0.5 mm/day or decrease by 1 mm/day (three of the four models show a decrease of about 1 mm/day), while the summer precipitation will remain unchanged. Converting this daily change to a seasonal change results in a range of a 4.5 cm (1.8 in) increase to a 9 cm (3.5 in) decrease for the winter.

The modeling effort described in Snyder et. al. (2002) produces similar results as the PNAS article models. The Snyder et. al. data was analyzed in GIS to provide more accurate results for the Mount Hamilton project area. Table 3-1 shows the mean seasonal and annual temperature and precipitation for the current climate conditions, the future climate conditions, and the change between the two, based on the Snyder et. al. (2002) modeling output. Table 3-2 provides the same information in English units.

Table 3-1: Current and Future Climatic Conditions, Mount Hamilton Project Area (Metric Units)

Climate Variable	*Current*	*Future*	*Change*
Average Winter Temp. (C)	7.9	10.3	2.4
Average Spring Temp. (C)	13.2	15.3	2.2
Average Summer Temp. (C)	20.3	22.4	2.1
Average Fall Temp. (C)	15.4	17.8	2.4
Average Annual Temp. (C)	14.2	16.5	2.3
Total Winter Precip. (cm)	24.9	27.4	2.5
Total Spring Precip. (cm)	12.8	11.1	-1.7
Total Summer Precip. (cm)	0.5	0.3	-0.2
Total Fall Precip. (cm)	9.6	6.8	-2.8
Total Annual Precip. (cm)	47.8	45.8	-2.0

Table 3-2: Current and Future Climatic Conditions, Mount Hamilton Project Area (English Units)

Climate Variable	*Current*	*Future*	*Change*
Average Winter Temp. (F)	46.2	50.5	4.3
Average Spring Temp. (F)	55.7	59.6	3.9
Average Summer Temp. (F)	68.6	72.3	3.8
Average Fall Temp. (F)	59.7	64.0	4.3
Average Annual Temp. (F)	57.6	61.7	4.1
Total Winter Precip. (in)	9.7	10.7	1.0
Total Spring Precip. (in)	5.0	4.3	-0.7
Total Summer Precip. (in)	0.2	0.1	-0.1
Total Fall Precip. (in)	3.8	2.7	-1.1
Total Annual Precip. (in)	18.7	17.9	-0.8

The Snyder et. al. (2002) data show that the average winter temperatures are projected to increase by 2.4° C (4.3° F), the average summer temperatures are projected to increase by 2.1° C (3.8° F), and the annual temperatures are projected to increase by 2.3° C (4.1° F). These values are on the low end but within the ranges estimated in the PNAS article. As such, using this data for future modeling will provide a more conservative estimate of the impacts of climate change when compared to the ranges estimated in the PNAS article.

The Snyder et. al. data predict an increase in winter precipitation of 2.5 cm (1.0 in), but a decrease in precipitation during the rest of the year, with the largest decrease coming in the fall. For the year, the total precipitation is predicted to drop by 2 cm (0.8 in). The winter increase value falls within the range of scenarios presented in the PNAS article, although most of the PNAS article models predicted a decrease in winter precipitation. The Snyder et. al. results do show a total annual decrease in precipitation, but the timing of the change in precipitation is important for the different species, especially the threatened and endangered species. Figures 3-4 and 3-5 show the spatial patterns of the current and future mean annual temperature and total precipitation, based on the Snyder et. al. modeling results.

3.2 Research on Ecological Climate Sensitivity

3.2.1 Oak Woodlands

California's oak woodlands are some of the most picturesque and unique habitats in the country. They range from rolling hills dotted by lone oaks to thick mountainous forests. The Mount Hamilton project area contains many different oak species, but TNC has identified three oak woodland types as priority natural systems for recovery. These include blue oak woodlands, coast live oak woodlands, and valley oak woodlands. A brief description of these woodland types is given below, along with a discussion of the climatic variables that are most important for determining the location of the woodland types.

The range of the various types of oak woodland is determined by the seasonal temperature extremes and, perhaps more importantly, the annual amount of precipitation (Pavlik et. al., 1991; McBride and Mossadegh, 1990). Certain oaks cannot withstand the long hot dry summers found in the lower elevations near the Central Valley, while other oaks cannot withstand the prolonged freezing temperatures found at the higher elevations.

Oaks have also developed a variety of adaptations to the seasonal variability in precipitation that is characteristic of the Mediterranean climate. Some oaks are able to survive and out-compete other species in areas with very little annual precipitation, while other oaks require much more water and thrive in wetter areas. Thus, three climatic variables most important for determining the distribution of the various oak woodland types are: (1) average summer temperature, (2) average winter temperature, and (3) annual precipitation.

Blue Oak Woodland

Blue oak woodlands are dominated by blue oaks (*Quercus douglasii*), but they can also contain coast live oak (*Quercus agrifolia*) in the Coast Range and California juniper (*Juniperus californica*) in the interior of the state. Blue oaks are also prevalent in blue oak/ foothill pine woodlands. Blue oaks are broad-leaved trees that are typically 5 to 15 m (16 to 50 ft) tall and form open savanna-like stands. Some blue oak individuals can reach 25 m (82 ft) tall. Of all the California oaks, blue oaks are the best adapted to hot dry conditions (Ritter, CDF).

Many rare and endangered species rely on blue oak woodlands for habitat. According to the California Wildlife Habitat Relationships (CWHR, http://www.dfg.ca.gov/whdab/html/cwhr.html), 63 rare, threatened, and endangered species utilize blue oak woodlands for one or more life stages in the six counties that contain the Mount Hamilton Project Area (Alameda, Merced, San Benito, San Joaquin, Santa Clara, and Stanislaus counties). These include the kit fox (*Vulpes macrotis*), mountain lion (*Puma concolor*), Alameda whipsnake (*Masticophis lateralis*), the burrowing owl (*Athene cunicularia*) and many more species. Appendix A provides a full list of all of the rare, threatened, and endangered species found in blue oak, valley oak, and coast live oak woodlands.

Climatic Adaptations and Sensitivities

Blue oaks have developed several unique traits that allow them to survive in conditions that are too hot and dry for other oak species. First, blue oak acorns germinate whenever conditions are favorable, instead of waiting till the spring to become active, as do the acorns from other oak species. The cool October rains stimulate blue oak root growth. This gives the roots a competitive advantage because they are able to grow deeper before the roots of grasses and other plants start growing in the spring. Blue oaks tend to have a higher proportion of root biomass to total biomass compared with other oak species. They also have smaller leaves that are covered in a waxy coating. This waxy coating gives the leaves a bluish appearance and is the reason for the species common name (Pavlik et. al., 1991).

During periods of seasonal drought, blue oaks fortify their leaves with cellulose and lignin (a chemical component of wood) to withstand the stresses imposed by dehydration. Blue oaks are normally winter deciduous, but they are able to drop their leaves during periods of extended droughts. This is a rare trait among all oak species worldwide. After dropping its leaves, the tree is dormant, but will sprout new leaves and shoots with the arrival of the fall rains. These adaptations to California’s Mediterranean and variable climate have allowed blue oaks to dominate over half of the oak covered land in the state (Pavlik et. al., 1991).

Despite these adaptations, blue oak woodlands have had low reproduction (recruitment) rates since the early 1900s. Changes in land use, damage to seedlings from grazing animals and insects, and competition from non-native species have been cited as causes for the lack of young blue oak seedlings (Ritter, CDF). Blue oak seedlings survive best in the shade of older oaks, so as the woodlands become thinner and thinner, seedling survival drops (Swiecki and Bernhardt, 1998). Concern for the long term survival of these woodlands has prompted TNC to make them a high priority natural system for conservation.

Habitat and Range

Blue oaks typically inhabit thin, poorly developed soils. They can survive in areas with 38 to 90 cm (15 to 35 in) of annual precipitation, and in areas where the midday temperature exceeds 38° C (100° F). Blue oak woodlands are typically found below 3,500 feet in elevation (Pavlik et. al., 1991). Their general range is shown in Figure 3-6.

Regression Analysis

As discussed in Chapter 2, a spatial regression analysis was conducted to determine the relevant variables that influence the location of each woodland type compared to other oak woodland types. This analysis focused only on oak woodland habitat, not the state as a whole. Thus, the regression results should be interpreted as the influence of each variable in determining where blue oak woodland will be found relative to the other types of oak woodland.

Table 3-3 provides the logistic regression analysis results for blue oak woodlands. The coefficient column refers to the increase or decrease in likelihood of finding blue oak woodlands given a one unit increase in the climatic variable. The significance column indicates the probability that the coefficient is zero (i.e., the climatic variable has no explanatory power in determining blue oak woodland distribution). The probability column is the same as the coefficient, but it expresses the likelihood in a percentage terms. Finally, the Nagelkerke R^2 gives an indication of how much the variables included explain the spatial variation in the distribution of blue oak woodland.

Table 3-3: Blue Oak Woodland Binary Logistic Regression Results

Climatic Variable	*Coefficient*	*Significance*	*Probability*
Winter Temperature (°C)	-0.18	0.00	-17%
Summer Temperature (°C)	0.28	0.00	32%
Annual Precipitation (cm)	-0.04	0.00	-4%
Nagelkerke R^2	*31%*		

The results presented in Table 3-3 agree with the climatic adaptations mentioned above. Compared to other oak woodlands, blue oaks are best adapted to hotter drier climates. As shown in Table 3-3, a 1° C increase in temperature means there is a 32% greater chance of finding blue oak woodlands compared to other types of woodlands. Also, for a one centimeter increase in precipitation, there is a 4% less chance of finding blue oak woodland. Interestingly, the winter temperature coefficient is negative, perhaps indicating that blue oaks survive best in more variable climates. The Nagelkerke R^2 indicates that the three climatic variables explain roughly 31% of the variation in the distribution of blue oak woodlands.

Coast Live Oak Woodland

Coast live oak woodlands are dominated by coast live oak (*Quercus agrifolis*) and are typically found within 80 km (50 mi) of the ocean. Fog from the ocean gives the oaks relief from the summer heat, but they typically are found outside of the range of the salt spray. Coast live oaks can commonly live for 250 years or more, and the largest individuals have crowns that spread 40 m (130 ft). Appendix A provides a full list of all of the rare, threatened, and endangered species found in blue oak, valley oak, and coast live oak woodlands.

Climatic Adaptations and Sensitivities

Coast live oaks have a specialized root system with a deep tap roots and tiered feeder roots that can collect moisture at several different levels in the soil. The evergreen leaves have a waxy cuticle, similar to the blue oaks, that protect against desiccation. The size and shape of the leaves also vary on the inner and outer shells of each tree's canopy to maximize photosynthesis and reduce moisture loss (De Rome, 1997).

Fire plays a key role in coast live oak ecology. The adult trees have thick bark that protects them from small fires. In the event of a large catastrophic fire, all of the above ground biomass might be lost, but the root crown is able to re-sprout. This gives the coast live oak an advantage to repopulate an area before other pioneer species take root (De Rome, 1997).

Habitat and Range

Coast live oak woodlands stretch north and south along California's coastline (see Figure 3-6). Mean annual precipitation varies from 100 cm (40 in) in the north to 38 cm (15 in) in the southern and interior regions. Mean winter temperatures range from 2° to 7° C (29° to 44° F) and summer temperatures range from 24° to 36° C (75° to 96° F). Coast oak woodlands survive on a variety of soil types, but most are moderately well drained and moderately deep (Holland, CDF).

Regression Analysis

Table 3-4 provides the logistic regression results for the distribution of coast live oak woodlands, relative to other oak woodland types.

Table 3-4: Coast Live Oak Woodland Binary Logistic Regression Results

Climatic Variable	*Coefficient*	*Significance*	*Probability*
Winter Temperature (°C)	0.64	0.00	90%
Summer Temperature (°C)	-0.52	0.00	-41%
Annual Precipitation (cm)	0.002	0.00	0.2%
Nagelkerke R^2	*49%*		

Table 3-4 indicates that all three of the climatic variables are significantly different than zero and thus help to explain the distribution of coast live oak woodlands. Coast live oak woodland appears to prefer climates with less seasonal variation in temperature when compared to other oak woodlands. An increase in winter temperature makes it 90% more likely to find coast live oak woodlands, while an increase in summer temperature makes it 41% less likely, holding all else constant. Annual precipitation is a significant variable, but an increase in 1 cm only makes it 0.2% more likely to find coast live oak woodlands, so the impact is not large. The large R^2 indicates that the distribution of coast live oak woodlands is quite dependent on these three climatic variables.

Valley Oak Woodland

Valley oak woodlands are dominated by valley oaks (*Quercus lobata*) and are typically found in the thick alluvial soils of valley bottoms. The thick soils give the valley oaks access to a steady water supply and allow them to grow to great heights (over 30 m or 100 ft tall) and live for 400 to 600 years (Pavlik et. al., 1991). However, in the central coast and in the Mount Hamilton project area, valley oaks are also found on ridges and on hill-slopes (R. Cox, personal communication, 2005). Because of their age and stature, Bruce Pavlik refers to the valley oak as the monarch of California oaks (1991). Appendix A provides a full list of all of the rare, threatened, and endangered species found in valley oak woodlands.

