Climate Change and Natural Resources in Pima County: Anticipated Effects and Management Challenges

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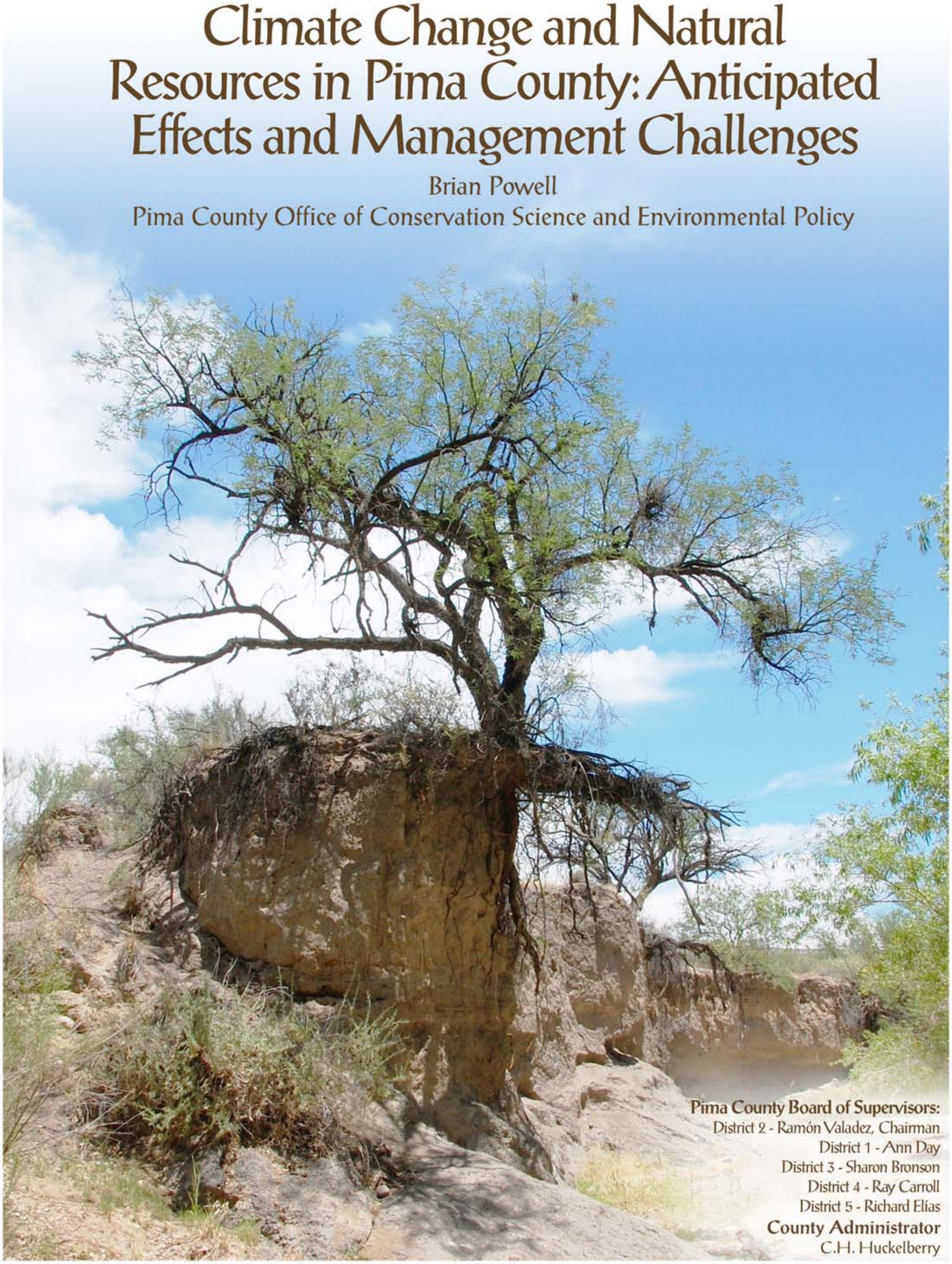

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Cover Photo taken at Cienega Creek Preserve by Brian Powell

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Abstract

Climate change (also referred to as *climate disruption*) is a considerable threat to the biota of Pima County and beyond and therefore warrants special attention in any large-scale planning process such as Pima County's Sonoran Desert Conservation Plan and Multiple-species Conservation Plan. During the 20th Century, the earth's surface warmed by approximately 1.0°F, a trend that appeared to be even more severe in the Southwestern United States. Climate models for the 21st Century show ever-increasing temperatures and prolonged drought in the Sonoran Desert. Precipitation is expected to become more variable and most models for the Sonoran Desert predict a slight increase in summer precipitation but significant decreases in winter precipitation.

The ecological consequences of a changed climate will present serious long-term challenges to the maintenance of proper functioning ecosystems and the species that rely on them. Projected ecological effects on natural resources in Pima County include:

- Within-community shifts in vegetation composition due to higher atmospheric carbon dioxide and temperatures;
- Vegetation communities will move upslope, thereby endangering communities at the tops of mountain ranges;
- Impaired hydrological function due to more intense flooding and subsequent runoff;
- Conditions in the lower elevation upland communities favoring the spread of invasive species such as buffelgrass;
- Less water in valley-bottom aquatic and riparian systems;
- Longer fire seasons and more intense fires;
- Species shifts in abundance, distribution, and phenology.

The extinction risk from climate change is greatest for those species that are already at risk, such as many of the Priority Vulnerable Species that formed the foundation of the planning effort for the Sonoran Desert Conservation Plan. Climate-driven effects on ecosystem structure and function (e.g., fire, nutrient cycling, succession, and invasion by exotic species), coupled with non-climate related threats (e.g., off-road vehicle use, mining, and pollution), will effect Priority Vulnerable Species and other species and their habitats in Pima County. As a first approximation of effects on specific species, I provide a qualitative evaluation of 49 species that are proposed for coverage in the forthcoming Habitat Conservation Plan for Pima County. Not surprisingly, the most significant climate-related impacts are likely to be to aquatic and riparian species.

Given the anticipated effects of climate change on natural resources in Pima County, it will be critical for climate assessments to be included in any natural resource planning effort by the County such as restoration projects and the ranch management programs. To facilitate these assessments, Pima County must continue to be engaged with the scientific and land management community to promote regional adaptation strategies into the Sonoran Desert Conservation Plan. Monitoring and adaptive management programs and processes, led by both the County and our partners, will also be

important. Finally, minimizing the use of fossil fuels (the most significant contributor to climate change) through the facilitation of a compact urban form, and promoting investments in energy efficiency in housing and urban infrastructure will lessen Pima County's contribution to a warming planet.

1 Overview of Climate Change

1.1 Climate Change or Climate Disruption?

This report is intended as an overview of past and projected impacts resulting from a warming climate. Because of the severe changes that have and will continue to impact our environment as a result of this warming, I occasionally use the term *climate disruption* instead of the more benign terms *climate change* or *global warming*. Just as habitat destruction is more apt term for what happens to a species' habitat as a result of conversion from a natural state to an unnatural state, climate disruption is an appropriate term to describe the alarming and ever-increasing impacts of earth's rapid and unnatural warming on our natural resources. Because the general public and much of the scientific community are accustomed to the term *climate change*, I employ its use throughout the report.

1.2 Recent Climate Change

Climate change is occurring at a more rapid rate than at any time in at least the last 650,000 years due to the rapid increase in carbon dioxide (CO_2) and other greenhouse gases (Solomon et. al. 2007). Carbon dioxide, the most common greenhouse gas in the atmosphere, has increased by a startling 22% since the 1950s, with the principal cause being a six-fold increase in the use of hydrocarbons (Solomon et al. 2007). Greenhouse gases (principally CO_2, methane, and nitrous oxide) are termed such because of their effect on the earth's atmosphere (Fig. 1). Solar radiation from the sun penetrates the earth's atmosphere. About one half of this radiation is absorbed by the earth's surface, and the remaining radiation is converted to heat energy, causing the emission of longwave (infrared) radiation back into the atmosphere. Some of this infrared radiation passes through the atmosphere, but some is absorbed by the greenhouse gas molecules. The result is a warming of the earth.

During the 20th Century, temperatures on the surface of the earth increased by 0.5°F to 1.1°F, with a dramatic rise in temperatures in the last 50 years (PRISM Group 2007; Fig. 2). Models of temperature increases in Arizona have exceeded average global temperature increases by 50% since the 1970s (PRISM Group 2007; Figs. 3, 4). A recent assessment of climate change vulnerabilities in New Mexico found that areas in the southwestern portion to the state experienced hotter and drier conditions relative to other parts of the state (Enquist and Gori 2008).

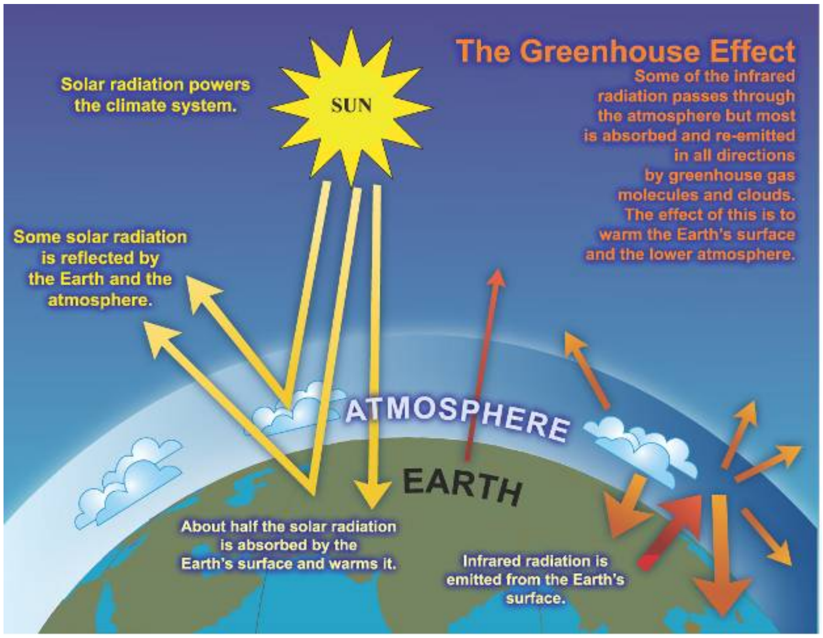

Figure 1. Diagram showing the greenhouse gas effect. Figure FAQ1.3 from IPCC (2007).

