Sonorensis
ARIZONA-SONORA DESERT MUSEUM

2018 Sonorensis
ARIZONA-SONORA DESERT MUSEUM

Volume 38, Number 1
2018
The Arizona-Sonora Desert Museum
Co-founded in 1952 by
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Sonorensis is published as a benefit to the Arizona-Sonora Desert Museum membership as a resource for furthering understanding of the Sonoran Desert Region. 2021 N. Kinney Road, Tucson, Arizona 85743.

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Cover: Illustration by Kayla Velasquez, Graphic Designer, Arizona-Sonora Desert Museum

Back cover: Close-up of cover illustration.

We gratefully acknowledge all the authors, translators, photographers, and organizations who contributed articles, photos, or maps for this issue of *Sonorensis*.

Photos on this page, above left: A farmer in Arlington trying to clear his field with a controlled burn ended up setting fire to the dry brush in the Gila River. Winds gusting to 40 MPH fanned the flames for the whole day. Above right: El Mirage, October 2, 2018. Rainfall from the remnants of Hurricane Rosa overflows into desert bushes at Basin Park in El Mirage Arizona, before flowing into the Agua Fria River.

Contents

INTRODUCTION

Debra Colodner, Ph.D.
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With the release of the *Fourth National Climate Assessment*[1] in November, 2018, and the *Global Warming of 1.5°C Special Report*[2] in October, climate change has been in the news a lot recently. But climate change is also an old story. Our cultural consciousness is steeped in stories of devastating droughts and floods that transformed societies, perhaps from some ancient memories of the tumultuous transition from the last Ice Age. However, the changes in climate we are seeing today are the beginning of an entirely new chapter. Modern civilization evolved and expanded in a period of relatively stable climate. We've planted and built densely on coastlines, in floodplains, in deserts and in fire-prone forests. Adapting to the changes we are likely to see will be difficult for many, especially those with the fewest resources. The latest reports say that we still have the chance to avert the most drastic impacts, those that will occur if the Earth warms by 2°C or more, but that it will take rapid and large adjustments to our economy and infrastructure to do this. The alternative is to expect even larger, more costly disruption to our economy and infrastructure in the coming decades.

Preparing for and adapting to climate change is no longer just the realm of academics and futurists, it is becoming part of the every-day calculus of just about anyone who plans for the future. In this issue of Sonorensis, we focus on climate change adaptation – what changes are we already seeing in our region, what we are likely to see in the future, and how are we preparing to deal with them. In the first article, "Managing for Change in the Sonoran Desert: What are we doing? What can we do?" author Dr. Gregg Garfin explains adaptation planning, and looks at how those we entrust to plan for our future are dealing with both the certainties and uncertainties of future climate. In the second article, "Adapting to Climate Change on the Tohono O'odham Nation", Dr. Selso Villegas focuses in on the Tohono O'odham Nation and shares its planning processes and preparations for future climate conditions.

Above, and clockwise: A massive wall of dust rolling into a rural area west of Phoenix, Arizona; Elegant trogon have been moving north; Saguaros on hillside; Lake Mead; Butterfly finding sustenance in a drying wash; Invasive buffelgrass.

One of the most important changes in our region is the drying trend that we are already seeing. In the third article, "Through the Looking Glass; climate change and the future of water in the Tucson region", Dr. Katharine Jacobs gives us a glimpse at our potential water futures and the tools water managers are using to prepare for them, in the absence of Alice's magical looking glass. Another major impact of climate change, very evident in recent news, is the increase in the frequency of large fires. In "Climate Change, Forests and Fire in the Southwestern US and Northern Mexico", Dr. Don Falk and Dr. Citlali Cortés-Montaño compare forests and forest management in the Southwest United States and Northwest Mexico. In the final article, "Taking the Long View: ecological monitoring helps National Parks, and all of us, prepare for change," Dr. Andy Hubbard, Dr. Alice Wondrak Biel, and Dr. Sarah Studd look more broadly at impacts to ecosystems, showing us changes that are already occurring, and how land managers are adapting their strategies for monitoring and stewarding our public lands. Finally, we offer some suggestions for further learning about the actions you can take at the personal or community scales. A common theme that emerges from these articles is that humans have changed the very "nature of nature," and we need to create new systems for managing this humbling responsibility. Harkening back to Lewis Carroll, time is of the essence for us, as it was for Alice's friend, the White Rabbit.

As we plan for a warmer, more arid future in the west, it is important to make choices that don't further increase greenhouse gas levels in the atmosphere - the underlying driver of modern day climate change - and in fact do the opposite, by making changes that reduce our emissions. The Fourth National Climate Assessment presents the most certain predictions to date of the consequences of climate change for the United States. This report, representing the work of 13 federal agencies, warns that if significant steps are not taken to reduce greenhouse gas levels in the atmosphere in the next decades, we will suffer hundreds of billions of dollars in damage from sea level rise, other damage to infrastructure, heat-related deaths and other impacts. This adds up to taking 10% off the size of the US economy by the end of this century. Of course, action is needed at a global scale, but our region, and the US can play an outsized role via political, scientific and technological leadership, if we choose to do so.

1. Fourth National Climate Assessment, US Global Change Research Program, https://www.globalchange.gov/nca4
2. Global Warming of 1.5oC Special Report, Intergovernmental Panel on Climate Change, https://www.ipcc.ch/sr15/ S

Managing for change in the Sonoran Desert:

What are we doing? What can we do?

Gregg Garfin

Deputy Director of Science Translation and Outreach, Institute of the Environment, University of Arizona

John D Sirlin

Haboob (dust storm) and shelf cloud at sunset.