Climatic Sensitivities and Adaptations

Valley oaks thrive when they have access to a permanent water supply. Young valley oaks have an unbranched tap root that can reach down 50 to 60 feet to find ground water. As the oak matures, it develops a tiered root system with feeder roots that access water in each layer of the soil profile. With thick enough soils and an accessible ground water table, valley oaks can withstand high summer temperatures. However, they thrive in relatively moist environments such as riparian zones (Pavlik et. al., 1991).

Many valley oaks are dependent on groundwater supply. If this water supply is diminished from human pumping of groundwater or from climate change, the valley oaks can decline or die (Pavlik et. al., 1991).

Habitat and Range

Valley oaks once covered much of the Central Valley floor and subtle slopes throughout the Coast Range. Unfortunately, the flat valley bottoms they thrive on are also sought for human urban and agricultural uses. Thus, their current habitat has been reduced to the less accessible valley floors in the Sierra foothills and the Coast Range (see Figure 3-6). Valley oaks are typically found one ridge away from the coastal fog zone. They prefer deep, rich, bottomland soils below 2,000 feet in elevation, but they can range up to 5,600 feet if the soil conditions are right (Pavlik et. al., 1991).

Many valley oaks rely on groundwater supply, which can be affected by the geology of the area, the soil type, and amount of precipitation that falls in the entire drainage basin. These oaks are going to be less affected by the precipitation where they are found, and more affected by other factors in the drainage area and underground that are difficult to model. Other valley oaks found on hillslopes and ridges are more dependent on the local precipitation regime. This variation makes it difficult to determine a statistically significant or reliable correlation between the spatial location of valley oaks and the local precipitation.

Regression Analysis

Table 3-4 provides the logistic regression results for the distribution of coast live oak woodlands, relative to other oak woodland types.

Table 3-5: Valley Oak Woodland Binary Logistic Regression Results

Climatic Variable	*Coefficient*	*Significance*	*Probability*
Winter Temperature (°C)	-0.01	0.34	-1%
Summer Temperature (°C)	-0.42	0.00	-34%
Annual Precipitation (cm)	-0.05	0.00	-5%
Nagelkerke R^2	*17%*		

As mentioned above, valley oak woodlands lose their leaves in the winter, and thus do not have some of the adaptations that other oaks have to withstand high summer temperatures. The regression analysis reflects this fact by showing an increase of 1° C in summer temperature makes it 34% less likely to find valley oak woodlands. The winter temperature variable is not significantly different from zero, indicating it may not help explain the distribution of valley oak woodlands. However, it is kept in the equation and in the climate envelope estimation later because other regression models showed a significant negative relationship with the temperature of the coldest month. Since this variable is not available for the future climate estimate, average winter temperature is used as a proxy variable.

Since valley oaks require a large supply of water, a negative coefficient for the precipitation variable is not the expected result. However, as mentioned above, valley oaks on valley bottoms rely on groundwater supplies, which are likely to be more a function the geology, soil type, and the size and rainfall in the entire drainage area, not just the specific location in the valley bottom where the trees are found. While statistically significant, the negative sign on the precipitation variable may be a biased result because other relevant variables, such as groundwater supply, are not included in the model. Unfortunately, statewide data on groundwater supply is not available at this time. In addition, valley oaks on ridges and hill-slopes will be more dependent on local precipitation. Omitted variables and variation in water sources for valley oaks help to explain the low R^2 in Table 3-5.

3.2.2 California Red-legged Frog (*Rana aurora draytonii*)

The California red-legged frog (CRLF) is the largest native frog in the western US. The body length of adults range from 40 to 130 mm in length (1.6 in to 5.1 in). The rear legs of the adults vary in color but are often red or salmon pink. The back has small black flecks and dark blotches against a brown, grey or olive background (see Figure 3-7). Two subspecies of red-legged frog have been identified in California: The northern red-legged frog (*Rana aurora aurora*) and the California red-legged frog (*Rana aurora draytonii*). This report focuses on the later because it was listed as a threatened species by the U.S. Fish and Wildlife Service (USFWS) on May 23rd, 2003, and because it is found in the Mount Hamilton project area. The USFWS also proposed a critical habitat designation for the CRLF on April 13, 2004, covering almost 4.2 million acres throughout California (See Figure 3-8) (USFWS, 2004b).

Life History and Habitat

The CRLF breeds from late November to early April. This timing is likely to ensure the water is cool enough for embryonic survival and that there is enough water for larval growth and metamorphosis (Davidson, 1996). This metamorphosis typically takes place between July and September, although more recent studies have found some larvae overwinter with new metamorphs emerging in March and April (USFWS, 2004b). Adults reach sexual maturity after 3-4 years, and can live for at least 8-10 years (Davidson, 1996).

CRLF live in a variety of habitats, as long as there is a permanent source of surface water. These habitats include ephemeral ponds, intermittent streams, seasonal wetlands, springs, seeps, permanent ponds, perennial creeks, manmade aquatic features, marshes, dune ponds, lagoons, riparian corridors, blackberry thickets, nonnative annual grasslands, and oak savannas. Nonnative bullfrogs and fishes eat and compete with CRLF, so the best habitats are free of these invasive species. Thus, intermittent streams that cannot support non-native bullfrogs and fishes, but still retain some water in pools year round, are the best remaining habitats for the CRLF. Dense riparian vegetation is also important to screen the frogs from predators and to lower water temperatures, but CRLF have been found in areas with no riparian vegetation. Stock ponds are also important man-made features that act as habitat for the CRLF (Davidson, 1996; USFWS, 2004b).

Climatic Sensitivities

CRLF are most sensitive to the presence of standing water which is directly related to the amount of precipitation. CRLF populations will proliferate during wet years and suffer steep declines during extended drought (USFWS, 2004b). However, since the CRLF is able to use man-made reservoirs and stock ponds, the relation between precipitation and suitable habitat is influenced by human actions. CRLF are also sensitive to temperature changes, especially water temperature changes. Adult CRLF stress when exposed to water temperatures of 29° C or greater and can die if exposure is chronic (Davidson, 1996). While Licht (1971) found that the northern red-legged frog will only begin breeding when the air temperature reaches 5° C, no studies have been done on the air temperature requirements for breeding for the CRLF subspecies.

One important way in which species are able to cope with a changing climate is the ability to disperse and migrate from areas with poor conditions to areas with better conditions. CRLF have been found in streams 2.9 km (1.8 mi) from their breeding sites, but they typically remain within 60 m (200 ft) of water. During the start of the wet season, CRLF individuals can travel 1.6 to 3.2 km (1 to 2 mi) through upland areas, without apparent regard to topography, vegetation type, or riparian corridors (USFWS, 2004b). This dispersal ability may allow CRLF to adapt to a changing climate better than less mobile species.

Habitat loss and alteration (from urbanization, mining, grazing, water diversions and dams), overexploitation (from harvesting in the early 1900's), and introduction of exotic predators (including bullfrogs and non-native fishes), have been significant factors in the decline of the CRLF populations. However, CRLF populations have also been declining in areas where these factors are minimal. A recent study by Davidson et. al. (2001) looked at other possible causes, including recent climate change, UV-B radiation, pesticides, and habitat alteration. Based on recent climate change, Davidson et. al. expected to find more declining populations and local extirpations in southern latitudes and at lower elevations. Using a multiple regression analysis, they actually found no clear correlation between latitude and species persistence, and actually found more individuals at lower elevations compared with higher elevations. Thus, recent increases in temperature and decreases in precipitation do not appear to be a significant cause of CRLF population declines.

Climatic Variables

Winter and spring precipitation is important for CRLF populations because this is their breeding season and when the larvae live in ponds. Freezing winter temperatures are likely to slow adult frog activity which could disrupt breeding activity. Summer and fall temperatures are important because the juvenile and adult frogs cannot survive in water that exceeds 29° C for an extended period of time. Summer and fall precipitation is also important since the species must be close to surface water at all times. However, lower precipitation may cause intermittent streams to dry up, which will cause a decline in bullfrog and non-native fish predator populations.

Regression Results

As discussed in Chapter 2, the spatial regression analyses for the T&E animal species was slightly different than for the oak woodland types. The data analyzed included all non-agricultural and non-urban land within the bioregions in which the species is found. For the CRLF, this included all of the bioregions in the state except the Mohave and Colorado Desert bioregions. Table 3-6 provides the regression results for the CRLF critical habitat.

Table 3-6: California Red Legged Frog Critical Habitat Binary Logistic Regression Results

Climatic Variable	*Coefficient*	*Significance*	*Probability*
Summer Temperature (°C)	-1.63	0.00	-80%
Fall Temperature (°C)	3.14	0.00	2207%
Winter Temperature (°C)	-1.75	0.00	-82.7%
Summer Precipitation (cm)	-1.41	0.00	-75.6%
Winter Precipitation (cm)	0.03	0.00	2.9%
Nagelkerke R^2	36%		

Holding all else constant, fall temperature appears to have the largest contribution to determining the distribution of CRLF habitat, with the frogs preferring a warmer fall. While the life history of the CRLF indicates fall temperatures are important, one would expect to see cooler temperatures predicting better CRLF habitat. Also, cooler winters appear to improve CRLF habitat, which is somewhat counter intuitive, since freezing temperatures are likely to interfere with breeding. Perhaps this relationship is not linear, as modeled here.

As expected, a cooler and drier summer makes it more likely to find CRLF. This can be explained by the importance of cooler water temperatures for CRLF survival, but also the negative impact on the CRLF predators of having streams dry up during the summer. CRLF also appear to prefer cooler and wetter winters, as predicted by their life history. The R^2 of 36% indicates these 5 variables explain over a third in the spatial variation of CRLF critical habitat.

3.2.3 California tiger salamander (*Ambystoma californiense*)

The California tiger salamander (CTS) is a large, stocky, terrestrial salamander, averaging 170 to 200 mm (7 to 8 inches) in length. The CTS are black with white or pale yellow spots (see Figure 3-7). The USFWS listed the entire CTS species as threatened on August 4, 2004, and designated critical habitat for the Central California population on August 10, 2004 (see Figure 3-8). Two other distinct population segments have been identified: The Santa Barbara County population and the Sonoma County population. However, this report focuses on the Central California population because it is the one found in the Mount Hamilton project area (USFWS, 2004a).

Life History and Habitat

CTS begin breeding during the first heavy rains of the late fall or early winter. Males typically arrive first at the breeding ponds, followed by the females. Some East Bay populations have been observed to lay eggs twice in both December and February. During years of drought, the CTS may not breed at all. Breeding habitat consists of vernal pools (seasonal pools that dry up during the summer). However, since many of the vernal pools have been destroyed in the Bay Area and Coast Ranges, including the Mount Hamilton project area, CTS rely on agricultural stock ponds for breeding habitat. CTS can breed in perennial ponds, but these ponds may support bullfrogs and other non-native predators, lowering the number of larvae that survive to breeding age (USFWS, 2004a).

CTS larvae are the top predators in vernal pool ecosystems, and they can remain in the larval stage for 3-6 months or until the vernal pool dries up. A minimum of 12 weeks of inundation is required for metamorphosis, but longer inundation periods allow for more larval growth and increase the success of the individuals once the pool dries (USFWS, 2004a).

After metamorphosis, juvenile CTS will disperse into upland grassland and oak savanna habitats. CTS cannot dig their own burrows, so they must rely on the burrows of small mammals for shelter. CTS spend the hot summer and fall months in the burrows. Upland burrows have often been referred to as “aesthevation” sites, indicating a period of inactivity, but recent studies show CTS remain active in their underground burrows (USFWS, 2004a). CTS typically reach sexual maturity after 4-5 years (Trenham et. al., 2000).

Climate Sensitivity

Vernal pool ecosystems are sensitive to changes in precipitation and temperature. For example, low rainfall in the southern San Joaquin Valley may limit the southern extent of the distribution of the CTS species (USFWS, 2004a). However, many CTS populations in the Mount Hamilton project area rely more on stock ponds and other human-enhanced wetlands that may be more stable than natural vernal pool systems. Unfortunately, certain problems, such as sedimentation, pond breaching, stock animal impacts, and berm failure, affect both natural and human-enhanced wetlands in the Mount Hamilton project area. Also, if the wetlands are perennial, they can support bullfrogs and other non-native predators that can feed on CTS larvae. Seasonal precipitation is likely an important factor in determining CTS population success (USFWS, 2004a).

Little research has been done on the impact of air temperature on CTS survival. Since the species spends the summer and fall months underground, winter and spring temperatures are likely to be more important. However, Trenham et. al. (2000)

postulated that an area 8 km south of their study site did not support CTS because of the extreme summer climate, with negligible precipitation and temperatures exceeding 35° C from June to October. Desiccation can cause mortality, but CTS are typically active at night, so daily temperature highs may not be as important as average temperatures for the day or month.

Juvenile CTS have been found 1.6 km (1 mi) from breeding sites. Most adult CTS return to the same breeding site where they hatched, but about 20% will migrate to new breeding ponds (Trenham et. al., 2000). The USFWS estimates that the majority of CTS will stay with 1.2 km (0.7 mi) of their breeding site. CTS prefer to migrate through grassland instead of forested areas or thick scrub. This may limit their ability to migrate in response to climate change.