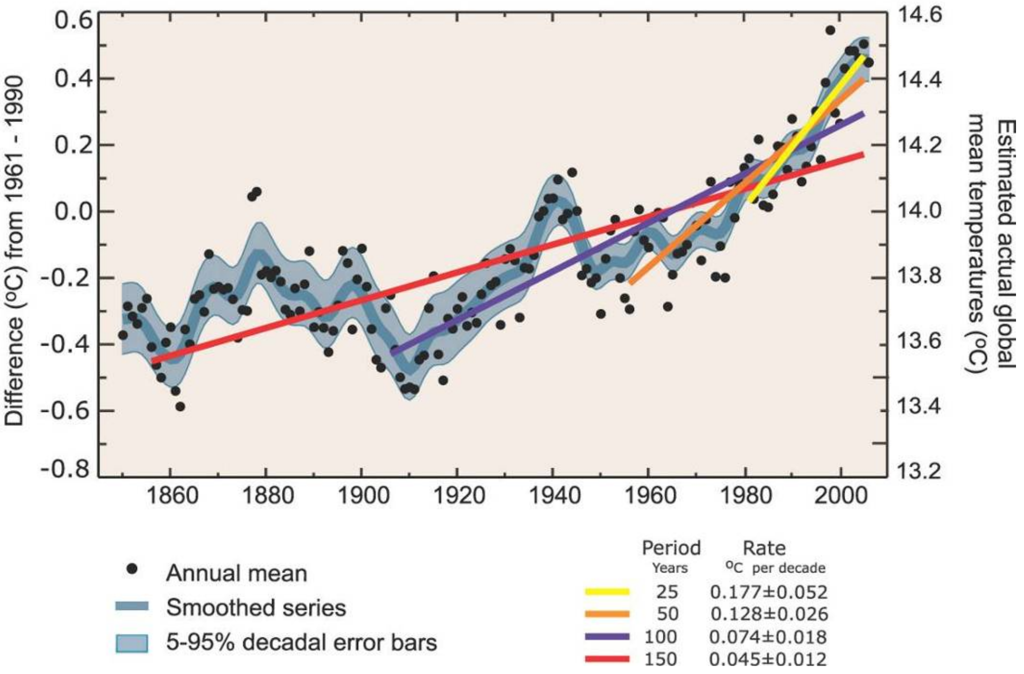

Figure 2. Rise in global temperatures since 1850. Note the rate of increase in temperatures in the last 25 years (yellow line) compared to the 150-year trend (red line). Figure TS.6 from Solomon et al. (2007).

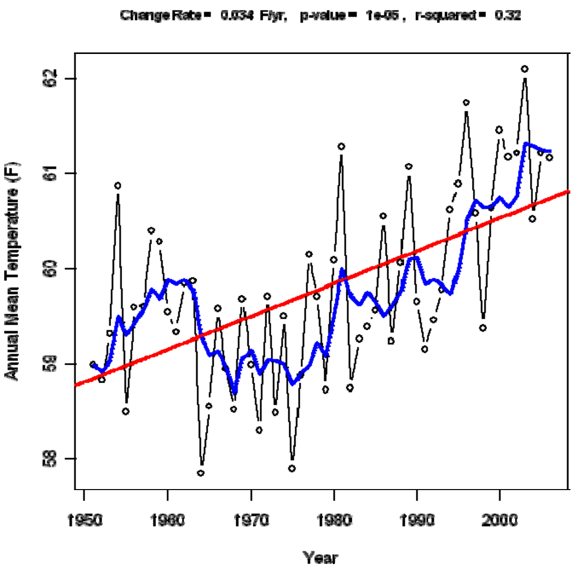

Figure 3. Change in the average temperature in Arizona from 1950-2007. Data and image from PRISM Group (2007) and Gibson et al. (2002). Red line is the linear trend; blue line is the 5-year moving average.

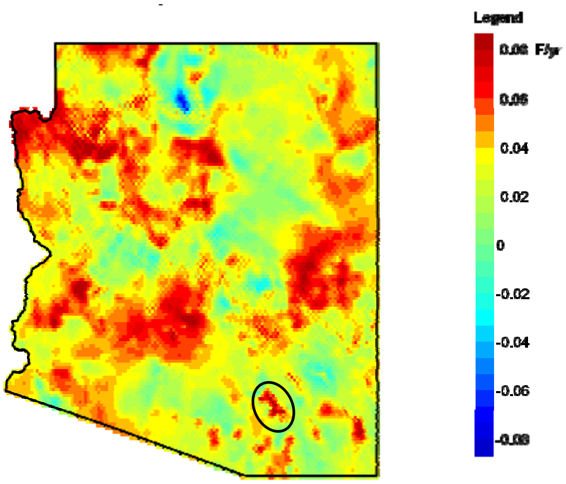

Figure 4. Modeled temperature changes in Arizona, 1951-2007. Temperatures were well above normal in high-elevation locations in southern Arizona such as the Catalina/Rincon complex (circled), in some cases four times greater than the national average. Image created by the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset.

1.3 A Glimpse of Our Climate Future

Future climate change scenarios are the subject of intense scientific debate, but the mainstream debate does not center on whether climate change will occur, but by how much. In their most recent report, the International Panel on Climate Change (IPCC) summarized the results of 23 climate-change predictions (models). Based on a set of assumptions about the future release of greenhouse gases, these models predicted an increase of between 3.2°F to 7.2°F in the next 100 years (Fig. 5; Meehl et. al. 2007). The current consensus among scientists is for an average global increase of at least 5.4°F in the next 100 years based on a scenario of steadily increasing greenhouse gas emissions (i.e., "business as usual" model). One thing is clear: climate change in the 21st Century will be far more significant than the warming that has occurred to date. The general patterns of change include: warming of the lower atmosphere, weakening of tropical circulation patterns, and poleward migration of mid-latitude storm tracks. The ecological effects of these changes are not known for certain, but observed changes in the later parts of the 20th Century and the significant investment in forecasting, gives us insights into likely changes.

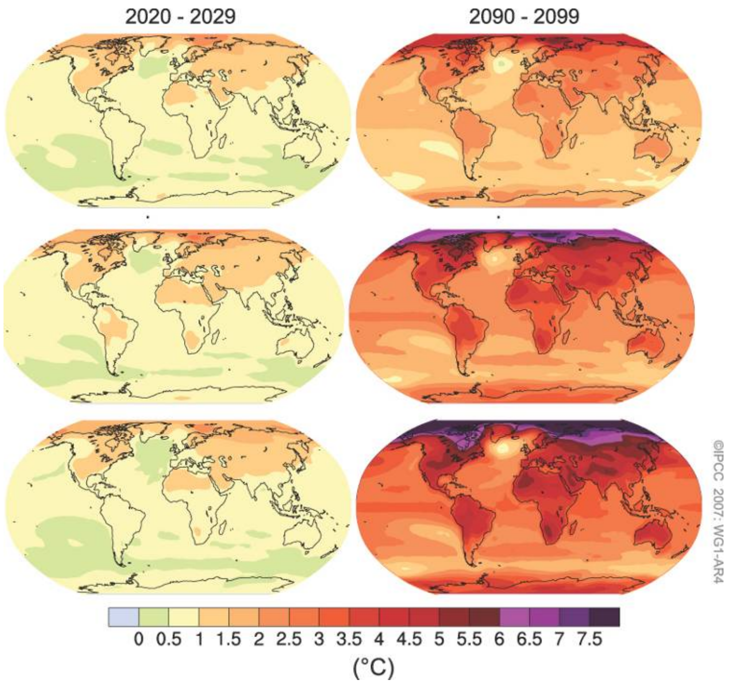

Figure 5. Projected surface temperature changes for the early and late 21st Century relative to the period 1980 to 1999. Panels show multi-model average projections (°C) for the B1 (top), A1B (middle) and A2 (bottom) climate-change scenarios, averaged over the decades 2020 to 2029 (centre) and 2090 to 2099 (right). Figure TS30 from Solomon et al. (2007).

1.4 Future Climate Change and Pima County

To understand ecological changes that will likely result from climate change in the southwestern U.S. in general and Pima County in particular, it is helpful to understand the current climate patterns, particularly as they relate to precipitation. Though warming is expected to be gradual and relatively uniform over the next century, precipitation will be more variable. Because of the importance of precipitation for controlling a host of ecological processes and species, it warrants special emphasis.

Precipitation in the southwestern U.S. is noted for its variability, which results from a number of factors including the Southwest's complex geography, elevations, position relative to the gulfs of California and Mexico, and from the fact that it is located between the mid-latitude and subtropical atmosphere circulation regimes (Sheppard et. al. 2002). This complex interplay has led to a climate that has been punctuated with periods of extreme drought (Swetnam and Betancourt 1998). Two important phenomena are now part of the vernacular for residents in the region: *El Niño,* a warming of the sea temperature in the eastern Pacific, often causes an increase in winter precipitation in the Southwest, whereas *La Niña* usually results in dry winters. The interplay of these two forces is known as El Niño-Southern Oscillation (ENSO). Finally, the Pacific Decadal Oscillation (PDO), a temporal variation in sea surface temperature in the Pacific, usually interacts with ENSO by amplifying its effect.

No specific analysis of the effects of climate change have been made for Pima County, but the southwestern U.S. has received a number of assessments (Field et. al. 2007). There is considerable variation in the models used, but most predict a 10-20% reduction in precipitation in the Southwest region in the next 75 years (Fig. 6; Christensen et. al. 2007), with most reductions in precipitation during the winter months when circulation patterns over the Pacific Ocean prevent moisture from entering the region through a movement of the storm track to the north. This leaves southern Arizona more arid (Fig. 6). Drier conditions are expected to be particularly severe during years when La Niña patterns predominate (Seager et. al. 2007). By contrast, summer monsoons in Pima County result from warm, moist air from the Gulf of Mexico and eastern Pacific, resulting in high-intensity monsoon rains. The processes which bring monsoon rains to southeastern Arizona is not expected to be disrupted in the same way as those processes that affect winter precipitation, though there is considerable uncertainty in these models. Overall, the climate of Pima County will be hotter and dryer with more extreme periods of high temperatures and extreme weather events (Fig. 7).

Even if precipitation in Pima County remains at historical averages, higher average temperatures will have the effect of lower rainfall because of greater evaporation and evapotranspiration. Recent work by The Nature Conservancy indicates that moisture stress (annual evaporation minus precipitation) from 1970-2006 led to an effective decrease in precipitation of approximately 1/3 inches over much of Pima County (Rob Marshall, *unpublished data*). Moisture stress will increase in the coming decades.

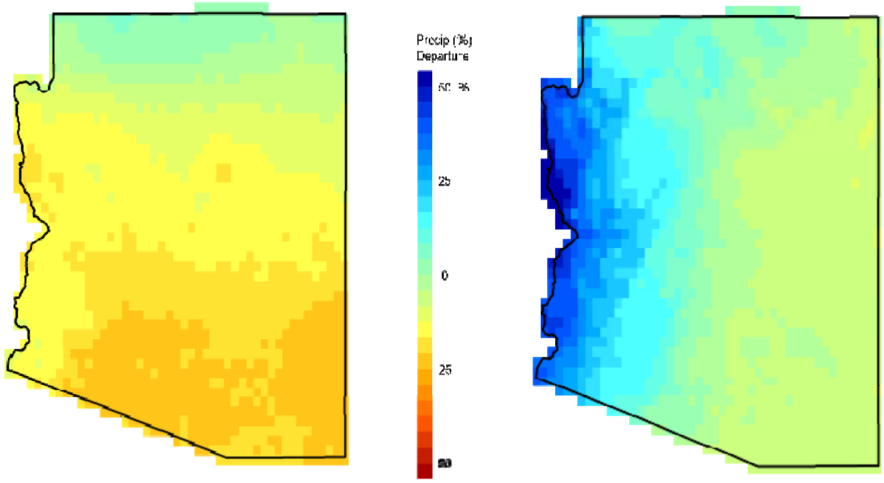

Figure 6. Projected change in precipitation for winter (left) and summer (right) by 2099 under the "business as usual" climate scenario. Projections downscaled by Maurer et al. (2007). Image created by the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset.

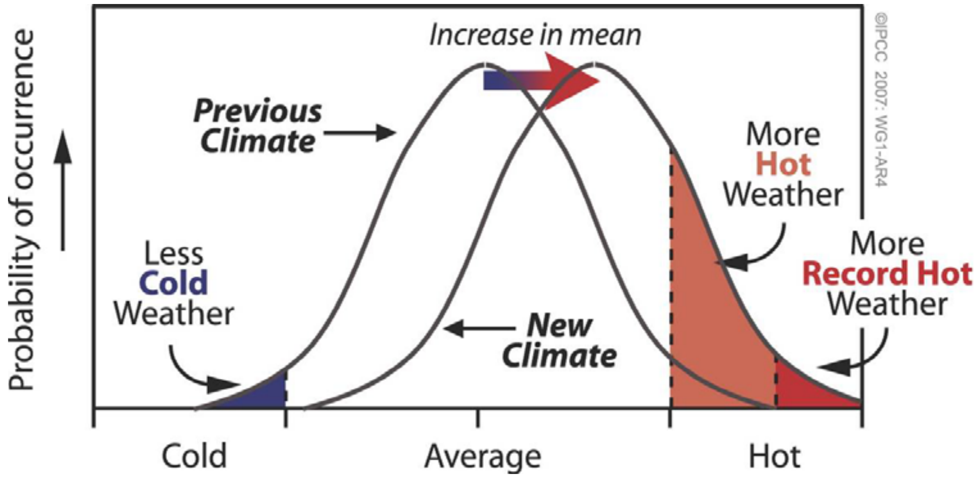

Figure 7. Pima County will experience fewer frosts, a greater number of hot days, and an increased incidence of extreme record high temperatures. Figure TS.5 from Solomon et al. (2007).

2 Effects of Climate Change on Ecological Resources in Pima County

This section highlight the most likely effects of climate change on a suite of ecological resources in Pima County, including ecological function, water resources, and species. This report builds off of the report by Scalero et al. (2001), which touched briefly on projected effects of climate change on natural resources. This report is not intended to be an exhaustive analysis of climate-change effects, but rather an overview of the literature as it relates to resources and systems in the Southwest and my extrapolation of these effects to natural resources in Pima County. This report does not attempt to address the many human-dimension consequences of climate change including threats to infrastructure and impacts on human health, agriculture, and water security. These issues should be addressed in any long-term planning efforts, such as is being undertaken by Pima County's Sustainability Initiative and the joint City of Tucson/Pima County water study.

2.1 Ecological Processes

Ecosystems are a unique set of structural and compositional characteristics that are largely shaped by ecosystem processes such as the water cycle, mineral cycle, energy flow, and community dynamics. Changes in these processes often have cascading effects on the structure and function of ecosystems components and most ecosystem processes are sensitive to climate change. Though there are many ecological processes of interest (e.g., competition, transpiration, decomposition), I focus here on primary productivity and wildland fire. Other ecosystem processes (e.g., plant community succession) are addressed in other sections of this report.

2.1.1 Primary Productivity

Primary productivity is the amount of biomass produced through photosynthesis and is a fundamental measure of ecosystem processes. Elevated CO_2 levels may lead to increased primary productivity in some ecosystems (Boisvenue and Running 2006). Termed "CO_2 fertilization," its effect on plants and plant communities in Pima County may differ among the major vegetation communities, primarily due to differences in water availability, which regulates photosynthesis. Also impacting ecosystem productivity will be increases in temperature. In forested regions such as the Santa Catalina Mountains there is already a climate-driven increase in productivity because of a longer growing season, whereas valley floor communities such as the semi-desert grasslands may experience no increases in productivity because of a reduced availability of water for use by plants in these areas (Lockwood 2000). Other factors may also complicate our understanding of the response of primary productivity to increases in temperature and CO_2, including competition among species and the effects of ozone, pollutants, and nitrogen deposition (Boisvenue and Running 2006). More research is needed before we can determine the severity of climate-change effects on primary productivity.

2.1.2 Wildland Fire

Fire has historically played an important, natural role in most of the vegetation communities of Pima County, from semi-desert grasslands to the highest-elevation conifer forests (Allen 1996, Swetnam and Baisan 1996). Fire suppression has caused an increase in the severity and extent of recent wildland fires, but climate-induced changes are exacerbating the problem. Westerling et al. (2006) found that the wildfire season in the western U.S. in the last three decades has increased by 78 days, and burn durations of fires >1000 ha in area have increased from 7.5 to 37.1 days in response to recent climate change. Looking to the future, the hotter, drier conditions portend important changes to wildland fires in Pima County. General predictions include more fires occurring earlier and later than normal. This will increase the chance for catastrophic fires, such as the Bullock and Aspen fires in the Santa Catalina Mountains in 2002 and 2003, respectively. More frequent and intense fire will hasten transitions to new plant communities, have cascading effects on sensitive plant and animal species (McKenzie et. al. 2004), and impair ecosystem functions.

Though fire was once restricted to montane forests, woodlands, and semi-desert grasslands, there is now an increased fire risk in low-elevation desert upland communities because of the spread of buffelgrass and other invasive species such as brome (Franklin et. al. 2006; see section 2.5.2). Historically, these communities have not been prone to fire because of a lack of fine fuels, most notably grasses. Buffelgrass fills in the spaces between plants and provides fuel for intense fires that threaten the desert ecosystem. Unless buffelgrass, in particular, is brought under control in many areas such the Santa Catalina and Rincon Mountains, there will be a continuous fire threat from the bottoms to the tops of these and other mountain ranges.

2.2 Soils

Soil is the intermediary between climate and vegetation and it plays a critical role in regulating the biogeochemical cycles that regulate the flow of energy in natural systems. Soils play a direct role in the accumulation or decomposition of nutrients and organic matter, processes greatly controlled by climactic conditions, most especially temperature and precipitation. The elevated levels of atmospheric CO_2 combined with higher temperature and more variable precipitation has spawned great debate about the effects of climate change on the historic rates of soil formation and respiration, most especially soil organ carbon sequestration and loss (Grace and Rayment 2000, Davidson and Janssens 2006). Recent long-term experiments have largely shown that increased temperature will increase soil carbon loss from most systems (Knorr et. al. 2005), but the change in precipitation patterns predicted for the Sonoran Desert—from less winter precipitation to shorter-duration but higher intensity summer (monsoon) storms—may complicate the effects of climate change on soil respiration and carbon sequestration. It is possible that reduced winter rains will make our region more of a net carbon emitter because winter rains are too cold to stimulate microbial respiration that gives off CO_2 at levels comparable to the amount captured by plant photosynthesis. Much research is needed in this area because soil microorganisms such as mycorrhizal fungi and heterotrophic bacteria respond differently to the timing and intensity of rainfall events and the picture is further complicated by soil type and plant cover (Huxman et. al. 2004, Cable et. al. 2008). Impaired soil microbial activity is expected to be pronounced along the urban fringes of desert cities (Hall et. al. 2009) such as Tucson.

2.3 Watershed Function

Soils also play a critical role in runoff, recharge, and sediment movement and these critical ecosystem processes will be seriously affected in a warmer climate. Warmer and drier soils will generally store more water, thereby increasing the threshold for initiation of runoff, a situation whereby precipitation is in excess of the soil's capacity to store water. However, a combination of more intense summer storms with an increase in urbanization—which can impair the ability of many systems to absorb water (Kepner et. al. 2004)—can lead to cascading impacts, most importantly by changing the structure of stream beds, thereby affecting aquifer recharge (Fig. 8). This impairs hydrological function of the system by increasing depth to groundwater, which in turn, affects riparian vegetation that relies on groundwater. All of these changes could have severe consequences for key conservation targets, particularly aquatic species (e.g., Parker 2006) (Fig. 9).

2.4 Water Resources

For Pima County, human utilization of water resources will be affected by lower projected rainfall in Pima County, increased demand for water because of higher temperatures and population growth, and likely cuts in allocation of Colorado River water (Christensen et. al. 2004, Barnett et. al. 2005). These and other factors will likely result in less water for natural systems.

During the Sonoran Desert Conservation Plan planning process, Pima County identified a number of aquatic resources that require special conservation status. These Special Elements such as ephemeral and perennial creeks (Fig. 9), springs, and seeps (Fonseca and Connolly 2002) will be affected by climate change because of reduced runoff and recharge. These resources are especially critical for aquatic invertebrates as well as fish, amphibians (e.g., lowland and Chiricahua leopard frogs), bats, and other wildlife that requires periodic water sources (Pounds et. al. 1999, Kirkpatrick et. al. 2007).

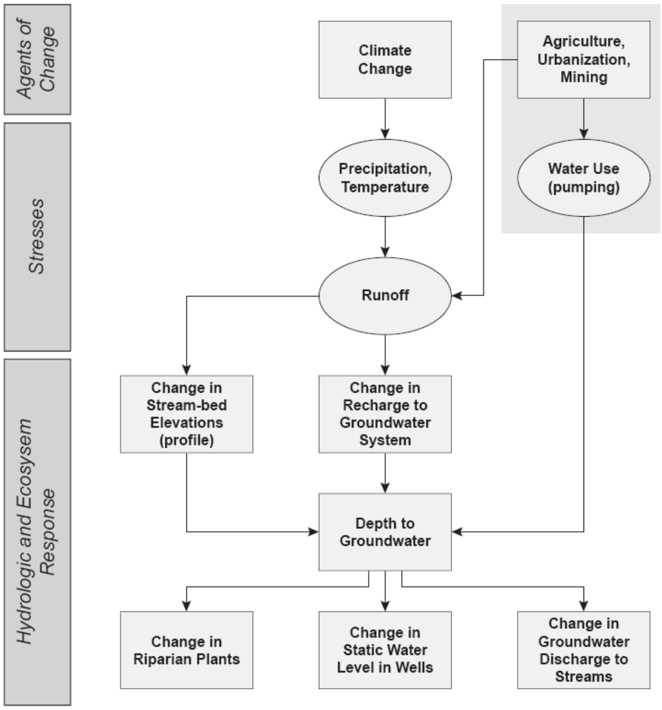

Figure 8. Climatic variation has always affected groundwater-based ecosystems, but climate change and the increased scale of human activities constitute new agents of change. Figure from Fonseca (2008).