Climatic Variables

Fall and winter precipitation are highly important for the CTS breeding season. Spring precipitation and temperature are also important because they determine how long the vernal pools stay inundated and thus how large the larvae become before metamorphosis. Summer precipitation and temperature may be important because hotter temperatures and low precipitation will tend to dry up seasonal wetlands and man-made ponds, making bullfrog and other non-native predator survival more difficult. However, high summer temperatures may cause desiccation of CTS if they are active or not deep enough in their burrows. Lower fall temperatures may be important to avoid desiccation as the adult CTS travel to ponds for breeding. Finally, winter air temperature is not likely to be as important, since the larvae are underwater for most of this season.

Regression Results

Table 3-7 shows the regression results for the CTS critical habitat relative to all non-urban and non-agricultural land in the bioregions in which the species is found. This does not include the Mohave, Colorado Desert, South Coast, Klamath/ North Coast, and Modoc bioregions.

Table 3-7: California Tiger Salamander Critical Habitat Binary Logistic Regression Results

Climatic Variable	*Coefficient*	*Significance*	*Probability*
Summer Temperature (°C)	-1.95	0.00	-86%
Fall Temperature (°C)	3.16	0.00	2247%
Winter Temperature (°C)	-2.25	0.00	-89.4%
Spring Temperature (°C)	0.86	0.00	137.0%
Summer Precipitation (cm)	-2.68	0.00	-93.1%
Fall Precipitation (cm)	0.27	0.00	30.5%
Winter Precipitation (cm)	-0.27	0.00	-23.6%
Spring Precipitation (cm)	0.39	0.00	48.0%
Nagelkerke R^2	24%		

The regression results for the CTS show an interesting pattern. The CTS appears to prefer cooler and drier summers and winters, and warmer and wetter falls and springs. This could be explained by the fact that the CTS is in burrows most of the summer and has less need for water, but could be affected if the temperature gets high enough. During the fall, the precipitation is important to begin filling the seasonal wetlands for breeding, but as with the CRLF, the high positive coefficient on fall temperature is difficult to explain. During the winter, the CTS larvae are underwater so they are not as affected by air temperature. Drier winters appear to improve habitat, which is somewhat counter intuitive. Perhaps bullfrogs are less able to survive in areas with drier winters, so the CTS are better able to survive. Wetter springs make the pools last longer and thus improve juvenile survival, and perhaps warmer springs make the juveniles more active but the temperatures do not get high enough to lead to desiccation. These 8 variables explain less than a quarter in the spatial variation of the CTS habitat, so other factors are likely to be important.

3.2.4 Bay Checkerspot Butterfly (*Euphydryas editha bayensis*)

The Bay Checkerspot Butterfly (BCB) is a medium-sized butterfly with an average wingspan of 5 cm (2 in). Its wings have black bands with bright red, yellow and white spots (see Figure 3-7). The BCB was listed as threatened in September 1987, and critical habitat was designated for the species in April 2001 (see Figure 3-8). Except under rare circumstances, each BCB generation only lives one year (USFWS, 2001). This means the entire population of the species is heavily dependent on the annual climate, and makes the BCB very sensitive to climate change.

Life History

Adult BCB emerge from pupae (a non-hairy cocoon) in early spring of each year. The adult butterflies feed, mate, and lay eggs during the brief flight season. The flight season can last 4-6 weeks, but each individual butterfly has an average life span of about 10 days. Females lay their eggs on host plant species. The BCB prefers the dwarf plantain (*Plantago erecta*) as a host species, but it will also lay eggs on the purple owl’s clover (*Castilleja densiflora*) or the exserted paintbrush (*Castilleja purpurascens).* The eggs typically hatch after 10 days (USFWS, 2001).

The emerging larvae eat the host plants and grow for the next two weeks or more during mid-late spring. As they grow, the shed their skin three times, after which they enter the fourth instar stage of development. While in the fourth instar, the larvae are able to enter a period of dormancy called diapause that lasts through the hot dry summer. The larvae in diapause are usually sheltered under rocks or in large cracks in the clay-rich soil (USFWS, 2001).

After the first rains in the fall, the larvae resume activity and feed until large enough to pupate. Occasionally, if there is not enough rain and thus not enough food during the fall, the larvae will enter a second diapause period for one or more years. During normal years, the larvae remain in the pupae stage until spring when they emerge as adult butterflies (USFWS, 2001).

Habitat

Suitable habitat for the BCB is closely tied to the suitable habitat for their host plants. Dwarf plantain is an annual native plant that is typically found in shallow, serpentine-derived or similarly droughty or infertile soils. Serpentine soils are high in magnesium and low in calcium and are toxic to many introduced plant species. Thus, they have become a refuge for the native plants that have adapted to their unique chemistry. While BCB prefers serpentine soils habitat, populations are also found in areas with no serpentine, so these soils are not essential to the BCB survival (USFWS, 2001).

Topographic heterogeneity is another important characteristic of BCB habitat. During hot dry years, the BCB populations shrink and take refuge on the cooler north-facing slopes in hilly terrain. During wetter and cooler years, the populations are able to expand to the south facing slopes. A long term study conducted by McLaughlin et. al. (2002) found that a BCB population in a topographically complex region was able to withstand climatic fluctuations much better than a population found on in a flatter area.

Climatic Sensitivity

BCB survival is closely tied to the date when their host species dry up. Most BCB mortality occurs during the spring larvae stage. In dry years, the dwarf plantain species dry up (senesce) early in the spring. If this happens before the larvae have shed its skin for the last time, the larvae will not be able to enter diapause and will die during the summer. The host plants from the Castilleja family typically senesce later than the plantain. If these plants are nearby, the larvae will move to the longer lasting species and have a better chance of survival. However, the Castilleja species are distributed in patches across the typical BCB habitat, so these alternate host plants may not be available to every larva (Hellmann, 2002). BCB are also sensitive to too much precipitation. Larvae survive better in sunny conditions, so if there is too much rain, the larvae population fall, even though there is plenty of food from the host plants. Thus, years with average or slightly above average rainfalls are the best for the BCB survival (McLaughlin, 2002).

Temperature is important to BCB survival as well as precipitation. Hellmann (2002) conducted a controlled experiment with two separate BCB host plants and larvae populations in two greenhouses at Stanford University. The air temperature in one greenhouse was controlled to simulate the typical temperature found in natural BCB habitat, while the air temperature in the other greenhouse was increased to 3.3° C (5.9° F) above normal. Hellmann found that the larvae that could only access the dwarf plantain host plants died more quickly in the hotter greenhouse because the host plants dried up more quickly. However, the larvae in the hotter greenhouse had a survivorship advantage when they were able to move to the longer lasting Castilleja host plants compared to the counterpart larvae in the cooler greenhouse. This means that higher temperatures actually improve BCB larvae survival, as long as there is enough food from the host plants (Hellman, 2002).

BCB are able to disperse to a limited extent to adapt to climate changes. As mentioned above, BCB populations will move from warm south-facing slopes to cooler north-facing slopes depending on the annual climate. During the flight season, biologists have observed adults typically dispersing 150 m (490 ft). In more detailed mark and recapture studies, about 5% of the population was observed to travel 1 km (0.6 mi) or more. The longest documented travel distance was 7.6 km (4.7 mi). Populations can also change location over time, as long as suitable stepping-stone habitat is found along the way. Studies indicate that BCB move rapidly over suitable grassland habitat, but are more reluctant to cross scrub, woodland, or other unsuitable habitat. Roads with fast moving cars also present a formidable barrier to the delicate butterflies (USFWS, 2001).

Climatic Variables

Based on the BCB life history and climatic sensitivity, precipitation and temperature during the spring and fall are climatic variables most likely to impact the quality of the BCB habitat. The timing of the first rains in the fall and the last rains in the spring is also essential for larval growth. Summer and winter climate is not as important since the species is in diapause and pupae stages, respectively, and thus somewhat sheltered from the weather. However, the amount of winter rains is likely to be important for the number and distribution of host plants.

Regression Results

Table 3-8 shows the regression results for the BCB critical habitat relative to all non-urban and non-agricultural land in the Bay Area/ Delta and South Central Coast bioregions.

Table 3-8: Bay Checkerspot Butterfly Critical Habitat Binary Logistic Regression Results

Climatic Variable	*Coefficient*	*Significance*	*Probability*
Fall Temperature (°C)	-20.06	0.00	-100%
Winter Temperature (°C)	2.40	0.00	999%
Spring Temperature (°C)	13.85	0.00	>1000%
Fall Precipitation (cm)	2.23	0.00	828.2%
Winter Precipitation (cm)	-1.87	0.00	-84.6%
Spring Precipitation (cm)	1.13	0.00	210.5%
Nagelkerke R^2	46%		

The distribution of BCB habitat is significantly impacted by seasonal temperature. Summer temperature and precipitation were excluded from the model because the BCB larvae are in diapause during the summer. All else being equal, BCB prefer cooler fall temperatures, and warmer winter and spring temperature. A preference for a warmer spring temperature is consistent with the finding that holding precipitation constant, larvae survive better with warmer spring conditions, as long as alternate host plants are available. The negative coefficient on the fall temperature variable is interesting, because the BCB larvae are active during the fall, so one would expect the same results as with the spring. Since BCB larvae spend most of the winter in the pupae stage, winter air temperature is not likely to be important, but it is significant in this model.

As expected, the more fall and spring precipitation an area receives, the more likely it is to support the BCB habitat. The winter precipitation coefficient is negative, but this may be related to other variables such as temperature. This regression analysis shows that several climatic variables are very important in determining the location where BCB can survive.

3.3 Climate Envelope Analysis

Based on existing research and other modeling efforts, the current and future climate of the Mount Hamilton project area can be estimated. The relevant and important climatic variables for each natural system and species have also been analyzed. Next, the ranges of the variables for each species are estimated based on the current habitat distribution. With this information, the spatial extent of the climatically suitable habitat for current and future conditions (i.e., climate envelopes) can be estimated. The result of this analysis is presented below.

3.3.1 Oak Woodland Climate Envelopes

Table 3-9 presents the ranges of each relevant climatic variables based on the current statewide and local extent of each woodland type. Table 3-10 presents the same information in English units.

Table 3-9: Climatic Variable Ranges for Oak Woodland Types (Metric)

	Winter Temperature (°C)			Summer Temperature (°C)			Annual Precipitation (cm)		
	Mean	Low	High	Mean	Low	High	Mean	Low	High
Statewide Ranges									
Blue Oak \ Foothill Pine	7.1	4.3	10.0	22.3	18.1	26.4	79.2	33.5	124.8
Blue Oak Woodland	7.2	2.2	12.2	21.2	15.0	27.4	74.5	14.0	135.0
Coast Live Oak Woodland	8.4	4.0	12.7	17.8	13.9	21.6	85.2	15.5	154.9
Valley Oak Woodland	7.4	3.0	11.8	18.0	13.4	22.6	65.4	14.7	116.0
Local Ranges									
Blue Oak \ Foothill Pine	7.0	5.2	8.8	20.1	17.7	22.4	49.2	34.1	64.4
Blue Oak Woodland	7.2	4.7	9.6	20.1	17.3	22.8	46.9	28.6	65.2
Coast Live Oak Woodland	8.3	5.4	11.2	19.0	16.5	21.5	55.0	35.3	74.6
Valley Oak Woodland	6.9	4.9	8.8	19.1	17.3	20.8	55.0	44.3	65.6

Table 3-10: Climatic Variable Ranges for Oak Woodland Types (English)

	Winter Temperature (°F)			Summer Temperature (°F)			Annual Precipitation (in)		
	Mean	Low	High	Mean	Low	High	Mean	Low	High
Statewide Ranges									
Blue Oak \ Foothill Pine	44.8	39.7	50.0	72.1	64.6	79.5	30.9	13.1	48.7
Blue Oak Woodland	44.9	35.9	53.9	70.1	58.9	81.3	29.1	5.5	52.8
Coast Live Oak Woodland	47.1	39.3	54.8	64.0	57.0	70.9	33.3	6.0	60.5
Valley Oak Woodland	45.4	37.4	53.3	64.4	56.1	72.6	25.5	5.7	45.3
Local Ranges									
Blue Oak \ Foothill Pine	44.7	41.4	47.9	68.1	63.9	72.3	19.2	13.3	25.1
Blue Oak Woodland	44.9	40.5	49.3	68.1	63.2	73.1	18.3	11.2	25.5
Coast Live Oak Woodland	46.9	41.7	52.1	66.2	61.8	70.6	21.5	13.8	29.2
Valley Oak Woodland	44.3	40.8	47.8	66.3	63.1	69.5	21.5	17.3	25.6

Tables 3-9 and 3-10 show the average, low, and high value for each of the three climatic variables most important for oak distribution (winter temperature, summer temperature, and annual precipitation). The vegetation classification used in the FRAP GIS layer contained two types of blue oak woodland, so the climate ranges for both are presented here. Interestingly, the blue oak woodland can withstand both the highest average summer temperatures (27.4 °C or 81.3° F) and the lowest average winter temperatures (2.2° C or 35.9° F). Blue oak woodland also requires the least amount of annual precipitation (14 cm or 5.5 in). These adaptations probably help to explain why it is the most prevalent oak species in California. Blue oak/ foothill pine woodlands have similar temperature tolerances, but on average require more precipitation. However, since the blue oak woodland ranges are greater than and thus incorporate the blue oak/ foothill pine ranges, only blue oak woodland figures will be used for climate envelope analysis.

On average, coast live oak woodlands require the most precipitation and have the tightest range of suitable temperatures. However, as mentioned above, the results for valley oak woodland precipitation requirements may be somewhat misleading because many valley oaks rely heavily on alluvial soils and groundwater supplies. The local climate envelopes are also provided to show the range of temperature and precipitation found for each woodland type in the Mount Hamilton project area. In general, these ranges of these climate envelopes are smaller than statewide envelopes. This could reflect the fact that the climatic variation within the Mount Hamilton project area is less than all the variation found for all oak woodlands statewide. It also could reflect the fact that the local populations have adapted to more specific climatic conditions than the statewide species.

Figures 3-9 through 3-11 show the calculated climate envelopes based on the ranges of climate tolerances listed above. These figures show the current extent of each woodland type, and the combination of both the current climate envelope and the future climate envelope. This is done so quick comparisons can be made between the current conditions and the future conditions. Areas shown in white indicate areas that are not climatically suitable habitat in either the current or future climate conditions. These areas, called “Not habitat” on the maps, are locations where the current and future climate conditions fall outside the ranges of one or more of the climatic variables listed in Tables

3-9 and 3-10. Areas in red currently fall within the climatic variable ranges, but based on the future climate, they fall outside one or more of these ranges. The interpretation of these areas is that they can currently support the species, but will no longer be viable habitat in the future. Areas in green satisfy all of the climatic restrictions in both the current and future climate scenarios and thus are prime habitat for preservation. Areas in yellow are not currently habitat, but could become suitable habitat based on projected future climate conditions. For example, these areas may be too cold now for a certain woodland type, but with global warming, they could support the woodland type in the future. These areas will only become occupied by the oak species if the oaks are able to migrate from their current locations to reach the newly suitable habitat. Additional information about migration rates of oak species is presented in the Discussion chapter.

Figures 3-9 through 3-11 each have two separate panels. The first shows the climate envelopes based on the statewide tolerances of each woodland type. The second shows the climate envelopes based on the climate tolerances of the populations found within the local Mount Hamilton project area. In general, the local envelopes are smaller in extent than the statewide envelopes, reflecting the smaller ranges shown in Tables 3-9 and 3-10. Finally, Figures 3-9 through 3-11 show the current extent of each woodland type in black cross-hatches. This gives the reader an idea of which areas that are currently occupied by the woodland will be lost based on future climate conditions.

Blue Oak Climate Envelopes

Figure 3-9 shows the local and statewide climate envelopes for blue oak woodlands. The cross-hatching shows the extent of both blue oak woodland and blue oak/ foothill pine woodland. Since blue oaks are so well adapted to hot dry climates statewide, the first panel of Figure 3-9 shows that little if any areas that currently support blue oaks will be lost. This can be seen because all of the area covered by cross-hatching is also green, meaning it is both current and future habitat. However, if the local populations of blue oak in the Mount Hamilton range are less adapted to hot climates than the other populations statewide, the result of climate change may resemble what is shown in the second panel of Figure 3-9. Much of the cross-hatched areas become red, indicating that the future climate will either be too hot or too dry for the blue oaks. This area will likely be converted to grassland or shrub-land. Blue oaks will instead be restricted to the areas of higher elevation, much of which is not currently occupied by the species.

Another important impact shown in the local envelope panel in Figure 3-9 is the loss of contiguity in climatically suitable habitat with climate change. The large red area of currently suitable habitat is relatively contiguous across the entire study area. However, the green areas indicating habitat that is projected to be climatically suitable in the future is separated into two distinct areas. Since they are geographically separated by unsuitable habitat, these two areas could function as islands, with little genetic mixing between the two populations. This could reduce the genetic diversity in the local populations and make them less able to adapt to future changes in their environment.

Table 3-11 quantitatively presents the same information as Figure 3-9. The top half of the table compares the sizes of the climate envelopes of suitable habitat with the total size of the Mount Hamilton project area, while the bottom half of the table compares the predicted amount of current and future habitat with the total amount of currently occupied habitat.

Table 3-11: Blue Oak Woodland Climate Envelope Comparison

	Statewide		Local	
	Area (km^2)	% of Total	Area (km^2)	% of Total
Total Mount Hamilton Project Area	6,173		6,173	
Current Suitable Habitat Envelope	6,165	100%	5,055	82%
Future Suitable Habitat Envelope	5,574	90%	1,796	29%
Current and Future Suitable Habitat	5,566	90%	1,770	29%
Suitable Habitat Lost	599	10%	3,285	53%
Suitable Habitat Gained	8	0%	26	0%
Not Suitable Habitat	0	0%	1,092	18%
Area Occupied	1,717	28%	816	13%
	Area (km^2)	% of Occupied	Area (km^2)	% of Occupied
Current and Future Habitat (Occupied)	1,717	100%	364	45%
Lost Habitat (Occupied)	0	0%	445	55%
New Habitat (Occupied)	0	0%	3	0%
Not Habitat (Occupied)	0	0%	4	0%

Table 3-11 clearly highlights the difference between the statewide climate envelope estimation method and the local method. The climate envelopes are smaller using the local method, and the amount of suitable habitat lost is significantly greater (3,285 km^2 compared to 600 km^2). Table 3-11 also quantifies the portions of the suitable habitat that are currently occupied and compares that with the portions that will be suitable in the future. Based on the statewide method, all of the currently occupied habitat will be suitable in the future, but only 45% or 364 km^2 will be suitable using the local method. This 45% reduction does not account for the loss in habitat contiguity mentioned above. It is difficult to assess which estimation is better without detailed genetic studies of the local Mount Hamilton blue oak population compared with the statewide population.

However, the actual amount of habitat that will be lost is likely to fall somewhere in between the results of the statewide and local methods.

Coast Live Oak Woodland Climate Envelopes

Figure 3-10 shows the climate envelopes and current distribution of coast live oak woodland. The colors and symbols used are the same as in Figure 3-9. The cross-hatch pattern shows that costal oak woodlands are found on the western ocean side of the Mount Hamilton range, and are rarely found on the drier eastern side facing the Central Valley. The calculated climate envelopes follow this pattern with most of the suitable habitat in the western portions of the Mount Hamilton project area. Interestingly, both the statewide and local envelope estimation methods show similar patterns of current and future habitat, indicating that the local population of coast live oak is not likely to be genetically much different than the statewide population. The amount of red on both panels in Figure 3-10 show that much of the suitable habitat will be lost due to future climate change. This is especially true in the southern portion of the project area. While there is a lot of green in the higher elevations, much of this area is not currently occupied. These areas may not become occupied since oak species have trouble migrating uphill, especially during a 100-year timeframe. Additional information about oak migration is presented in the Discussion chapter.

Table 3-12 shows a quantitative estimate of the climate envelope comparison for coast live oak woodlands.

Table 3-12: Coast Live Oak Woodland Climate Envelope Comparison

	Statewide		Local	
	Area (km^2)	% of Total	Area (km^2)	% of Total
Total Mount Hamilton Project Area	6,173		6,173	
Current Suitable Habitat Envelope	5,032	82%	4,695	76%
Future Suitable Habitat Envelope	1,674	27%	1,128	18%
Current and Future Suitable Habitat	1,674	27%	1,020	17%
Suitable Habitat Lost	3,358	54%	3,675	60%
Suitable Habitat Gained	0	0%	108	2%
Not Suitable Habitat	1,141	18%	1,370	22%
Area Occupied	1,088	18%	1,088	18%
	Area (km^2)	% of Occupied	Area (km^2)	% of Occupied
Current and Future Habitat (Occupied)	555	51%	331	30%
Lost Habitat (Occupied)	525	48%	694	64%
New Habitat (Occupied)	0	0%	29	3%
Not Habitat (Occupied)	8	1%	34	3%

Table 3-12 shows that a large amount of suitable habitat is lost with predicted climate change (3,675 km^2 or 64% of the project area based on the local envelope method). Much of this lost habitat is currently occupied (694 km^2). In other words, between 48% and 64% of the habitat that is currently occupied by blue oak woodland is likely to become unsuitable with global climate change.

The last two rows in table 3-12 present an estimate of the accuracy of the envelope prediction methods. They show areas that are currently occupied (and thus clearly habitat suitable for coast live oak) but that are not inside the current climate envelope ("New Habitat (Occupied)"), or are not in either the current or future climate envelopes ("Not Habitat (Occupied)"). For example, the local envelope estimation inaccurately identified a total of 63 km^2 as not current habitat (29 km^2 plus 34 km^2). The statewide method did a little better and only missed 8 km^2.

Valley Oak Woodland Climate Envelopes

Figure 3-11 shows the climate envelopes for valley oak woodlands. The lack of cross-hatching shows that this woodland type is rare in the Mount Hamilton project area. The local climate envelopes are much smaller that the statewide envelopes, perhaps reflecting the small distribution in the project area. Based on the statewide method, much of the currently occupied habitat will remain habitat in the future. Based on the local method, some of the lower elevation woodlands will be lost.

Table 3-13 shows the extent of the valley oak woodlands and climate envelopes.

Table 3-13: Valley Oak Woodland Climate Envelope Comparison

	Statewide		Local	
	Area (km^2)	% of Total	Area (km^2)	% of Total
Total Mount Hamilton Project Area	6,173		6,173	
Current Suitable Habitat Envelope	5,747	93%	2,570	42%
Future Suitable Habitat Envelope	3,093	50%	318	5%
Current and Future Suitable Habitat	3,093	50%	298	5%
Suitable Habitat Lost	2,654	43%	2,272	37%
Suitable Habitat Gained	0	0%	20	0%
Not Suitable Habitat	426	7%	3,583	58%
Area Occupied	192	3%	192	3%
	Area (km^2)	% of Occupied	Area (km^2)	% of Occupied
Current and Future Habitat (Occupied)	151	79%	38	20%
Lost Habitat (Occupied)	41	21%	105	55%
New Habitat (Occupied)	0	0%	1	1%
Not Habitat (Occupied)	0	0%	48	25%

Table 3-13 highlights the differences between the statewide and local estimation techniques, since the size of the future suitable climate envelope varies by a factor of ten (3,093 km^2 statewide and 318 km^2 local). However, it is possible that the local populations of valley oaks have been isolated from the other populations for long enough that they are genetically different, meaning the local method better predicts the fate of the valley oaks. Table 3-13 also shows that between 21% and 55% of the occupied habitat is likely to become unsuitable for valley oaks over the next 100 years. However, certain caution should be exercised in interpreting the results, since the local estimation technique missed 49 km^2 or 26% of the occupied habitat.

3.3.2 T&E Animal Species Climate Envelopes

The climate envelopes for the T&E animal species are calculated and presented in a manner almost identical to the oak woodland climate envelopes. However, only the statewide estimation technique was used, since many these T&E animal species have higher mobility and are already defined as sub-species and distinct populations by the USFWS.

Table 3-14 (Metric) and Table 3-15 (English) presents the mean, high, and low values for the climatic variables observed in each of the T&E species critical habitat.

Table 3-14: Climatic Variable Ranges for T&E Animal Species (Metric)

	California Red-Legged Frog			California Tiger Salamander			Bay Checkerspot Butterfly		
	Mean	*Low*	*High*	*Mean*	*Low*	*High*	*Mean*	*Low*	*High*
Average Summer Temp. (C)	19.3	15.2	22.9	22.0	16.4	26.3	*19.4*	*16.7*	*20.2*
Average Fall Temp. (C)	15.0	11.3	17.2	16.5	13.3	18.5	15.7	14.8	16.4
Average Winter Temp. (C)	8.4	3.4	12.1	8.7	6.2	10.5	9.3	8.3	10.3
Average Spring Temp. (C)	*12.7*	*8.3*	*15.2*	14.6	10.3	16.8	13.9	12.6	14.8
Average Annual Temp. (C)	*13.9*	*10.3*	*16.0*	*15.5*	*12.0*	*17.7*	*14.6*	*13.5*	*15.4*
Total Summer Precip. (cm)	0.8	0.2	3.2	0.6	0.2	1.0	*0.6*	*0.5*	*1.0*
Total Fall Precip. (cm)	12.0	5.7	29.1	9.6	5.5	13.1	10.2	8.5	16.6
Total Winter Precip. (cm)	*36.8*	*17.9*	*70.3*	25.9	15.3	42.2	27.6	23.3	43.3
Total Spring Precip. (cm)	*17.8*	*8.9*	*37.9*	13.6	8.2	18.9	14.2	12.3	20.7
Total Annual Precip. (cm)	*67.3*	*33.1*	*137.3*	*49.6*	*29.4*	*72.9*	*52.6*	*44.6*	*81.6*

** Figures in italics are not used climate envelope estimation*

Table 3-15: Climatic Variable Ranges for T&E Animal Species (English)

	California Red-Legged Frog			California Tiger Salamander			Bay Checkerspot Butterfly		
	Mean	*Low*	*High*	*Mean*	*Low*	*High*	*Mean*	*Low*	*High*
Average Summer Temp. (F)	66.8	59.3	73.2	71.5	61.6	79.3	*66.9*	*62.1*	*68.4*
Average Fall Temp. (F)	59.0	52.4	62.9	61.7	56.0	65.3	60.2	58.6	61.6
Average Winter Temp. (F)	47.2	38.1	53.8	47.7	43.1	50.8	48.8	46.9	50.5
Average Spring Temp. (F)	*54.9*	*46.9*	*59.3*	58.2	50.5	62.2	56.9	54.8	58.7
Average Annual Temp. (F)	*57.0*	*50.6*	*60.9*	*59.8*	*53.7*	*63.9*	*58.2*	*56.4*	*59.7*
Total Summer Precip. (in)	0.3	0.1	1.2	0.2	0.1	0.4	*0.2*	*0.2*	*0.4*
Total Fall Precip. (in)	4.7	2.2	11.4	3.7	2.2	5.1	4.0	3.3	6.5
Total Winter Precip. (in)	*14.4*	*7.0*	*27.4*	10.1	6.0	16.5	10.8	9.1	16.9
Total Spring Precip. (in)	*6.9*	*3.5*	*14.8*	5.3	3.2	7.4	5.6	4.8	8.1
Total Annual Precip. (in)	*26.3*	*12.9*	*53.6*	*19.4*	*11.5*	*28.5*	*20.5*	*17.4*	*31.9*

** Figures in italics are not used climate envelope estimation*

Tables 3-14 and 3-15 show the CTS critical habitat is found in the areas with the highest average annual and summer temperatures and lowest annual precipitation. CRLF can endure the lowest range of winter temperatures (3.4° C or 38.1° F). The BCB requires the most low-range annual precipitation (44.6 cm of 17.4 in) of all three species.