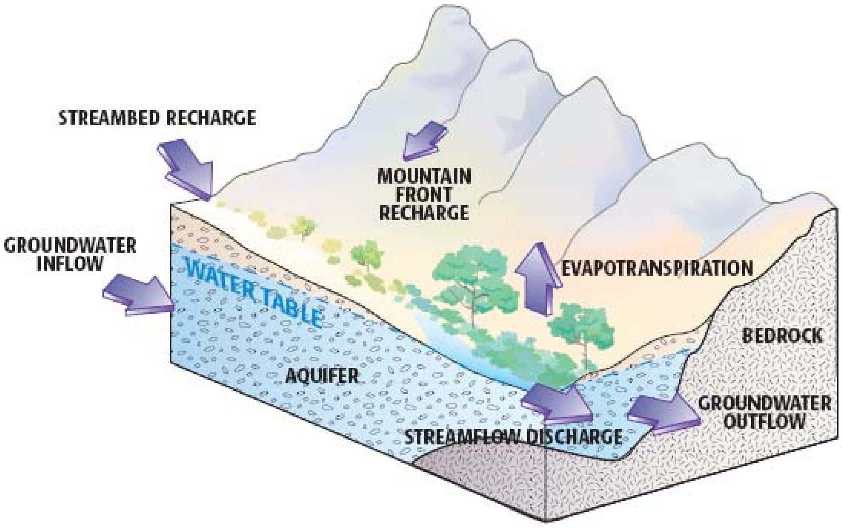

Figure 9. Sources of water inflow and outflow to a basin. A high water table can support streamflow discharge and plant water needs (evapotranspiration) during the driest times of the year. Climate change can impair hydrological function by causing an increase in extreme flooding events, channel scour, and possibly a lower water table. Figure from Fonseca (2008).

Figure 10. Perennial water sources, such as along Rincon Creek, Saguaro National Park, are hotspots of biodiversity in Pima County. A warmer climate and less winter precipitation will likely affect these areas and further stress these already endangered resources.

2.5 Vegetation Community Composition and Structure

As noted in the previous sections, the response of vegetation to increased temperate and greater CO_2 concentrations are uncertain because ecosystem responses to climate change are often difficult to predict because of so many interacting factors (Burkett et. al. 2005). Yet, a common phenomenon in the past few decades has been a shift in vegetation communities, both in elevation and in latitude. The interface between communities, known as an *ecotone*, is often the place where change is first and most notable. An excellent example of this happened in the 1950s in New Mexico, where a severe drought caused a rapid ecotone shift between ponderosa pine forest and piñon-juniper woodland (Allen and Breshears 1998, Breshears et. al. 2005, Mueller et. al. 2005). Shifts in the dominant plant species has important implication for fire intensity and frequency.

Ecotonal shifts will be particularly prevalent in the Sky Island regions of southern Arizona and Mexico, where plant communities will migrate up in elevation in response to climate change. This will likely result in the expansion the desert uplands in the Catalina, Rincon, Santa Rita, and Sierrita Mountains and into the semi-desert grasslands throughout eastern Pima County. The most likely and consequential shift in vegetation communities in the region will be those at the tops of mountain ranges. Having nowhere to migrate to, these communities will likely disappear. Examples of likely changes include remnants of semi-desert grasslands in places like Wasson Peak in the

Tucson Mountains (Rondeau et. al. 1996) and spruce trees on places like the Santa Catalina Mountains.

Semi-desert grasslands of Pima County will experience one of the most profound changes due to climate change. These systems have already experienced climate-induced changes in composition and structure through shrub encroachment into areas that historically were grass-dominated. Woody plant encroachment has been facilitated by non-climate factors such as cattle grazing and fire suppression, but climate change effects (most notably drought) have also played an important role (Grover and Musick 1990, Van Auken 2000). The effect of these woody invasions on soil organic carbon and nitrogen fixation and their effects on grassland productivity is a subject of research and debate (Throop and Archer 2008). It is likely that grasslands in Pima County will face increasing woody shrub encroachment under hotter conditions and higher CO_2 concentrations (Brown et. al. 1997, Polley et. al. 2002). As noted earlier, a larger proportion of annual precipitation will be from summer monsoons storms and this will favor woody plant encroachment, particularly along woodland/grassland ecotones (Weltzin and McPherson 2000). Much research remains in the area of grassland-shrubland dynamics because many uncertainties exist. For example, mesquite invasions of grassland appear to follow strong winter rainfall seasons. What will happen to this pattern under scenarios of warming and drying?

As was documented numerous times in the development of the Sonoran Desert Conservation Plan, the most at-risk vegetation community is the bottomland cottonwood/willow (i.e., mesic riparian) forests of the County (Fig. 11). Trees in these communities are susceptible to mortality in the late spring. With a possible reduction in average winter precipitation, dieoff of individuals or entire communities may occur. Acute drought stress on trees in this community was seen throughout the region in the last 10 years, for example along the Santa Cruz River in Santa Cruz County (Amy McCoy, *unpublished data*) and Rincon Creek in eastern Pima County (Kirkpatrick et al. 2007).

2.5.1 Moisture Stress on Plants

Water availability plays a critical role in the establishment and maintenance of plants and ecosystem function in semiarid systems. Because of increased temperatures and lower average annual rainfall, plants will increasingly experience what is known as *moisture stress*: the increased demand for respiration with less water to perform this critical function. The result of moisture stress varies by species, but it has been shown to influence the distribution and abundance of species, such as we see so dramatically in the Sky Islands of Pima County. Considerable attention is being directed at the effects of moisture stress, particularly in arid and semi-arid ecosystems (e.g., Enquist and Gori 2008), because of the tight water budgets of plants in these areas. A recent assessment of moisture stress for the four-corner states of Utah, Colorado, New Mexico, and

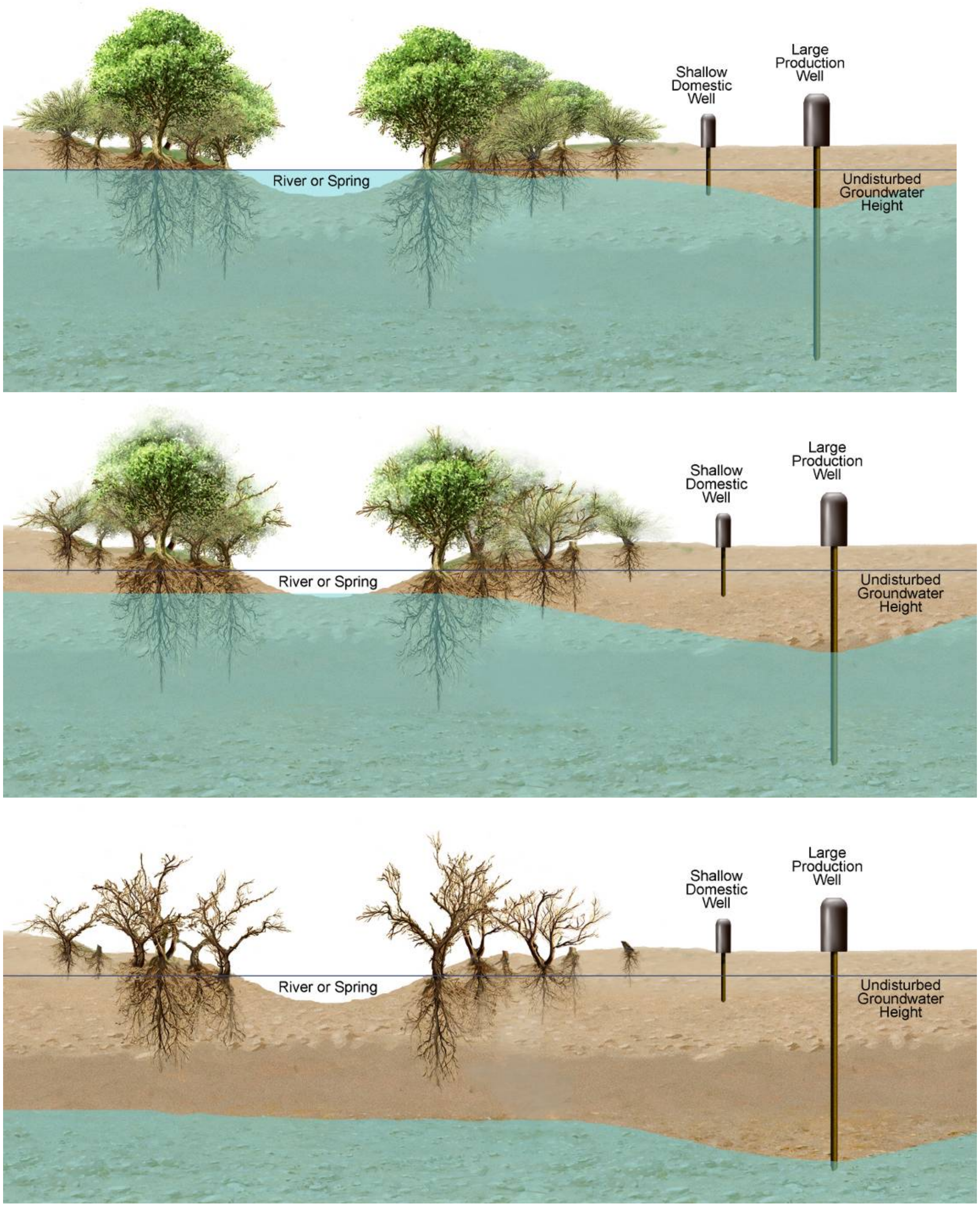

Figure 11. Effects of groundwater decline upon riparian vegetation, from climate change and/or groundwater pumping. The first effects include reduced canopy foliage and reduced herbaceous vegetation diversity and cover. Loss of base flows to stream is shown in second panel, followed by death of characteristic woody riparian trees as groundwater declines below the root zone. Illustration by Bill Singleton and Julia Fonseca originally appeared in Fonseca (2008).

Arizona, found that moisture stress was greatest in the Sonoran Desert region of Arizona (The Nature Conservancy, *unpublished data*).