CRLF Climate Envelopes

As shown in Figure 3-8 above, the CRLF has the widest statewide distribution of the three T&E animal species in this analysis. This adaptability also results in the largest climate envelopes, as shown in Figure 3-12. Most of the Mount Hamilton project area is currently suitable for the CRLF, but much of it could become unsuitable with climate change, as shown by the large amount of red in Figure 3-12. The green areas show that the species is likely to become isolated in three distinct population areas separated by inhospitable habitat. As discussed in the blue oak section above, this removal of contiguity could reduce the genetic mixing between populations which may make them less able to adapt to future stresses like new diseases, predators, or additional climate change. Some of the green areas are not covered in cross-hatching, while much of the red area is, indicating that the CRLF will have to migrate in order to maximize the remaining habitat. The dispersal information presented above indicates this is possible, provided the rate of climate change is relatively smooth and not step-wise and abrupt.

Table 3-16 shows the CRLF climate envelope information expressed in terms of areas and percentages.

Table 3-16: CRLF Climate Envelope Comparison

	Statewide	
	Area (km^2)	% of Total
Total Mount Hamilton Project Area	6,173	
Current Suitable Habitat Envelope	5,885	95%
Future Suitable Habitat Envelope	1,826	30%
Current and Future Suitable Habitat	1,813	29%
Suitable Habitat Lost	4,072	66%
Suitable Habitat Gained	13	0%
Not Suitable Habitat	275	4%
Area Occupied	2,901	47%
	Area (km^2)	% of Occupied
Current and Future Habitat (Occupied)	994	34%
Lost Habitat (Occupied)	1,846	64%
New Habitat (Occupied)	1	0%
Not Habitat (Occupied)	60	2%

Table 3-16 shows that most of the project area is in the current climate envelope, but only 30% is in the future climate envelope. Roughly 1,846 km^2 (64%) of occupied habitat will become unsuitable with climate change, however roughly 800 km^2 of currently unoccupied habitat will be suitable if the species can migrate in time and if the area has the other necessary habitat requirements (surface water, few predators, etc.).

CTS Climate Envelopes

Figure 3-13 shows the combination of current and future climate envelopes for the CTS. As with the CRLF, much of the lower elevation habitat will become unsuitable with climate change. However, certain high elevation areas that are not currently suitable habitat are likely to become climatically suitable (yellow areas on the map). Certain populations in the current distribution of CTS appear like they could migrate in response to climate change, since the lower portions of the habitat is in the red while the upper portions are in the green and yellow. However, natural and man-made barriers may restrict this movement. For example, populations in the central west side of the Mount Hamilton project area would have to cross a freeway and the urbanized and agricultural land in the Santa Clara valley in order to reach the future climatically suitable habitat since the habitat directly upslope is unsuitable. CTS prefer grasslands for dispersal, so this dangerous migration is not likely.

Table 3-17 presents the quantitative information regarding the CTS climate envelope comparison.

Table 3-17: CTS Climate Envelope Comparison

	Statewide	
	Area (km^2)	% of Total
Total Mount Hamilton Project Area	6,173	
Current Suitable Habitat Envelope	5,290	86%
Future Suitable Habitat Envelope	2,618	42%
Current and Future Suitable Habitat	1,996	32%
Suitable Habitat Lost	3,294	53%
Suitable Habitat Gained	622	10%
Not Suitable Habitat	261	4%
Area Occupied	343	6%
	Area (km^2)	% of Occupied
Current and Future Habitat (Occupied)	100	29%
Lost Habitat (Occupied)	197	57%
New Habitat (Occupied)	44	13%
Not Habitat (Occupied)	2	1%

Table 3-17 shows that the amount of climatically suitable habitat drops from 83% of the Mount Hamilton project area to 32% with climate change. While 261 km^2 of new climatically suitable habitat is gained, it is not enough to offset the 3,294 km^2 lost. Of the 343 km^2 of occupied habitat, 197 km^2 or 57% is likely to be lost over the next 100 years. Table 3-17 also shows that the current model missed about 46 km^2 or 14% of the occupied habitat, although it estimated most of it would be future habitat.

BCB Climate Envelopes

Figure 3-14 shows the current and future climate envelopes for the BCB. Both the current and future climate envelopes are smaller for the BCB than any other species or natural community analyzed. This is likely a combination of the fact that the species is so vulnerable to climatic conditions, as mentioned above, and because its current range has been reduced to such a small area. Another interesting feature of Figure 3-14 is that the current and future climate envelopes do not overlap at all. In other words, all of the currently suitable habitat will be lost, and none of the future habitat is currently suitable or occupied. Thus, in order for the species to survive in the Mount Hamilton project area, it must travel between 15 and 50 km over the next 100 years to reach its new habitat areas. The freeway system is included in Figure 3-14 to show that some of the BCB populations will have to cross urban areas and high-speed roads to get to the future climatically suitable habitat areas.

Table 3-18 shows the quantitative results of the climate envelope comparison for the BCB.

Table 3-18: BCB Climate Envelope Comparison

	Statewide Area (km^2)	 % of Total
Total Mount Hamilton Project Area	6,173	
Current Suitable Habitat Envelope	722	12%
Future Suitable Habitat Envelope	144	2%
Current and Future Suitable Habitat	0	0%
Suitable Habitat Lost	722	12%
Suitable Habitat Gained	144	2%
Not Suitable Habitat	5,307	86%
Area Occupied	84	1%
	Area (km^2)	% of Occupied
Current and Future Habitat (Occupied)	0	0%
Lost Habitat (Occupied)	77	92%
New Habitat (Occupied)	0	0%
Not Habitat (Occupied)	7	8%

Table 3-18 shows that all 722 km^2 of currently climatically suitable habitat will be lost with climate change, and only 144 km^2 will be gained. The species currently inhabits 84 km^2, but all of this occupied habitat will become unsuitable.

3.4 Other Impacts of Climate Change

The results presented above show one prediction of how climatically suitable habitat will change with climate change. However, increasing the atmospheric concentrations of CO_2 and other greenhouse gasses are likely to alter natural communities in additional direct and indirect ways. For the Mount Hamilton project area, the most important impacts to natural communities and species besides changes in precipitation and temperature are CO_2 fertilization, changes in the fire regime, and the spread of invasive species.

3.4.1 CO_2 Fertilization

Plants require atmospheric CO_2 for photosynthesis. Several experimental studies have found that increasing atmospheric CO_2 concentrations increases photosynthetic rate and net primary production, especially in arid ecosystems (Smith et. al., 2000; Gill et. al., 2002; Shaw et. al., 2002). These experimental studies tend to focus on smaller short-lived plants (such as annual grasses) in order to observe the entire life cycle of the plants. Few studies focus on larger trees, especially long-lived California oak species. However, since trees rely on photosynthesis to grow and reproduce, it is reasonable to hypothesize that increases atmospheric CO_2 concentrations will aid the blue oak, coast live oak, and valley oak populations in the Mount Hamilton project area.

Diffenbaugh et. al. (2003) attempted to model the impacts of increased atmospheric CO_2 concentrations using a vegetation model called BIOME4. While the modeling was conducted at a relatively coarse resolution (0.5° by 0.5° geographic grid, or approximately 9 km x 9 km), the researchers found that the predicted increase in atmospheric CO_2 concentrations by 2100 would result in a shift from non-woody vegetation types to woody vegetation types. This effect would tend to moderate the climatic influences of climate change presented above, and may help certain oak woodlands from being converted to grasslands.

Several experimental studies have shown that it is important to simulate all of the impacts of climate change together, and that these multi-factor experiment will give different results than studying the impacts of increasing atmospheric CO_2 alone. For example, Shaw et. al. (2003) found that increasing temperature, precipitation, and nitrogen deposition tends to increase net primary production for plants at the Jasper Ridge study site in California. However, adding an increased CO_2 treatment to these experimental plots tends to dampen the increase in net primary production. In the Diffenbaugh et. al. modeling study, the researchers found similar results when they combined the climatic and CO_2 impacts in the BIOME4 model. The resulting vegetation patterns were different than either treatment alone. For the Mount Hamilton project area, their combined climate and CO_2 results indicate a transition from temperate grassland to temperate woodland. While this study was not meant to provide results at the scale of the Mount Hamilton project area, it does indicate the CO_2 impacts may be more important than climatic impacts in this area.

3.4.2 Fire

Large-scale catastrophic wildfires can be very destructive to both human and natural systems. Increasing temperature and decreasing precipitation will tend to increase the risk of wildfire. Brown et. al. found that recent climate change predictions will tend to increase the number of days with high fire danger throughout the western U.S. (2003). However, the impact and severity of wildfire is more closely related to the vegetative fuel load in an area.

Through sophisticated modeling efforts, Lenihan et. al. (2003) found an interesting relation between climate change and wildfire. Climate change predictions with more precipitation tend to result in more woody vegetation. This leads to more available fuel and thus catastrophic fires in the dry years. When using climate change predictions that show a reduction in precipitation, like the one used in this study, Lenihan et. al. found that more of the landscape will be covered by grasslands. These grasslands are better adapted to the more frequent fires that result from the hot dry climate. More area is burned in this scenario, but the fire intensity declines since the fuel loads are reduced. In other words, climate, fire, and vegetation are all linked with complex relationships that are difficult to understand, let alone predict 100 years into the future. However, one can imagine fire playing a role in the Mount Hamilton project area by converting oak woodlands to annual grasslands, and then keeping the grasslands open with more frequent fires due to the hotter and drier climate. Thus, fire may have the opposite effect of CO_2 fertilization, and the two effects may tend to cancel each other out.

3.4.3 Invasive Species

Invasive species are already a significant factor in natural systems throughout California and in the world. One recent experimental study in the Mojave Desert found that elevated atmospheric CO_2 treatments increased the above ground production and seed rain of an invasive annual grass species. While the native plants also benefited from the treatment, they did not benefit as much as the invasive plant. Consequently, climate change may enhance the long-term success of exotic annual grasses (Smith et. al., 2000).

For the Mount Hamilton project area, the impacts of climate change on the spread of invasive species will depend on which species benefit more (or is harmed less) by the changing conditions. This will depend on the characteristics of the invasive species and their native counterparts. Perhaps the most important impact will be increased stress to the native communities that have adapted to the local climate regime. Strain from inhospitable climate and forced migrations may tip the balance in favor of invasive species. Many endemic California plants and animals are already under siege by introduced species, and climate change may cause enough strain to give the invasive species the upper hand.

Chapter 4: Discussion

As shown in the previous chapter, predicted climate change could render between 55-100% of the habitat currently occupied by the six species and natural communities climatically unsuitable. With such drastic reductions in habitat, many populations will die, and some of the species may be come locally extirpated. However, new higher-elevation areas that are not currently occupied by the species will remain or become climatically suitable. These areas are likely to be essential for the viability of the local populations. This chapter will examine if these areas could become habitat, what management actions are needed, and determine new land conservation targets based on this analysis. This chapter also discusses the uncertainties and limitations of the data and methods used in this analysis, and suggests areas for future research.

4.1 Future Habitat Conditions and Accessibility

The maps and tables in the results chapter indicate areas that are *climatically* suitable for habitat for the natural communities and species studied. Yet, not all of even the currently climatically suitable habitat is actually occupied by the woodlands and species. This is because other local conditions, such as soil type, slope, and water availability influence and limit species distribution. This section will look briefly at local conditions within the future climate envelopes presented in the Results chapter, to see which areas are ideal to target for future conservation. Of course, additional fieldwork and analysis is essential to confirm and refine the results presented here.