2.5.2 Invasive Plant Species

Non-native, invasive plant species appear to be favored in a warmer, drier climate with higher concentration of CO_2 (Huxman and Smith 2001). As regional droughts intensify and cause mortality of shrubs in the desert upland communities (Turner 1990), it appears that invasive species are gaining a greater foothold. Species such as buffelgrass threaten to transform large portions of the Sonoran Desert uplands into an African savanna-like system (see Rogstad 2008 for more information). This ability to outcompete native shrubs for scarce water resources and nutrients, coupled with an increase in frost-free days and warmer temperatures upslope (Weiss and Overpeck 2005) will allow buffelgrass and other frost-sensitive exotic species to expand into higher elevation areas of Pima County. As noted earlier, changes in vegetation structure on a site (e.g., from desert uplands to a savanna system) will greatly alter watershed functions such as runoff and sediment transport.

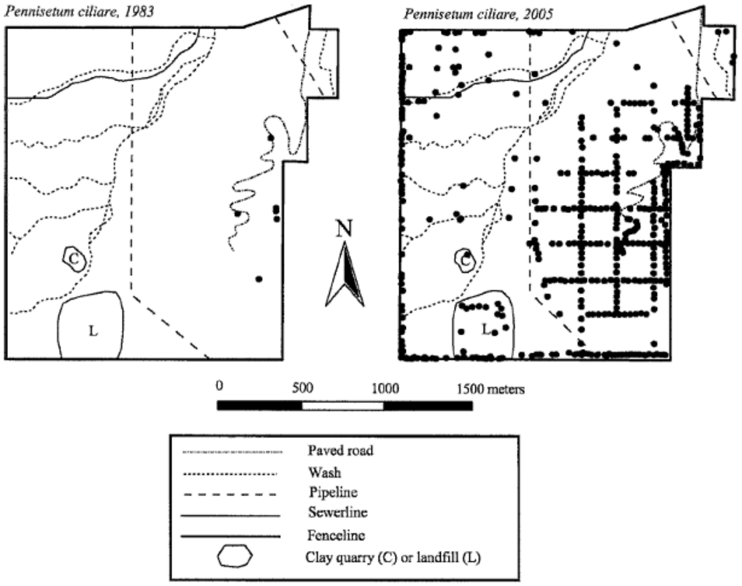

Figure 12. An increase in cold intolerant grasses, such as buffelgrass, will be favored by a warmer climate in Pima County. This figure depicts the increase in buffelgrass on Tumamoc Hill from 1983 to 2005. The species now covers large areas of the Tucson Mountains. Image from Bowers et al. (2006). Printed with permission of the Ecological Society of America.

2.6 Effects on Individual Species

Modeled effects of climate change on biodiversity are ominous; by one estimate 15-37% of the earth's species may go extinct by 2050 as a result of climate change (Thomas et. al. 2004). Climate change has an effect over the broad range of species' responses, from individual fitness to the distribution and abundance of species. Predicting these changes can be difficult. Nevertheless, a number of key changes in vertebrate species and their habitats have been noted in the last few decades. Key among these changes are abundance, distribution, and phenology.

2.6.1 Extirpation, Abundance, and Range Changes of Native Species

Next to habitat loss, climate change is considered to be the second most significant cause of species decline and extinction (Thomas et al. 2004). In addition to affecting their habitat features (e.g., vegetation, soils, water), climate change is causing an unprecedented change in species composition on sites as species seek conditions that match their physiological "envelope" and food resources. In a broad-ranging study of North American wildlife, Parmesan and Yohe (2003) found that 59% of species exhibited measurable changes in their distributions in the last 20-140 years. Range boundaries for many species also changed, moving an average of 6.1 km per decade northward or 6.1 m per decade upward in elevation.

Altitudinal migration is of particular interest in Pima County, and as noted earlier, will likely take place as key vegetation communities that constitute habitat for many species move upslope. In a recent study in the Sierra Nevada Mountains of California, 48 of the 53 species studied moved higher in elevation in response to climate change (Tingley et. al. *In Press*). We would expect the same response in the Sky Islands of Pima County, though the phenomenon has not yet been studied here. Birds may be particularly sensitive to climate change because of their close association with vegetation resources, but for other vertebrate taxa, vegetation is not the only environmental factor that determines habitat suitability. Ranges and distributions of reptiles, amphibians, and fish are often controlled more by physiological tolerances unrelated to vegetation. These species-specific physiological traits can be difficult to quantify and harder to attribute to climate change. However, in the hot and dry areas of Pima County, where species are at or near their physiological limit, increase moisture/heat stress may impair an aspect of their life history. For example, in a number of turtle species (including the desert tortoise), temperature has been shown to influence gender differentiation, with hotter temperatures potentially leading to an increase in the number of females in a population.

Population extirpations are expected to increase, particularly for species that are at the edge of their ranges or are isolated on mountaintops, such as the Mt. Graham red squirrel (Koprowski et. al. 2005). Because Pima County lies at the confluence of four major biogeographic provinces, we anticipate that species loss will occur, particularly for high-elevation species for which the Sky Islands in Pima County are the southernmost populations for these species. For example, 35 high-elevation plant species, most of them near the southern extent of their range, may be extirpated in recent years from the Rincon Mountains, despite concerted efforts to find the species (Bowers and McLaughlin 1987, Powell et. al. 2006). The phenomenon of plants moving up in elevation has been noted in the Santa Catalina Mountains (Crimmins et. al. 2009). For species that follow their "climate envelope" upslope, there is at least hope that such habitat might exist in Pima County with a changing climate (with the exception of those species on mountaintops, as noted earlier). Contrast this to other areas of the world that are flat and therefore species are not able to shift to a higher elevation.

Latitudinal migrations have been noted for a number of species in the greater Sonoran Desert ecosystem. Hill et al. (1998) documented the northward shift in the overwintering of rufous hummingbird in the United States and Mexico. In recent decades a number of species expanded their range northward into southern Arizona (Brown and Davis 1995) and this is expected to continue into the 21st century, particularly for frost-intolerant species from northern Mexico that continue to expand into southern Arizona. This northward shift in species' ranges coincides with a widening of the tropical belt northward (Seidel et. al. 2007). For Pima County, this will likely result in an increase in tropical species northward into southern Arizona. Though future temperature regimes in eastern Pima County may favor range expansion of species from northern Mexico into Pima County, precipitation, particularly during the warm season, may ultimately determine if these species are able to persist here.

2.6.2 Phenology

Phenology is the timing of natural events such as flowering, migration, and egg laying. There is now widespread evidence that changes in phenology are occurring at an alarming rate as a result of climate change. For example, Parmesan and Yohe (2003) found an average change in phenological events of 2.3-5.1 days per decade across a wide range of species. Here in southern Arizona, Brown et al. (1999) found that Mexican jays in southern Arizona initiated breeding earlier by 10.8 days between 1971-1998. For many species, the primary effect of climate change will be the decoupling of the synchrony between a species' key resources such as food and habitat. Examples include predator/prey interactions (Anders and Post 2006), herbivorous insects and host plants, and pollinators and their host plants (Visser and Both 2005). Insects are particularly susceptible to climate change because for many species, timing of emergence is related to temperature (Singer and Thomas 1996).

The emergence of many plant species in the Sonoran Desert are regulated by soil moisture, so as climate affects rainfall, so too will it affect germination, flowering, and seasonality of many plants. If a decoupling of flowering phenology occurs, it could disrupt the host/pollinator interactions. For example, flowering of the ocotillo is regulated by rainfall (Bowers and Dimmitt 1994), but its primary pollinators are hummingbirds (Waser 1979), which are typically triggered into migration by photoperiod (i.e., day length). Phenological changes are often greatest in and adjacent to urban areas (White et. al. 2002), which act to amplify the effects of climate change through the heat island effect (Baker et. al. 2002). Therefore, change in and around the more developed areas of the County will likely cause increased phenological disruptions.

2.6.3 Climate Change and Pima County's Multiple-species Conservation Plan

Pima County has embarked on a comprehensive conservation plan for Pima County known as the Sonoran Desert Conservation Plan. As a part of this planning effort, Pima County is submitting a Habitat Conservation Plan (HCP) for 49 species (4 plants, 8 mammals, 8 birds, 6 fish, 2 amphibians, 7 reptiles, and 14 invertebrates) that may be harmed as a result of the otherwise lawful activities of the County and its development community. In light of the potential changes that can occur to the abundance and distribution of species as a result of climate change, it is instructive to use them to illustrate the potential effects of climate change on species.

Table 1 represents the hypothesized direct and indirect threats that these species face as a result of climate change. This analysis is not intended as an exhaustive list of effects, nor is it an attempt to articulate the effects of climate change as it relates to the issuance and adherence to the terms of the Habitat Conservation Plan. Rather, this is starting place from which a more thorough analysis can be performed.

2.7 A Precautionary Note about Climate Change Effects

Awareness of climate change effects and future scenarios has reached new heights among policy makers, managers, and the general public. Because of the attention paid to the issue in recent years, it may be a surprise to many in Pima County that land-use changes have and will continue to have a greater impact on most natural resources than will climate change in the foreseeable future. Indeed, climate change is a serious threat and should be placed among a host of other threats such as land degradation, mining, and pollution. Because climate change effects are often masked by and interact with these other stressors, it can be difficult to determine the direct impacts of climate change.

Table 1. Potential impacts of climate change on species that are being proposed for coverage by Pima County's Multiple-species Conservation Plan (MSCP). More general impacts may include increased incidence of pests, diseases (e.g., West Nile virus), pathogens, and heat/moisture stress. Abundance and distribution of species are likely to change as a result of climate-facilitated habitat changes such as increases in invasive species and shrub invasions into semi-desert grasslands. This assessment builds on work by Scalero et al. (2001) and is not intended as a formal analysis of Changed Circumstances for the Pima County MSCP.

Taxon Group	Species	Potential Direct and Indirect Impacts from climate change
Plants	Pima pineapple cactus	Lack of synchrony of flowering with native pollinators; shrub invasions
	Needle-spined pineapple cactus	Altered synchrony of flowering with native pollinators; invasive plants introduce fire and compete for resources
	Huachuca water umbel	Habitat altered by drought and scouring floods
	Tumamoc globeberry	Drought affects host plants; habitat loss from invasive plants
Mammals	Mexican long-tongued bat	Altered synchrony with host plants that provide nectar; habitat loss from invasive plants leads to loss of host plants
	Allen's big-eared bat	Loss of water sources may lead to shifts in habitat used; possible change in phenology of insect prey
	Western red bat	Loss or degradation of mesic riparian vegetation from drought; possible change in phenology of insect prey
	Southern yellow bat	Warmer temperatures may facilitate regional increase in population; possible change in phenology of insect prey
	Lesser long-nosed bat	Altered synchrony with host plants that provide nectar; loss of host plants due to habitat conversion and non-native species invasions; sensitivity to cold temperatures may extend period of annual stay in Pima County
	California leaf-nosed bat	Change in phenology of insect prey; change in structure and composition of desert uplands from invasive grasses
	Pale Townsend's big-eared bat	Change in phenology of insect prey
	Merriam's mouse	Closely tied to mesquite forests, which are likely to be affected by drought and increased fire risk
Birds	Burrowing owl	Habitat change via invasive species; prey resources change
	Cactus ferruginous pygmy-owl	Closely tied to fate of saguaros and large ironwood and mesquite, which may be affected by buffelgrass invasion; prey resources may change
	Rufous-winged sparrow	Loss of habitat from invasive grasses; potential change in prey abundance
	Swainson's hawk	Shrub invasions into semi-desert grasslands and reduction in winter rains will degrade habitat; prey base may change
	Western yellow-billed cuckoo	Mesic riparian habitat may be lost due to flooding (i.e., scour) and prolonged drought; lack of synchrony with critical food sources during chick rearing; effects on non-breeding habitat unknown
	Southwestern willow flycatcher	Mesic riparian habitat may be lost due to flooding (i.e., scour) and prolonged drought; increased heat stress; lack of synchrony with food sources during chick rearing; effects on non-breeding habitat unknown
	Abert's towhee	Riparian habitat may be lost due to prolonged drought; lack of synchrony with food sources during chick rearing
	Bell's vireo	Riparian habitat may be lost in some areas due to prolonged drought and flooding, but increased in some areas due to increased in shrub density; lack of synchrony with food sources during chick rearing; effects on non-breeding habitat unknown
Fishes	Longfin dace	Drought conditions will affect water availability and aquatic habitat features; higher temperatures will lead to stress and lower oxygen availability; prey base may change. Positive result of higher

Taxon Group	Species	Potential Direct and Indirect Impacts from climate change
		temperatures may mean fewer freezing events, thereby reducing mortality.
	Desert sucker	See longfin dace; potential effects would be considered in any potential re-establishment
	Sonora sucker	See longfin dace; potential effects would be considered in any potential re-establishment
	Desert pupfish	See longfin dace; potential effects would be considered in any potential re-establishment
	Gila chub	See longfin dace
	Gila topminnow	See longfin dace
Amphibians	Chiricahua leopard frog	Drought conditions lead to loss of open-water habitat; intense fires in uplands leads to loss of habitat from silt and debris buildup; increased water temperatures. Potential positive effects may be a decrease in chytrid fungus because that disease prefers colder water
	Lowland leopard frog	See Chiricahua leopard frog
Reptiles	Desert box turtle	Loss of grassland habitat through shrub encroachment and fire; potential impaired reproduction and survival due to physiological stress; changes in rainfall will change timing of emergence; sex ratios, which is determined by temperature, may be affected;
	Sonoran desert tortoise	Loss of habitat due to invasive grasses; increased heat stress but also possibly increased forage time due to higher temperatures; lower winter rainfall can affect food sources
	Tucson shovel-nosed snake	Higher temperatures may increase above-ground foraging; invasive grasses may alter habitat; increased forage time due to higher temperatures
	Mexican garter snake	Drought conditions will affect this species through loss of aquatic habitat and effects on prey species
	Giant spotted whiptail	Loss of habitat due to invasive plants; shifts in timing of activities
	Red-backed whiptail	Loss of habitat due to invasive plants; shifts in timing of activities
	Ground snake (valley form)	Higher temperatures may increase above-ground foraging; loss of habitat from invasive grasses
Invertebrates	Arkenstone cave pseudoscorpion	Flooding and lower humidity may affect movement, reproduction, and survival
	Talus snails, all species	Lower humidity from reduced winter rainfall may affect fungal food source, emergence, and other life-history functions; fire from invasive plants; increased physiological stress from higher temperatures

3 Management Responses and Recommendations

Climate change will create a new set of challenges for land manager and conservation efforts due to the scope of the effects and the long-term nature of the problem. Any conversation about how to respond to climate change effects must first start with how to reduce greenhouse gas emissions that are the root cause of global warming. In this respect, avoidance and mitigation of greenhouse gas emissions should be a foremost policy response. For example, in eastern Pima County, 34% of greenhouse gas emissions were from transportation, while 64% were from residential, commercial, and industrial sources (Pima Association of Governments 2008). Curtailing emission should focus efforts in all these areas. Indeed, a variety of initiatives are underway to reduce emissions, including for Pima County operations such as construction, maintenance and travel (Pima County 2008b). Pima County has also created mechanisms and tools for land conservation and land-use planning that also reduce or ameliorate greenhouse gas emissions, including:

- Land-use planning that seeks to limit urban sprawl and therefore reduce transportation actions, principally driving vehicles, to reduce greenhouse gas emissions;
- Infrastructure spending to make vehicle transportation more efficient and at the same time provide opportunities for alternative modes of transportation such as busing, biking, and walking;
- Acquisition and long-term retention of the natural open space, some of which would be otherwise be developed. The vegetation, soils, and fungi of the County's reserve system provide approximately 5,700 tons of CO_2 capture per year[1]. This amount is equivalent to the carbon emissions of approximately 647,000 gallons of gasoline[2].

These proactive land-use planning initiatives add to an ever-increasing list of local, national, and international efforts that seek to inventory (Pima Association of Governments 2008) and reduce greenhouse gas emissions. These efforts should be commended, but the scale of greenhouse gas emissions is enormous and will require radical shifts in energy use and production to realize even the most optimistic global warming scenarios (e.g., 3-5°F increase in the next 100 years).

The following sections provide an overview of strategies that can and have been employed to reduce the impact of climate change on natural resources in Pima County, assuming that widespread climate disruptions will occur. I highlight institutional challenges for dealing with

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[1] This is a gross approximation using the Voluntary Reporting of Greenhouse Gases-CarbOn Management Evaluation Tool (COMET-VR), a decision-support tool for agricultural producers, land managers, soil scientists and other agricultural interests. The calculation is based on 229,000 acres of County-owned and managed lands.

[2] CO_2 emissions from a gallon of gasoline = 19.4 pounds/gallon. Data from the Environmental Protection Agency.

climate change and focus particular attention on future land management challenges for the government of Pima County or other land management entities in the region.

3.1 Adaptation Strategies

In the face of unprecedented climate disruption, what tools can managers employ to lessen its effect on natural systems and species? This question is the subject of intense interest in the conservation science and management communities and is central to our ability to manage for change, whether the change comes from climate disruption or other anthropogenic threast. The umbrella concept of *adaptation* is central to any discussion of management response to climate change (West et. al. *In Press*). In this context, adaptation refers to adjusting management actions in the face of changing climatic conditions. This type of adaptation has been termed "planned adaptation" and includes a range of responses, from removing other threats to facilitating transitions of ecological systems from one state to another (Millar et. al. 2007).

The first line of defense in climate change adaptation is to create *resistance* to change. This often involves efforts at reducing or mitigating impacts of a non-climate threat on resources that are likely to be affected by climate change. Examples include fencing of sensitive areas; creating fire breaks; establishing new, year-round water sources; or adding water to aquatic or riparian systems. Promoting resistance provides a reduction in a threat before it has a chance to test the capacity of a system to withstand change. The main criticism of resistance strategies is that they can be seen as simply "buying time," and thereby ignores the underlying fundamentals that will put even more climate-induced stress on the system in the future.

The most widely discussed tenet of climate change adaptation deals with promoting system *resilience* (Turner et. al. 2003, Tompkins and Adger 2004, Millar et al. 2007, Heller and Zavaleta 2009). Resilience is the capacity of a system to resist or regenerate from change before that system undergoes a fundament shift to a different state (Fig. 13). Just as healthy humans are better able to deal with and recover from disease or illness, so too are healthy ecosystems able to deal with stresses and still return to a "healthy" state. Local examples of shifts in system states include: (1) the conversion of semi-desert grasslands to desert scrub and (2) the conversion of desert scrub to savanna following invasion by buffelgrass. Once a system is in a new state, it is very difficult, if not impossible, for the system to recover or be restored to the original state. Therefore, resilience strategies focus on supporting the ability of ecosystems to return to their natural state following disturbance (Dale et. al. 2001). The concept of resilience is similar to resistance, but is generally applied more broadly, as opposed to site-specific interventions. For example, promoting wildland fire in semi-desert grasslands may promote resilience by reducing shrub cover and maintaining conditions favorable for the growth of perennial grasses. Management actions that can foster resilience include reducing anthropogenic threats, reducing fragmentation and increasing connectivity among natural land-cover patches, maintaining adequate representation (e.g., communities and species), protecting key ecosystem features and processes, and focusing restoration efforts to those projects that restore and maintain ecosystem processes and functions (Heller and Zavaleta 2009).

As the effects of climate change intensify, promoting resilience and resistance may prove to be insufficient. Further actions may be necessary, including facilitation of state transitions or reallocation of resources in a way that does not cause broader system harm (Millar et al. 2007) or species extirpation. In other words, if a system is in the process of changing from one state to another (Fig. 13), then it may be deemed appropriate to facilitate an orderly transition to reduce further harm to both the system and human enterprises. Here in Pima County, buffelgrass has begun to transition a number of areas into savanna-like systems. In these areas, it may be appropriate to move from eradication of the species to fire management strategies so as not to cause further degradation of the environment from the fires that can result from buffelgrass. Species in aquatic systems in Pima County face a particularly difficult situation due to decreasing water availability and increasing temperatures (and subsequent reduction in dissolved oxygen). In this case, management efforts should focus on maintaining resilience (e.g., by restoring streamside vegetation to reduce effects on water temperature or by purchasing in-stream water rights), but at some point it may be deemed appropriate to relocate populations to more suitable habitat.

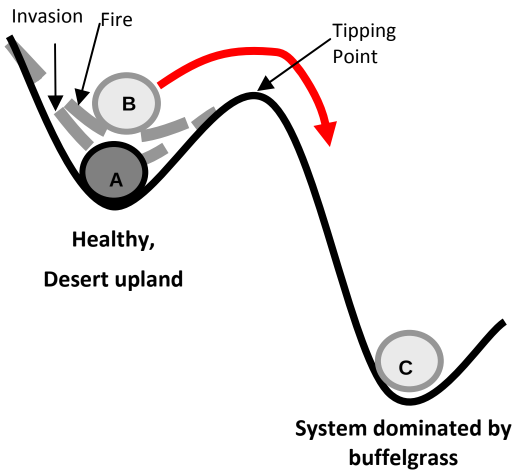


Figure 13. Diagram of a transition pathway from a healthy desert scrub vegetation community to one dominated by buffelgrass. In State A, the system can withstand stressors and still return to a "normal" state, but as the stressors of buffelgrass invasion and fire increase, the system losses resilience (State B) until finally it crosses a tipping point and enters a new state (State C), from which it may be impossible to recover.