Even if an area is climatically suitable in the future, and it contains certain local conditions that will support the target species or community, it may not naturally become habitat if the species cannot migrate to the area. This section will also look at observed dispersal and migration rates to try to determine which areas could be naturally colonized by the species, and which species will require human help to colonize new habitat.

4.1.1 Future Habitat Conditions

Oak Woodlands

Much of the Mount Hamilton project area has local conditions that are suitable for oak woodlands. Figure 3-6 in the previous chapter shows that oak woodlands are able to persist throughout most of the area, on both steep hillsides and on flat valley bottoms. Oaks are able to survive in a variety of soil types. For example, coast live oak is found in soils ranging from shaley clay to sandy soils. They are even found in serpentine soils, which are relatively infertile to species that have not adapted to their unique chemical composition (Steinberg and Howard, 2002). Valley oaks are found in deep rich soils, but can also be found on thinner soils with slopes of up to 35%. They survive in silty loams, clayey loams, and sandy clay loam (Howard, 1992a). Blue oaks can persist on infertile shallow soils. They prefer well-drained soils that are gravely loam and clay loam (Howard, 1992b). Since oak woodlands are found throughout much of the Mount Hamilton project area, and since they can tolerate a variety of soil types and slopes, climate is likely to be the dominating local factor determining their location in the future. This is not the case for the T&E species studied in this analysis, as discussed below.

California Red-Legged Frog

As mentioned in the Results chapter, the CRLF can live in a variety of habitats, as long as there is a permanent source of surface water. Intermittent streams are some of the best habitats, because they dry up during the summer and do not support non-native predators, but often retain some water in pools for the CRLF. Figure 4-1 shows a close-up of the northern portion of the Mount Hamilton project area. The areas in red and green are climatically suitable habitat based on current conditions, and the areas in green are climatically suitable based on predicted future conditions. The cross-hatched areas are areas of critical habitat for the CRLF, as proposed by the USFWS. Figure 4-1 also shows the location of the streams, ponds, lakes, and reservoirs. Many of the higher elevation streams are intermittent, and thus have the potential to be good habitat for the CRLF.

Figure 4-1 shows that much of the area in green that is projected to be climatically suitable for the CRLF also has streams and water bodies, and thus may support the necessary local conditions for the species. Of course, more detailed field studies such as bullfrog surveys and water source reliability and quality are required to determine which areas are best suited for CRLF habitat before land acquisition is considered. This analysis shows much of the climatically suitable future habitat may also contain the local conditions (streams and water bodies) necessary for CRLF survival.

California Tiger Salamander

CTS rely on vernal pools and agricultural stock ponds for breeding habitat, as well as upland oak and savanna habitats for feeding for adults. Digital spatial information on the location of vernal pools and stock ponds in the Mount Hamilton project area is not available, but information on streams, lakes, ponds and reservoirs are presented in Figure 4-2. Figure 4-2 shows similar information as Figure 4-1, but it includes habitat and climate envelope data for the CTS. All of the existing critical habitat units for the CTS contain part or all of at least one large reservoir. These reservoirs are not ideal habitat since they can harbor predators of CTS larva, they are likely to provide breeding habitat in dry years. The small unnamed reservoirs southeast of the summit of Mount Hamilton may provide the necessary local conditions for CTS survival, and they are predicted to be suitable habitat based on future climate conditions. As with the CRLF, more detailed field surveys are required before these areas should be targeted for conservation.

Bay Checkerspot Butterfly

The BCB requires the most specific local conditions for survival of all the species studied in this analysis. The BCB relies on certain host plants that are typically found in relatively rare serpentine-derived soils. BCB also require topographically diverse habitat that allows areas of refuge on cooler north-facing slopes, and areas for feeding on warmer south-facing slopes. Figure 4-3 shows the areas of serpentine soils within the BCB current and future climate envelopes.[1] Fortunately for the BCB, there are several patches of serpentine-derived soils in or near the yellow areas that are predicted to be climatically suitable with climate change. These patches of serpentine soils are labeled based on nearby geographical features. The two patches of serpentine soils near Mt. Day are the

---

[1] The available soil surveys only cover a portion of the Mount Hamilton project area shown in Figure 4-3. Some of the existing BCB critical habitat units not are covered by these soil surveys so they appear not to contain serpentine soils. However, almost all of the area in the future climate envelope is covered by existing soil surveys.

closest to the existing BCB population near highway 101. The patches near Cedar Mountain are promising because they are the most extensive. An examination of the topography of this area in Figure 1-10 indicates that it is also topographically diverse, with both north- and south-facing slopes. The Sunol Wilderness and Rocky Ridge patches could provide additional habitat for smaller BCB populations.

Since the labeled serpentine sites in Figure 4-3 areas are in the future climate envelope but not in the current climate envelope, they do not currently have the correct climatic conditions to support the BCB and/or its host plants. Introducing BCB populations to these areas now or in the near future may be unsuccessful because the climate could be too cold. However, if land managers wait too long, the current habitat areas may become too warm to support the species, and there may be no individuals to transplant. This example shows the interesting problem of a gradually changing climate for a species that has discrete areas of suitable habitat. The Sunol Wilderness site may be a way around this problem, because portions of the site are in both the current (red) and future (yellow) climate envelopes, indicating portions are climatically suitable now, and other portions are projected to be climatically suitable in the future. This site it already protected as a regional wilderness, which is an added bonus for an introduction effort. As with the other T&E species, detailed field studies should be conducted at the site to ensure it does contain the requisite host plants. If it does not, host plants should be introduced before introducing the BCB.

4.1.2 Future Habitat Accessibility

Oak Woodlands

The only means long-term migration for oak trees is the dispersion of viable acorns. Acorns are too heavy to be blown around by the wind and tend to rest where they fall or roll downhill. Despite these limitations, California oaks are found on ridges and in areas up to 5,000 feet in elevation. They are able to disperse uphill through a mutually beneficial relationship with several wildlife species. Scrub jays, stellar jays, yellow-billed magpies, grey squirrels, and ground squirrels all collect acorns from California oak species and bury them underground. They will return to these caches later to eat the acorns, but inevitably some caches are forgotten and sprout into new oak seedlings (Pavlik et. al., 1991). Through this relationship, the wildlife species gain a reliable source of food, and the oaks have the ability to migrate uphill and across the landscape.

Several studies have looked at the acorn caching behavior of scrub jays. Scrub jays may bury 5,000 acorns in a season, 5% of which escape being eaten. The remaining 5% have a high germination and survival rates because they are typically cached 1 cm below the soil surface. Scrub jays typically bury acorns within their home range which averages 2.5 hectares (6.2 acres) (Steinberg, 2002). If the home range is roughly circular, this results in an average radius of ~90 meters (~300 feet). California oaks may take several decades before they produce flowers and acorns (Pavlik et. al., 1991). Under an ideal scenario, a scrub jay could help a oak forest migrate uphill 90 m or 0.09 km every 20 years, or roughly 0.45 km per 100 years.

Interestingly, oaks have historically been able to migrate across large distances at much faster rates than that estimated above. Davis (1981) was able to estimate the migration rate for several tree species across the eastern U.S. for the last 15,000 years using preserved pollen samples. The oak genera were able to migrate from their ice-age refuge in Florida through the topographically diverse Appalachian range to northern Maine over roughly 8,000 years. This indicates an average migration rate of 25 km (15.5 miles) per 100 years, which is over 50 times greater than the rate estimated above.   Some of this difference could result from downhill transport of acorns by water, landslides, or simply rolling, but some acorns had to travel uphill. Additional research and study is necessary to reconcile this discrepancy.

If California blue oaks, coast live oaks, and valley oaks are able to migrate an average of 25 km (15.5 miles) per century, they should be able to colonize the areas of unoccupied habitat that will be climatically suitable with climate change. Examination of Figures 3-9 through 3-11 show that the centers of the existing populations are rarely more than 25 km from the centers of the climatically suitable future habitat for each of the woodland types. However, most of the moves will have to be uphill to take advantage of the cooler and wetter climates at higher elevations. If uphill migration rates are on the order of 0.45 km per 100 years, the oaks will not be able to colonize the new areas of climatically suitable habitat, and many existing populations will find themselves stranded in climatically inhospitable areas. In this case, human land managers may have to speed natural migration along by spreading acorns or saplings upslope throughout the Mount Hamilton project area.

Perhaps more important than the migration rate is the current lack of recruitment observed in valley and blue oak woodlands over the last 75 to 125 years, despite a relatively stable climatic regime. Many valley and blue oak woodlands are dominated by mature trees and saplings are almost completely absent. Cattle grazing, deer browsing, invasive ground cover species, altered fire regimes, dry years, and acorn predation from rodents are all perhaps partially to blame for this problem, but scientists still do not have a complete understanding of the causes, nor ways to fix the problem (Pavlik et. al, 1991). If the lack of recruitment of these oak species persists, the oak woodlands will be in jeopardy with or without climate change.

California Red-Legged Frog

Of the species and natural communities studied in this analysis, the CRLF may be the best able to migrate in response to climate change. As mentioned in the Results chapter, CRLF can travel 1.6 to 3.2 km (1 to 2 miles) through upland areas during the start of the wet season, without apparent regard to topography, vegetation type, or riparian corridors (USFWS, 2004b). If an average dispersal of 2 km per year is assumed, CRLF populations can migrate 200 km (125 miles) in 100 years. An examination of Figures 3-12 and 4-1 show that all areas within the Mount Hamilton project area are accessible with this migration rate over the next century. Even if a population of frogs needed to travel from the center of the currently occupied habitat that is in the red in Figure 3-12, to the center of the habitat in green, it would have to travel roughly 45 km over 100 years. Figure 4-1 shows there is a good change the CRLF populations will be able to find intermittent streams and small water bodies along the way.

California Tiger Salamander

Similar to the CRLF, juvenile and adult CTS are able to disperse across the landscape. Detailed mark and recapture studies have shown that roughly 20% of CTS migrate to a different breeding pond than the one they were born in (Trenham et. al., 2000). Juvenile CTS have been observed dispersing 1.6 km (1 mile) across upland areas (USFWS, 2004a). If an average annual dispersal rate of 1 km per year is assumed, CTS populations can migrate at a rate of 100 km per 100 years. Examining figures 3-13 and 4-2 show that the two populations to the west of Highway 101 may have difficulty crossing the developed portions of the Santa Clara valley to reach the higher elevation habitat to the east of Highway 101. However, as seen in Figure 4-2, most of the populations to the that are already east of Highway 101 can utilize riparian corridors to reach the higher elevation habitat. This will require migrations on the order of 12 to 15 km over the next 100 years. CTS prefer open grasslands for migration, which are likely to be more prevalent at the lower elevations as a result of climate change. The one limiting factor may be the presence of suitable breeding ponds spaced roughly 1 km apart along the riparian corridors. The existing digital data on wetlands is not detailed enough to determine if this is the case, so additional field studies are necessary to determine the viability of natural CTS migration in response to climate change.

Bay Checkerspot Butterfly

Even though they are airborne during the adult life stage, the BCB has lower dispersal rates than the CTS and CRLF. During the flight season, biologists have observed adults typically dispersing 150 m (490 ft). Roughly 5% of BCB populations have been observed to travel 1 km (0.6 miles) or more. The longest observed and documented travel distance was 7.6 km (4.7 miles). BCB populations move rapidly over suitable grassland, but are more reluctant to cross scrub, woodland, or other unsuitable habitat (USFWS, 2001).

As shown in Figure 4-3, the closest patch of serpentine soils near Mount Day is roughly 20 km from the existing BCB populations west of Highway 101. The probability of enough BCB adults reaching this site to establish a new population through natural dispersion is essentially zero. Instead, land managers will need to establish new populations by transplanting BCB larvae to the serpentine soil sites. As previously mentioned, the Sunol Wilderness site may be a good place to begin transplantation efforts, because it contains areas that are currently climatically suitable and areas that will be climatically suitable with climate change. As the climate continues to warm, new populations can be established at the large Cedar Mountain serpentine soil patch toward the middle or end of this century, depending on the actual rate of climate change. Due to the specific habitat requirements of the species, the BCB will not survive climate change without human intervention.

4.2 Land Conservation Targets

Land conservationists and managers must work in a world of finite resources, and cannot simply buy and protect all undeveloped land. Instead, they set priorities and develop targets based on a set of criteria, including the ecological value of the habitat for the targets species and natural communities, the degree of threat for conservation to an incompatible use (farmland or suburbs), and the cost and availability of the land.

Connectivity is also important, so large parcels or a set of contiguous parcels may be a higher priority for conservation than small, scattered parcels in a developing landscape.

TNC's current land conservation targets are based on current climatic and ecological conditions. These targets exhibit an emphasis on riparian corridors, important habitat for T&E species, and large contiguous areas of oak woodlands and other habitat. The targets are centered around the hills on both sides of the Santa Clara valley and Highway 101. These areas are the most likely to be converted to urban and suburban sprawl due to their proximity to existing development. Much of the high elevation areas north of the summit of Mount Hamilton are not currently targets for conservation.

Figure 4-4 is a summary of the analysis and results of this report. It presents a new set of land conservation targets that are based on future climate, local conditions, and patch accessibility for the species and natural communities analyzed in this report. The target areas are distinguished based on the species or community that is most likely to benefit from its conservation and management. However, many of the target areas will benefit several if not all of the species and communities. While some of the targets are the same as the current TNC targets, most of the targets in Figure 4-4 cover areas of higher elevation.