3.1.1 Adaptation Strategies in the Sonoran Desert Conservation Plan

The Sonoran Desert Conservation Plan (SDCP) is a regional conservation plan that was developed to address long-term conservation needs of the full range of natural and cultural resources in Pima County (Pima County 2001). Many SDCP initiatives are now being implemented and are guided by the SDCP biological goal:

> "To ensure the long-term survival of the full spectrum of plants and animals that are indigenous to Pima County through maintaining or improving the habitat conditions and ecosystem functions necessary for their survival"

In the face of climate disruption, it may be increasingly difficult to reach this biological goal. Though climate change was considered to be a secondary challenge to achieving this goal, a number of acquisition, management, and regulatory strategies of the SDCP can be considered climate adaptation strategies as highlighted in Heller and Zavaleta (2009) and West et. al (In press), including:

- Acquisition of over 71,000 acres of fee-owned (ownership) lands, and over 120,000 acres of leased lands (Fig. 14), with particular emphasis on lower elevation communities such as riparian corridors and semi-desert grasslands, which had poor representation in the montane-dominated reserve system prior to the initiation of the SDCP;
- Development of a regional reserve design (Maeveen Marie Behan Conservation Land System; see Pima County 2008a) that spans physical gradients such as topography, geology and soils (representativeness);
- Identification and protection of ecological refugia (riparian areas, talus, limestone);
- Preservation and repair of connectivity through designation of critical landscape connections and Priority Conservation Areas for specific taxa (see Pima County 2008a);
- Adoption of a new policy to minimize effects of new groundwater pumping on springs and streams;
- Reductions in stocking rates or forage utilization on County-managed ranches;
- Increase flexibility in rest/rotation grazing cycles by establishing grass banks;
- Investments in fencing for management of livestock on County-owned lands, and improved pasture management and restoration efforts on County ranches;
- Modifications of stock-watering systems to provide safer and more lasting access to water for wildlife;
- Buffelgrass management in reserves and along County roadways;
- Use of County-owned effluent for riparian projects;
- Additional allocation of effluent for riparian projects ("Conservation Effluent Pool");
- Acquisition of groundwater rights;
- Implementation of the Pima County Drought Management Plan.

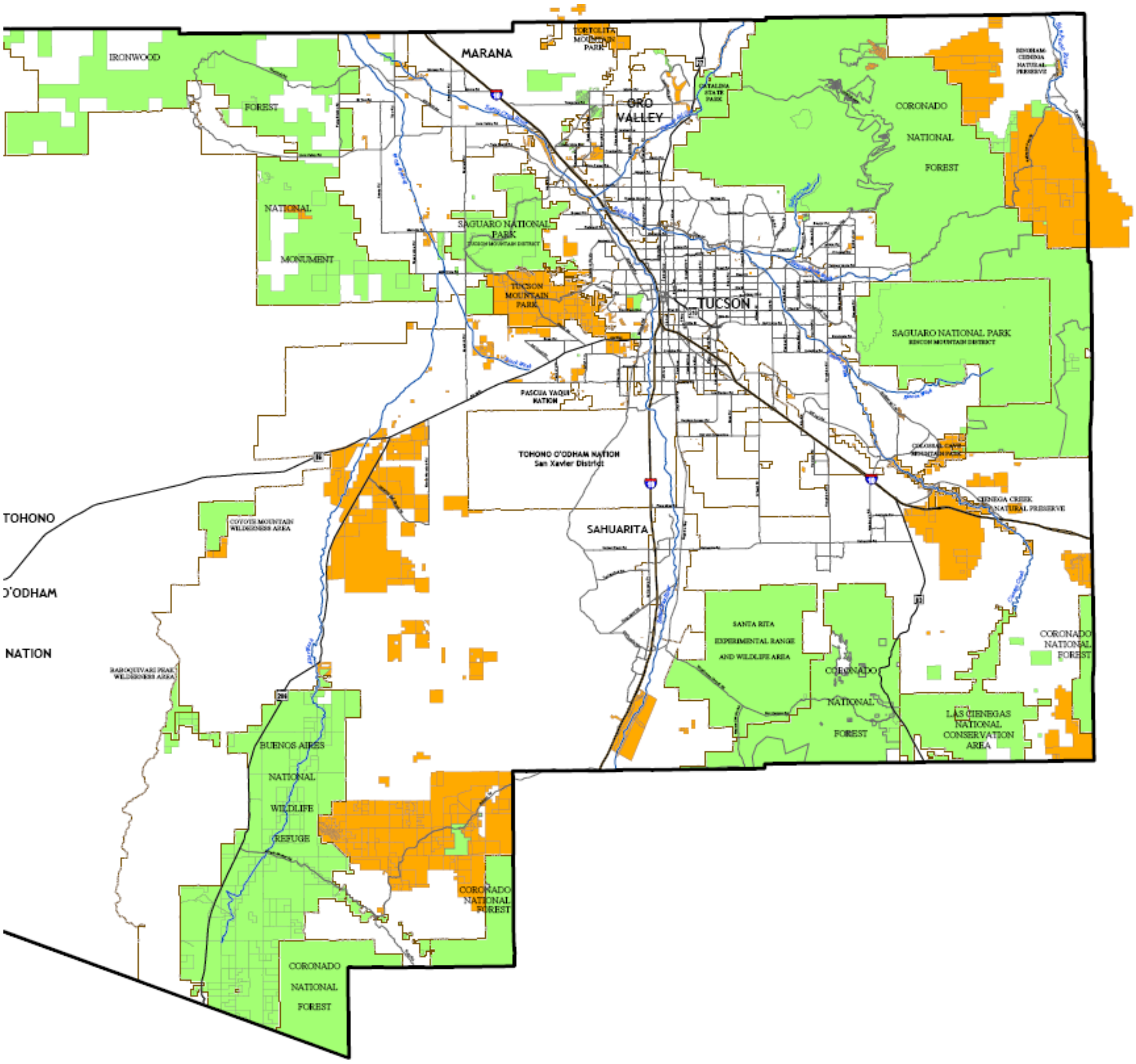
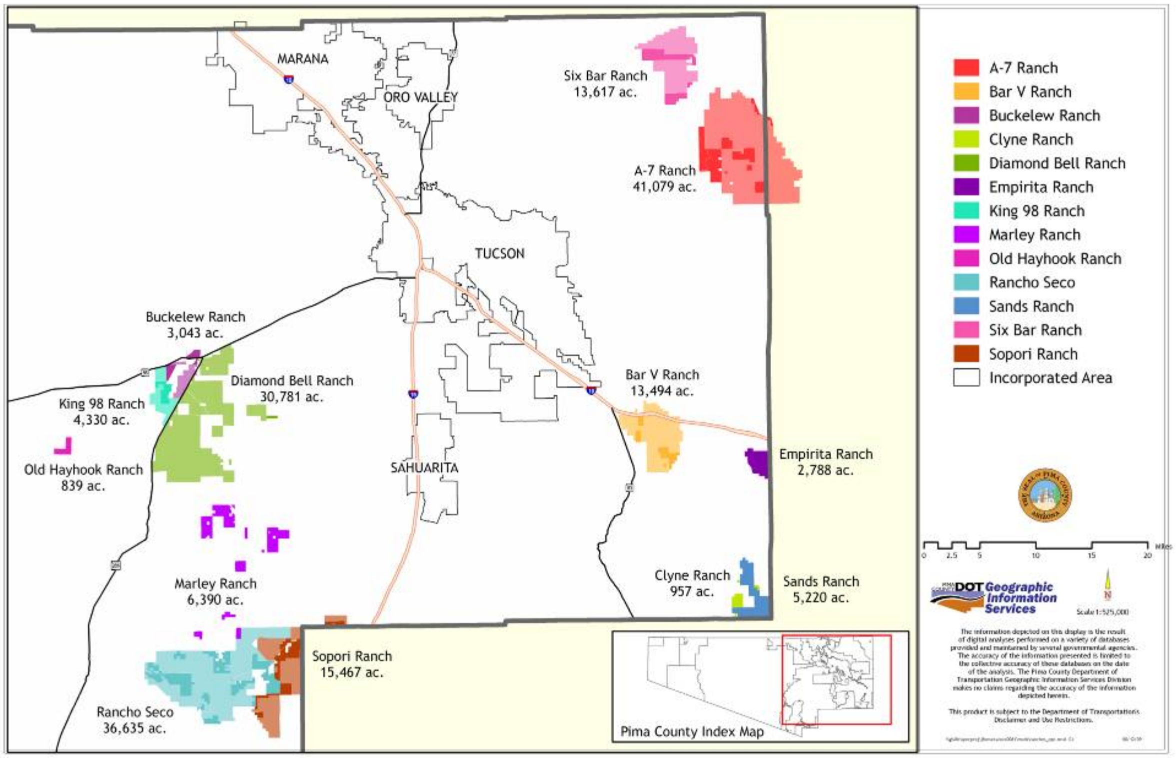


Figure 14. Preserve network in Pima County. Areas in green are under some type of conservation protection by a local, state, or national entity. Areas in orange are managed by Pima County, with most of these acquisitions having taken place since 2004. Because of their close proximity to other natural areas, Pima County preserves play a key role in mitigating climate disruption by protecting natural processes such as species dispersal.

3.2 Future Challenges and Opportunities for Pima County Land Management Activities

The SDCP will continue to be implemented through activities such as further land acquisitions, and may include further regulatory mechanisms to encourage development away from ecologically sensitive areas. Though these are undoubtedly positive conservation measures, the long-term health of these lands will be impaired by climate disruptions. The long-term nature of this problem and its uncertainties will require that Pima County, as land managers, adopt adaptive management strategies that foster flexibility, transparency in decision processes, and a reliance on science and collaboration to solve problems.

Pima County has some experience managing open-space lands, first with Tucson Mountain Park, then in the 1980's with Cienega Creek Preserve. Yet the scale of open-space management has increased exponentially in recent years with the acquisition of approximately 200,000 acres of ranchlands (Fig. 15). These lands provide critical functions for the maintenance of open space in an increasingly urbanizing environment in eastern Pima County and they provide habitat for many important species (Fonseca 2009). The current management paradigm for most of these newly acquired ranches is to continue cattle ranching, an endeavor that relies on precipitation to be successful. (Irrigated pastures make up a small but often important component of a few ranches). Without sufficient rain, cattle forage is much reduced and of poor quality. In addition to lower rainfall and less forage, most high-quality rangelands are being invaded by shrubs, which crowd out perennial grasses that are favored cattle forage. Given these challenges, what will be the future of cattle ranching on Pima County lands under current climate change scenarios? The answer to that question will rest with the County's ability to respond to the constraints



The information depicted on this display is the result of digital analyses performed on a variety of databases provided and maintained by several governmental agencies. The accuracy of the information presented is limited to the collective accuracy of these databases on the date of the analysis. The Pima County Department of Transportation Geographic Information Services Division makes no claims regarding the accuracy of the information depicted herein.

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Figure 15. Ranchlands make up a majority of lands managed by Pima County as part of the Sonoran Desert Conservation Plan and Multiple-species Conservation Plan. Ranching will likely become an increasingly difficult venture under future climate scenarios because of a anticipated decrease in precipitation. Nevertheless, these lands are critical for maintaining open space and wildlife habitat. Different shades of color for most ranches indicate fee title (darker color) and state-trust lands (lighter color).

imposed by climate change and may include grass banking (i.e., setting aside some lands to be used only when conditions on other lands warrant a period of rest) and/or shifts in livestock numbers or type of operations. These decisions have been and will continue to be made in consultation with ranch operators. Already the ranch management program is making stocking-rate decisions based on annual precipitation and forage production and new management and assessment strategies are in development (Pima County 2009).
The example of ranching on Pima County owned and managed lands illustrates the types of innovation and flexibility that will be required given the severity and unpredictability of future climate change. And Pima County will not be alone in this endeavor; other land managers will be challenged by new decision making in the face of climate change. A key question becomes: how to anticipate future challenges and build flexibility into management responses based on changing conditions? One solution is to make decisions within an adaptive management framework, which is an objective-driven and stakeholder-led exercise (Holling 1978, Williams et. al. 2007) that should seek both ecosystem resilience and periodic evaluations of the long-term viability of ranching as a management endeavor. Adaptive management and similar management paradigms, such as those being implemented by Pima County (2009), stress the need for flexibility in response to climate-induced changes.

Another important step is for Pima County to become engaged with the broader community of managers and climate-change scientists to stay educated on new tools and strategies for dealing with climate change. For example, climate-change initiatives have been or soon will be undertaken by all the federal agencies including the U.S. Fish and Wildlife Service, Bureau of Land Management, U.S. Geological Survey, and U.S. Forest Service (e.g., CCSP 2008, U.S. Fish and Wildlife Service 2009) and some non-profit organizations such as The Nature Conservancy (e.g., Climate Wizard: http://www.climatewizard.org/) (Girvetz et. al. 2009). Along with these initiatives will be funding and tools that Pima County can use for our conservation planning efforts. Staying abreast of these efforts will require long-term engagement by the County, yet will be valuable given that the County is not capable of producing these products and assessments.

Collaboration must extend beyond the use of data products and must be seen in on-the-ground management efforts by the County and our conservation partners. The static location of conservation reserves requires that we consider adjacent lands in any land management planning process. The need for cross-boundary collaboration is illustrated by species. As noted earlier, climate change is creating unparalleled shifts in species' ranges, so that if conditions in an area can no longer support a species or an entire community, then they must to be able to move to more suitable habitat or areas that match their physiological tolerances and habitat preferences. Given the patchwork of land ownership in eastern Pima County (Fig. 16), cross-boundary cooperation for activities such as restoration activities or planning will become all the more critical. Recent examples of cross-boundary collaboration by Pima County include fire planning; buffelgrass control, planning, and removal; and landscape-level bullfrog eradication.

3.3 Monitoring for Climate Change Impacts in Pima County

The Pima County Ecological Monitoring Program (PCEMP) is being developed as one component of Pima County's MSCP (RECON Environmental Inc. 2007, Powell 2008, Steidl et. al. 2009). Most of the focus of the PCEMP will be on documenting changes to the habitat and populations of species covered under the MSCP. Therefore, climate monitoring will play an important role in the PCEMP, but only insomuch as it will provide data to help us explain observed changes in species and their habitats. Climate data such as precipitation and temperature will be collected at a select set of PCEMP long-term monitoring sites at a total cost of approximately $18,000 per year (Appendix A). In addition to collecting our own data, we will obtain data from regional climate monitoring partners including:

- Arizona Automated Local Evaluation in Real Time Network,
- Arizona Meteorological Network,
- National Weather Service Cooperative Observer Program,
- Colorado River Basin Forecast Center,
- Rainlog.org volunteer network, and
- Remote Automated Weather Station Network

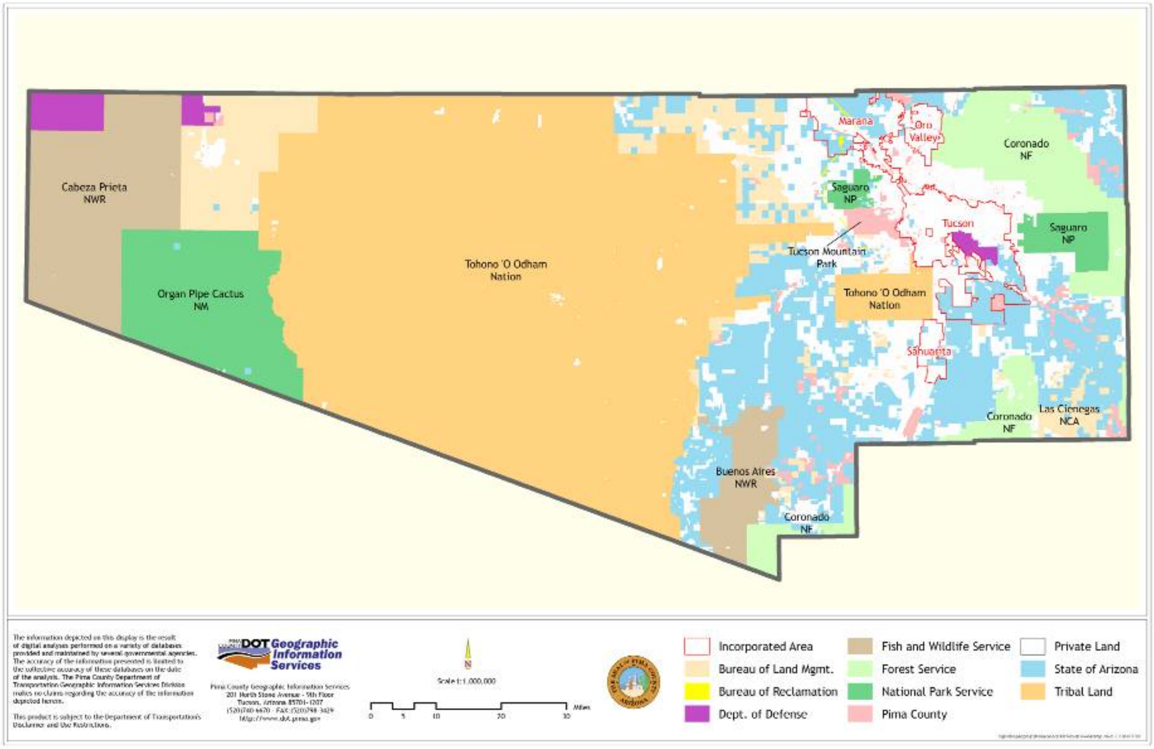

Figure 16. Land ownership in Pima County. The patchwork of ownership, particularly in eastern Pima County will require trans-boundary solutions to the challenges posed by climate change. As a government entity, Pima County only has regulatory authority over a subset of private lands in the County.

I anticipate that the PCEMP will provide data to periodic regional climate assessments, and data types may include precipitation, water resources, and wildlife.

There are a number of monitoring parameters that are directly related to climate and that can be monitored by citizen scientists. For example, monitoring streamflow length is an ideal function for a group of dedicated citizen scientists, some of whom have been conducting similar work in Cienega Creek since 1999. These outings have been an extraordinary educational opportunity for participants and have contributed critical information for understanding the response of Cienega Creek to drought conditions. As a result of this success, monitoring the presence of surface water in several key riparian areas in eastern Pima County (Sabino Creek, Tanque Verde Wash, Agua Caliente Spring, and Arivaca Creek) using trained observers would be ideal. Pima County also plans to partner with the National Phenology Network to provide interested Pima County citizens with the opportunity to monitor changes in phenological events such as initiation of flowering, nesting, or migration (see http://www.usanpn.org for more information).

3.3.1 Future Information and Planning Needs

Incorporating climate change effects into land management planning is relatively new and increasingly there are new tools and initiatives aimed at resolving uncertainties and developing useful tools. To make the most of these initiatives, Pima County will continue to work with other entities (e.g., U.S. Fish and Wildlife Service, The Nature Conservancy) that can assist in a more thorough analysis of anticipated effects. It is our hope that additional resources and a periodic updating of the current knowledge base will provide Pima County with information and tools for making more informed decisions. An example of new tools being developed include a vulnerability assessment for Arizona, similar to the assessment performed by Enquist and Gori (2008) for New Mexico (Carolyn Enquist, *personal communication*). Climate change effects on species niche models (e.g., Preston et. al. 2008) could provide quantitative evaluations of potential change in distribution, especially for species of conservation concern, such as the species proposed for coverage under the forthcoming Habitat Conservation Plan (Pima County 2008a). This type of assessment could be performed on a broader group of species; I have been working with researchers at the University of Arizona to identify habitat variables that are important to a wide range of vertebrate species in Pima County (Steidl et al. 2009). This assessment could use refined Southwest REGAP distribution models (Boykin et. al. 2007, Boykin et. al. 2008) or other planning efforts (e.g., by the USGS Southwest Biological Science Center) to investigate changes in species distributions based on anticipated changes to their habitats and constraints to movement that are faced by species.

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Appendix A. Pima County's approach to climate monitoring as part of the forthcoming Section 10 (incidental take) permit.

Justification. Monitoring precipitation, in particular, will be an important covariate in the Pima County Ecological Monitoring Program when attempting to explain the changes in the other program's parameters. Other climate parameters (temperature, humidity, wind speed, etc.) will be gathered if time and resources permit.

Approach. Precipitation monitoring will take place at all or most of the approximately 200 long-term monitoring sites. We will employ a combination of manual rain gauges and multi-function weather stations with data loggers. Monitoring will be performed by paid staff or volunteers who will check manual rain gauges or download data from automatic data loggers twice per year (September and May). If manual rain gauges are the only method employed, then data on other climate parameters will be gathered from the Pima County Flood Control District ALERT stations and other monitoring partners from throughout the region (e.g., National Weather Service, National Park Service). More details of the sampling design will be articulated in the future.

Costs. Cost will vary depending on the equipment, personnel and location of sampling units. Nevertheless, a rough estimate of cost can be based on a network of 60 sites, which include a mix of manual rain collectors (N = 30) and automatic data logger (N = 30) sites. We anticipate that a subset of manual data collection sites (n = 15) will be collected by volunteers at minimal cost ($1,500/year). The remaining 45 sites will be field checked by paid staff, 20 sites during the course of normal field operations ($3,000/year) and 25 sites as separate trips ($300/day for personnel and vehicles; approximately 3 sites/day = $8,000/year). Equipment costs per year for 30 multi-function weather stations is approximately $3,000/year (assuming units cost $500 each and remain operational for 5 years). Finally, initial program startup cost would be approximately $10,000 for protocol development and planning. Therefore, in the first five years of operation, annual program costs (excluding reporting) will be approximately $17,500/year.