The light blue areas in Figure 4-4 indicate future targets for blue oak, coast live oak, and valley oak woodlands. Since the climatically suitable future habitat was similar for all three woodland types, they were combined into one target category. These two target areas were based on areas that were in both the local and statewide climate envelopes, which are explained in the Results chapter. As shown in Figure 3-6, some of the outer portions of the two target areas are already occupied by the oak species, but most of the higher elevation areas around the summit of Mount Hamilton are not. If the oaks are able to migrate to these areas on their own, they will likely become occupied habitat in the future. However, since much of the migration will require uphill movement, human land managers may need to assist the scrub jays and ground squirrels and plant acorns upslope from existing oak stands. The light blue targets also cover excellent high elevation habitat for the T&E species.

The pink targets with cross-hatching indicate areas that are likely to become important future habitat for the CRLF. These areas include only the areas that are not currently critical habitat for the species, but are predicted to be climatically suitable with future climate change. Habitat corridors for the CRLF are not targeted due to the species relatively high mobility through a variety of upland habitat types. The three patches near the summit of Mount Hamilton were chosen because they contain intermittent streams and small reservoirs that may provide habitat, even in dry years. These areas are also likely to provide future habitat for the CTS. The two patches near the western border of the study area include high elevation habitat for an existing CRLF population in the Santa Cruz Mountains. These areas also may support some oak woodland future habitat, especially for the coast live oak.

The yellow targets with hatching were developed based on the current and future habitat locations for the CTS. Since CTS are less mobile than the CRLF, more emphasis was placed on movement corridors for the CTS. The targets follow riparian corridors that lead from areas of current habitat to areas of habitat that are likely to be suitable in the future. These corridors include some upland habitat to provide for upland feeding and dispersal for adult CTS as they migrate towards higher ground. Certain existing CTS populations are already in areas that are projected to be suitable in the future, so no migration targets are shown for these population in Figure 4-4.

The green stippled targets in Figure 4-4 indicate areas that are likely to be suitable for the BCB based on future climate and local serpentine soils. Migration corridors for the BCB are not targeted because there is not enough suitable habitat between existing populations and future targets. As mentioned above, land managers will need to introduce BCB to the future target areas in order to help the species survive climate change.

In order to best protect the biodiversity of the Mount Hamilton project area, TNC must consider both their current conservation targets and the future targets displayed in Figure 4-4. If habitat is destroyed in the lower elevation areas over the next 10 years, there may not be enough individuals to migrate upslope over the next 100 years, so land needs to be conserved now that faces the highest degrees of threat. Unfortunately, these properties tend to have the highest market value, and thus can be very expensive to conserve. Some of the upper elevation property has almost no development potential so it is unlikely to be destroyed in the near future. However, this usually means the land values are low, the parcels are larger, and more area can be conserved at a lower price. TNC’s area of expertise is weighing these types of factors and developing a balanced conservation strategy. The goal of this analysis is to ensure areas of future habitat are included in the decision making process since they are essential for the long-term conservation of the rare species and natural communities found in the Mount Hamilton range.

4.3 Uncertainty, Limitations, and Future Research

Due to uncertainties and limitations associated with the data and methods used in this analysis, the future land conservation targets presented in Figure 4-4 should be interpreted only as a best estimate of the locations of suitable habitat by the end of the century. In some cases, additional research will help to reduce the uncertainty. In other cases, land managers may have to wait and see what happens, and make changes adaptively. The following is a brief discussion of the uncertainty, limitations, and future research associated with these results.

4.3.1 Data Uncertainty and Limitations

The current climate data is based on a statistical interpolation of temperature and precipitation from existing weather stations. The interpolation is adjusted for elevation, but the spatial resolution is 1 km, which is relatively coarse for the size of this study area. With this resolution, variation in temperature from different solar radiation received on a north-facing slope compared to a south-facing slope is not represented. While this limitation does not bias the general trend of the results, it does limit the scale at which the results can be interpreted. Using finer grained elevation data, such as the ~10 or ~30 m digital elevation models available from the USGS, could improve the quality of the current climate data.

A large source of uncertainty in this analysis is the prediction of future climate. There is significant uncertainty in future greenhouse gas emissions, the connection between greenhouse gas concentrations and global surface temperature and precipitation, the impacts of climate change on an area the size of the Mount Hamilton project area, and how these impacts will affect seasonal, monthly, or even daily temperature and precipitation. Scientists try to minimize these uncertainties by using a variety of climate models, emission scenarios, and downscaling techniques. Almost all of these models predict some warming over the next 100 years, but predictions of precipitation are much less consistent. The Snyder et. al. data used in this analysis predict a low- to moderate-degree of warming, and a relatively small change in precipitation. If warming is greater, the future climate envelopes will tend to be smaller in the Mount Hamilton project area. Since the Snyder data is a relatively low-end projection of climate change, the results in this analysis may be optimistic. Changes in precipitation will impact the climate envelopes in different ways, depending on the species. Future studies could look at various precipitation and temperature scenarios to determine the sensitivity of the size of the climate envelopes.

The oak woodlands data has high spatial resolution, but it is not always consistent with other vegetation data, especially in noting the locations of different species. Differentiating oak species on the ground can often be difficult due to subtle differences between certain species. This difficulty is multiplied when the analyst must rely on aerial photos or satellite data. However, aerial photos and satellite data are more accurate in differentiating grassland from woodland, or bare rock from confer forests, especially when data from different seasons are examined. While the differentiation between blue oak and coast live oak woodland may be artificial in some instances, the differentiation between oak woodlands, oak savannas, and open grasslands is relatively accurate. These characteristics may explain why the current and future climate envelopes for all three woodlands were similar, and also why all three showed a trend of moving upslope to higher elevation with climate change. More field checking of aerial and satellite data will improve the accuracy of the vegetation data.

The T&E species' critical habitat is based in part on a buffer around documented field observations of the species. Thus, some portions of this habitat may not be inhabited by the species. On the other hand, the data set does not include locations where the species may exist, but has not been observed. The critical habitat also excludes portions of the historical habitat that have been developed or otherwise rendered unsuitable. For example, the CTS may once have been common in the Central Valley, but much of their habitat has been destroyed by certain agricultural practices. This will tend to bias the critical habitat data to higher elevation foothill locations, even though the Central Valley locations are climatically suitable. If the species are able to withstand a larger range in temperatures and precipitation (especially higher temperatures) the future climate envelopes calculated in this analysis are likely to be too small and overly conservative. More research on the historical habitat of the T&E species would help to reduce this bias.

4.3.2 Methods Uncertainty and Limitations

The climate envelope method is subject to certain limitations. The fact that a species is not found in an area does not mean it cannot survive the climate in that area. Consider a hypothetical example where a species prefers locations with more rain. These locations support predators for the species, so it is rare in rainy areas. A climate envelope analysis based on this data would predict less habitat for the species if precipitation increases, when, absent predators, the species would thrive in this situation. A more accurate approach would involve a series of experiments that vary temperature, precipitation, and other factors and see the results over the life spans of the species. Unfortunately, this approach would be very expensive, could increase mortality for endangered species, and is impractical for long-lived species such as California oaks. While the climate envelope method is potentially biased, it is much more practical for this type of analysis.

Another uncertainty in this analysis is the degree of genetic variability between spatially separated populations. While a statewide and local envelope approach was used with the oak woodlands, these two scales of analysis were chosen arbitrarily. There may still be genetic variation between the blue oak populations in the south of the project area and the populations in the north of the project area. One relatively inexpensive but time consuming method to test the genetic variability would be to plant acorns from various populations across the state in the same garden. If the growth patterns and phenology of these oaks vary systematically, it would support the argument that there is genetic variation between populations.

4.3.3 Interpretation Uncertainty and Limitations

As mentioned earlier in this chapter, there is significant uncertainty in the short-term migration rates for the oak woodlands and T&E species. This uncertainty is confounded by the lack of information about local conditions along migration routes. More fieldwork is needed to determine the local conditions, but migrations rates may have to be observed as climate change occurs.

There is also uncertainty in the complex and interconnected ecological responses to climate change. For example, warmer temperatures may increase the frequency of fires, which may aid the spread of opportunistic invasive grasses. These could out-compete oak seedlings, causing a continued lack of recruitment, which is not directly related to the temperature and precipitation requirements of the oak species. On the other hand, many of the species extant today have endured past changes in climate and may be better prepared for change than we expect. Answers to these questions may only come with careful observation and adaptive management as climate change continues over the next century.

Despite these uncertainties and limitations, the results in this analysis make intuitive sense. Higher elevation areas tend to be wetter and cooler. The climate is predicted to get warmer and drier. In response, we would expect species to need to migrate upslope to higher elevation areas, as long as these areas support the local conditions necessary for the species to survive. The future climate envelopes in the Results chapter and the future targets in this chapter tend to be located at higher elevations than the species current locations. While the specific locations may not be accurate, the general trends are likely to be correct.

Chapter 5: Conclusion

The climate of the earth has not been stable for as long as interpretable climate records exist. Over the last 60 million years, global climate has been both significantly hotter and colder than it is now. Life on earth to evolved to respond to changing climate by migrating or adapting to this ever-present change. Humans are currently presenting a new challenge to life on earth by increasing the rate of climate change, fragmenting and destroying habitat, disrupting migration corridors, and introducing new species where they never existed before. Predicting the response of life to these new challenges is difficult but essential if we want to begin helping other species, rather than making natural adaptations to change almost impossible.

One might expect the impacts of anthropogenic climate change to be relatively modest in the Mount Hamilton project area. Almost all of the area is high enough to be immune to predicted sea level rise. It is located in the middle latitudes where predicted temperature increases are moderate and precipitation may go up or down, but not by too much. There are few roads or other migration barriers bisecting the area. Despite this, and despite the use of a low- to moderate- climate change scenario, the predicted impacts of climate change are far from trivial. Blue oak woodlands are least affected since they are tolerant of drought and high temperature, but over half (55%) of their currently occupied habitat will become climatically unsuitable. The estimated amount of occupied habitat lost with future climate change goes up from there, with CTS losing 58%, CRLF losing 66%, coast live oak woodland losing 67%, valley oak woodlands losing 80%, and BCB losing 100% of currently occupied habitat in the project area.

While these are significant reductions in occupied habitat, climate change could open up new areas of habitat that are not currently suitable because they are too cold or too wet. Species and natural communities will only be able to utilize this new habitat if they can successfully cross kilometers of mostly uphill terrain and establish new populations in the next 100 years. Since the last ice age, oak woodlands have been able to traverse large distances, covering an average of 25 km per century. However, acorns do not fall uphill, so they will need help from animals and possibly humans to establish populations at higher elevations. The CRLF is relatively mobile, and can cross large distances at the beginning of the wet season, but even if it is able to colonize all of the climatically suitable future habitat, it will still suffer a reduction in total habitat area from its current range. The CTS is somewhat less mobile and will require new breeding sites every kilometer or so as it travels to the new habitat areas. Since the BCB requires rare serpentine soil patches for survival, there is no chance it will establish a population in the areas of future habitat on its own. Since all of its currently occupied habitat will be lost, the BCB must have human help to survive.

TNC and other land conservation and management organizations are making a spectacular effort to preserve the Earth's biodiversity. Instead of fragmenting habitat, they are connecting it. Instead of spreading invasive species, they are promoting natural ecosystems. Instead of destroying habitat, they are restoring it. However, certain factors will effect the species on TNC preserves that can not be managed locally. Climate change is already occurring, and despite the best efforts of many scientists and activists, it will likely worsen over the next 100 years and after that as well. TNC and other organizations need to consider future habitat and migration corridors in their current land conservation priorities. They need to actively propagate species that are unable to migrate fast enough to cope with climate change. With these actions, species will finally be getting some help, rather than more hurtles, from humans.

Figures

Appendix A

Rare, Threatened and Endangered Species found in Blue Oak, Valley Oak, and Coast Live Oak Woodlands in Alameda, Merced, San Benito, San Joaquin, Santa Clara, and Stanislaus Counties

CALIFORNIA WILDLIFE HABITAT RELATIONSHIPS SYSTEM 4/23/2005
Supported by
CALIFORNIA INTERAGENCY WILDLIFE TASK GROUP
and maintained by the
CALIFORNIA DEPARTMENT OF FISH AND GAME
Database Version: 8.0

SPECIES SUMMARY REPORT

I=Introduced 3=California Endangered 7=California Species of Special Concern 11=BLM Sensitive
N=Native 4=California Threatened 8=Federally-Proposed Endangered 12=USFS Sensitive
1=Federal Endangered 5=California Fully Protected 9=Federally-Proposed Threatened Candidate 13=CDF Sensitive
2=Federal Threatened 6=California Protected 10=Federal Candidate 14=Harvest

Note: Any given status code for a species may apply to the full species or to only one or more of its subspecies.

ID	SPECIES NAME	STATUS
A001	CALIFORNIA TIGER SALAMANDER	6 7 10
A007	CALIFORNIA NEWT	7
A012	ENSATINA	7 1112
A028	WESTERN SPADEFOOT	6 7 11
A040	RED-LEGGED FROG	2 6 7 12
A043	FOOTHILL YELLOW-LEGGED FROG	6 7 12
R004	WESTERN POND TURTLE	6 7 1112
R029	COAST HORNED LIZARD	6 7 1112
R019	BLUNT-NOSED LEOPARD LIZARD	1 3 5 6
R034	DESERT NIGHT LIZARD	7 12
R036	WESTERN SKINK	7 11
R043	CALIFORNIA LEGLESS LIZARD	6 7 10 12
R052	COACHWHIP	6 7
R053	STRIPED RACER	2 4 6
R059	CALIFORNIA MOUNTAIN KINGSNAKE	6 7 12
R061	COMMON GARTER SNAKE	1 3 5 6 7
R079	GIANT GARTER SNAKE	2 4 6
R080	TWO-STRIPED GARTER SNAKE	6 7 1112
B110	OSPREY	7 13
B111	WHITE-TAILED KITE	5
B113	BALD EAGLE	2 3 5 13
B114	NORTHERN HARRIER	7
B115	SHARP-SHINNED HAWK	7
B116	COOPER'S HAWK	7
B121	SWAINSON'S HAWK	4 12
B124	FERRUGINOUS HAWK	7 11
B126	GOLDEN EAGLE	5 7 11 13
B128	MERLIN	7
B129	PEREGRINE FALCON	3 5 13
B131	PRAIRIE FALCON	7
B269	BURROWING OWL	7 11
B272	LONG-EARED OWL	7
B273	SHORT-EARED OWL	7
B279	BLACK SWIFT	7
B281	VAUX'S SWIFT	7
B307	NORTHERN FLICKER	3
B410	LOGGERHEAD SHRIKE	1 7
B348	WESTERN SCRUB-JAY	7

B337	HORNED LARK	7
B338	PURPLE MARTIN	7
B398	CALIFORNIA THRASHER	2
B430	YELLOW WARBLER	7
B483	SPOTTED TOWHEE	7
B484	CALIFORNIA TOWHEE	2 3
B499	SAVANNAH SPARROW	3 7
B505	SONG SPARROW	7
B512	DARK-EYED JUNCO	7
M003	VAGRANT SHREW	7
M006	ORNATE SHREW	7 8
M018	BROAD-FOOTED MOLE	7
M037	TOWNSEND'S BIG-EARED BAT	7 1112
M038	PALLID BAT	7 1112
M042	WESTERN MASTIFF BAT	7 11
M045	BRUSH RABBIT	1 3 14
M051	BLACK-TAILED JACKRABBIT	7 14
M087	SAN JOAQUIN POCKET MOUSE	7 11
M095	CALIFORNIA POCKET MOUSE	7
M104	HEERMANN'S KANGAROO RAT	1 3 5
M117	DEER MOUSE	7
M127	DUSKY-FOOTED WOODRAT	1 7
M134	CALIFORNIA VOLE	1 3 7
M148	KIT FOX	1 4
M152	RINGTAIL	5
M161	WESTERN SPOTTED SKUNK	7 14
M165	MOUNTAIN LION	7

Total Number of Species: 65

References

Bartlein, P. C. Whitlock, and S. Shafer. 1997. “Future climate in the Yellowstone National Park region and its potential impact on vegetation.” *Conservation Biology*. 11(3): 782-792.

Bell, J., L. Sloan, and M. Snyder. 2004. “Regional changes in extreme climatic events: A future climate scenario.” *Journal of Climate*. 17:81-87.

Benning, T., D. LaPointe, C. Atkinson, and P. Vitousek. 2002. Interactions of climate change with biological invasions and land use in the Hawaiian Islands: Modeling the fate of endemic birds using a geographic information system. *Proceedings of the National Academy of the Sciences*, 99: 14246-14249.

Bloom, A. 1998. *Geomorphology*. 3rd ed. New Jersey: Pretence Hall.

Brown, T.J., B.L. Hall, A.L. Westerling, 2003: The impact of twenty-first century climate change on wildland fire danger in the western United States, an applications perspective. Climatic Change, 62, 365-388.

California Department of Forestry and Fire Protection. 1994. Digital GIS layers of hardwoods and land cover. Accessed at http://frap.cdf.ca.gov.

California Spatial Information Library. 2005. Digital GIS layers of California streams, lakes, counties, and shoreline. Accessed at http://gis.ca.gov.

Cox, R. et al. 1998. Mount Hamilton Project; Site Conservation Plan. The Nature Conservancy of California unpublished report.

Cox, R. et. al. 2004. Mount Hamilton Project Plan Update. The Nature Conservancy of California draft report.

Crowley, T. and G. North. 1988. “Abrupt climate change and extinction events in Earth history.” *Science*. 240(4855):996-1002.

Davidson, C. 1996. “Rana aurora – Red-legged frog.” Declining Amphibian Population Task Force. Accessed at http://ice.ucdavis.edu/CANVDecliningAmphibians/Species/aurora.htm on May 3, 2005

Davidson, C. et. al. 2001. “Declines of the California red-legged frog: climate, UV-B, habitat, and pesticides hypothesis.” *Ecological Applications*. 11(2):464-479.

Davis, M. and R. Shaw. 2001. “Range Shifts and Adaptive Responses to Quaternary Climate Change.” *Science*. 292:673-679.

Davis, M. B. 1981. “Quarterly history and the stability of forest communities,” in *Forest Succession: Concepts and Application.* D.C. West, H. H. Shugart, and D. B. Botkin (eds.). Springer-Verlag, New York, NY, pp. 134-153.

Daymet. 2001. Digital GIS layers of climatic variables developed by Numerical Terradynamic Simulation Group at the University of Montana (www.daymet.com).

De Rome, D. 1997. “Poly Land Revisited: A Field Guide.” Masters Thesis, California Polytechnic State University. Accessed at http://polyland.lib.calpoly.edu/overview/Archives/derome/ on May 3, 2005.

Devender, T., R. Thomson, and J. Betancourt. 1987. “Vegetation history of the deserts of southwestern North America; The nature and timing of the Late Wisconsin-Holocene transition.” In *The Geology of North America, North America and Adjacent Oceans During the Last Deglaciation*. Volume K-3. W. Ruddiman and H. Wright, eds. The Geological Society of America.

Diffenbaugh, N. et al. 2003. “Vegetation sensitivity to global anthropogenic carbon dioxide emissions in a topographically complex region.” *Global Biogeochemical Cycles,* 17: 1067.

ESRI, Geographic Data Technology, Inc.. 2004. Digital GIS layers of roads, cities, streams, lakes, etc.

Gill, R. et. al. 2002. “Nonlinear grassland responses to past and future atmospheric CO_2.” *Nature.* 417:279-282.

Hannah, L. et. al. 2002. “Conservation of Biodiversity in a Changing Climate.” *Conservation Biology.* 16(1):264-268.

Harte, J. et. al. 2004. “Climate change and extinction risk.” *Nature*. 1 July 2004.

Hayhoe K. et al. 2004. “Emissions pathways, climate change, and impacts on California.” *Proceedings of the National Academy of the Sciences*, 101: 12422-12427.

Hellman, J. 2002 “The effect on an environmental change on mobile butterfly larvae and the nutritional quality of their hosts.” *Journal of Animal Ecology.* 71:925-936.

Holland, V. “Coastal Oak Woodland.” California Wildlife Habitat Relationships System. Accessed at http://www.dfg.ca.gov/whdab/cwhr/pdfs/COW.pdf on May 3, 2005.

Holsinger, K. 2003. “Population Viability Analysis Bay Checkerspot Butterfly.” Lecture notes accessed at http://darwin.eeb.uconn.edu/eeb310/lecture-notes/checkerspot.pdf on May 2, 2005.

Howard, Janet L. 1992a. “Quercus lobata.” In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2005, April 24].

Howard, Janet L. 1992b. "Quercus douglasii." In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2005, April 24].

Joos, F. et. al. 2002. "Growth enhancement due to global atmospheric change as predicted by terrestrial ecosystem models: consistent with US forest inventory data." *Global Change Biology*. 8:299-303.

Jouzel, J. et. al. 1987. "Vostok ice core: a continuous isotope temperature record over the last climatic cycles (160,000 years)." *Nature*. 329:403-408.

Jouzel, J. et. al. 1993. "Extending the Vostok ice-core record of palaeoclimate to the penultimate glacial period." *Nature*. 364:407-411.

Kiesecker, J. 2001. "Complex causes of amphibian population declines." *Nature.* 410:681-684.

Lenihan, J. et. al., 2003. "Climate change effects on vegetation distribution, carbon, and fire in California." *Ecological Applications.* 13(6):1667-1681.

Licht, L.E. 1971. Breeding habits and embryonic thermal requirements of the frogs, Rana aurora aurora and Rana petriosa petriosa, in the Pacific Northwest. Ecology 52(1): 116-124.

Malcolm, J. et. al. 2002. "Estimated migration rates under scenarios of global climate change." *Journal of Biogeography.* 29:835-849.

McBride, J. and A. Mossadegh. 1990. "Will climatic change affect our oak woodlands?" *Fremontia.* California Native Plant Society. 55-57.

McLaughlin, J., J. Hellman, C. Boggs, and P. Ehrlich. 2002. "The route to extinction: population dynamics of a threatened butterfly." *Oecologia*, 132: 538-548.

Pavlik, B., P Muick, S. Johnson, and M. Popper. 1991. *Oaks of California.* Los Olivos, CA: Cachuma Press. 184 p.

Pyke, C. 2004. Habitat loss confounds climate change impacts. *Front Ecol Environ*, 2: 178-182.

Pyke, C. and D. Fischer. 2004. "Selection of bioclimatically representative biological reserve systems under climate change." *Elsevier* (in press).

Pyke, C. and S. Andelman. 2004. "Confronting climate change; biological vulnerability and biophysical tools." *Bioscience* (in press).

Ritter, L. “Blue Oak Woodland.” California Wildlife Habitat Relationships System. Accessed at http://www.dfg.ca.gov/whdab/cwhr/pdfs/BOW.pdf on May 3, 2005.

Ritter, L. “Valley Oak Woodland.” California Wildlife Habitat Relationships System. Accessed at http://www.dfg.ca.gov/whdab/cwhr/pdfs/VOW.pdf on May 3, 2005.

Sharsmith, H. 1982. “Flora of the Mount Hamilton Range of California.” California Native Plant Society, Special Publication #6. p. 289-382.

Shaw, R. et. al. 2002. “Grassland responses to global environmental changes suppressed by elevated CO_2.” *Science.* 298:1987-1990.

Shugart, H, R. Sedjo, and B. Sohngen. 2003. “Forests and global climate change; Potential impacts on U.S. forest resources.” Pew Center on Global Climate Change. 46 p.

Smith, S. et. al. 2000. “Elevated CO2 increases productivity and invasive species success in an arid ecosystem.” *Nature.* 408:79-82.

Snyder, M., J. Bell, L. Sloan, P. Duffy, and B. Govindasamy. 2002. “Climate responses to a doubling of atmospheric carbon dioxide for a climatically vulnerable region.” *Geophysical Research Letters*, 29: 1514.

Steinberg, Peter D.; Howard, Janet L. 2002. “Quercus agrifolia.” In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2005, April 24].

Swiecki, T. and E. Bernhardt. 1998. “Understanding blue oak regeneration.” *Fremontia.* 26(1):19-26.

Thomas C. et al. 2003. “Extinction risk from climate change.” *Nature*, 427: 145-148.

TNC, 2004. Digital GIS layers of protected lands, parcels, Mount Hamilton project area, conservation targets.

Trenham, P., et. al. 2000. “Life history and demographic variation in the California tiger salamander (Ambystoma californiense).” *Copiea.* 2000(2):365-377.

US Fish and Wildlife Service. 2001. Endangered and Threatened Wildlife and Plants; Final Determination of Critical Habitat for the Bay Checkerspot Butterfly (Euphydryas editha bayensis); Final Rule. *Federal Register*, 66 (83): 21450-21489.

US Fish and Wildlife Service. 2004a. Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the California Tiger Salamander, Central Population; Proposed Rule. *Federal Register*, 69(153): 48570-48649.

US Fish and Wildlife Service. 2004b. Endangered and Threatened Wildlife and Plants; Proposed Designation of Critical Habitat for the California Red-legged Frog (Rana aurora draytonii); Proposed Rule. *Federal Register*, 69 (71): 19620-19642.

USDA Soil Conservation Service. 1966. *Soil Survey of Alameda area, California.* Washington D.C.

USDA Soil Conservation Service. 1974. *Soil Survey of Eastern Santa Clara area, California.* Washington D.C.

USFWS. 2004. Digital GIS layers of proposed and final critical habitat.

USGS. 2004. Digital GIS layers of National Elevation Dataset (NED). Accessed at http://seamless.usgs.gov.

Walther, G et al. 2002. Ecological responses to recent climate change. *Nature,* 416: 389-395.

Wather, Gian-Reto et. al. 2002. “Ecological responses to recent climate change.” *Nature.* 416:389-395.

Zachos, J., M. Pagani, L. Sloan, E. Thomas, K. Billups. 2001. “Trends, rhythms, and aberrations in global climate 65 MA to present.” *Science,* 292: 686-693.