What is adaptation and why do we need it?

In the National Climate Assessment, adaptation is defined as "adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects" (https://nca2014.globalchange.gov). Adaptation to the effects of climate change is often contrasted with mitigation of the causes of climate change, primarily through reducing emissions of heat-trapping gases. Both actions—the adjustments to changing environments, and the reductions of heat-trapping gases—are needed to deal with existing and projected impacts of climate change. In this article, we are concerned mostly with adaptation, and refer you to many useful resources covering mitigation on page 28-29.

Climate adaptation is already happening all over the globe. The Sonoran Desert is already experiencing increased temperatures and altered precipitation regimes, and Sonoran Desert dwellers are already adapting. Planning for our future climate can determine how difficult further adjustments will be. In this article, we will focus on climate-related risks within the next 50-100 years, and the need to develop and implement strategies to deal with environmental changes in the region. Many of these strategies have benefits in the present as well.

What are those darn scientists saying, now?

The Fourth National Climate Assessment (NCA4) Climate Science Special Report shows that annual average temperatures across Arizona's Sonoran Desert region have increased over 1.5°F during the last 3 decades when compared with the first half of the 20th century. The region has been in the grip of drought for close to two decades, with precipitation decreasing in spring, summer, and fall seasons during the last 3 decades. One characteristic of drought is a marked decrease in regional winter and spring soil moisture, compared with natural variations. Concurrent with these changes has been a significant increase in large fires since the early 1980s.

Cautious projections of future climate from the NCA4 show 2-4°F increases in Sonoran Desert region annual average temperatures by mid-century, and 6-10°F increases in Sonoran Desert region annual average temperatures by the last 3 decades of this century (based on assumptions of medium-high greenhouse gas emissions). This is the equivalent of going down in elevation about 1700 feet – the average temperature in Nogales in 2100 will be the average temperature of Ajo today. In Arizona's Sonoran Desert region, projected changes in extreme temperatures include up to 20 fewer nights per year with temperatures below freezing by mid-century, and 20 to 60 more days per year with temperatures above 90°F. Throughout the Sonoran Desert, increased temperatures will lead to drier soils.

As the temperature of the atmosphere increases, so too does its ability to hold moisture. This increased moisture-holding capacity leads to increased likelihood of extreme precipitation. Already, the Southwest region of the U.S. has experienced an increase in the amount precipitation falling during extreme events. University of Arizona researchers concluded that during the last 20 years, there has been an increase in extreme monsoon season precipitation and intensity, accompanied by an increase in atmospheric moisture. The region is projected to receive 10-20% more precipitation in larger storms that recur every 20 years.

What are the potential challenges?

The upshot of these changes is earlier onset of warm and hot temperatures, less moisture throughout much of the year, and a likely earlier onset of the wildfire season. The combination of these projected changes increases the likelihood of chronic drought in the southwestern United States, which has implications for Sonoran Desert ecosystems and people. Paradoxically, increased climate and weather variability—drier dry spells and wetter wet spells—may set the stage for extreme floods and erosion impacts.

In addition to the direct impacts of climate and weather changes in the Sonoran Desert region, indirect impacts are projected to affect ecosystem processes, such as the frequency and extent of wildland fire, the timing of peak streamflows, and the degree of post-fire erosion. The timing of phenological events—that is, changes in the life cycles of animals and plants – is shifting as well, affecting the population dynamics of insects and their interactions with vegetation, and the ranges and migration of wildlife populations. Insects and pathogens that impact human health are also likely to be affected by climate change.

Climate change impacts to regions distant from the Sonoran Desert will also translate into impacts here. A recent example of this was the disruption of computer hard drive and automobile production during the 2011 floods in Thailand, which slowed deliveries and increased prices in the U.S. In Arizona, cities like Tucson import 97% of their food supplies, placing the city's population at risk from agricultural impacts in states as close as California, as important as the midwestern "breadbasket" states, and as distant as Central and South American countries that increasingly provide winter fruit and produce.

In addition, there is the prospect of complex, intersecting, and cascading risks of climate change—the potential domino effects associated with impacts to multiple systems. For example, in Arizona, the Department of Health Services has investigated the prospects of public health impacts related to an episode of high temperatures that coincides with a power outage. Taking such a scenario one step further, it is easy to envision the heatwave embedded within a drought that also takes a toll on water resources. Such episodes would affect not only humans, but wildlife and vegetation, no doubt.

Adaptation Thinking

Government agencies, organizations, and individuals in the Sonoran Desert region already have experience in adapting to climate-related changes, through drought plans, flood control measures, floodplain zoning requirements, and public health surveillance for insects, like mosquitoes, that carry diseases. One of the key tenets of adaptation thinking is an orientation toward assessing and managing risk. Risk is often assessed by examining the likelihood of an event or trend and the potential magnitude of the impact associated with it. For example, a community might plan for flood risk by assessing plausible changes to flood flow levels and comparing these potential levels with the estimated cost of damages to buildings, land and infrastructure. Engineers and emergency managers use this time-honored approach.

Assessments of risks to Sonoran Desert ecosystems and wildlife are less straightforward. Adaptation thinking, which includes considerations about the vulnerability and resilience of species and ecosystems, can help address the uncertainties related to future climate, land use, technology, laws, and policies. For ecosystem managers, some rules of thumb include reducing non-climate stressors, like pollution, establishing and maintaining key landscape processes like fire, protecting refugia for threatened animals and plants, and enhancing the connectivity between natural areas, to allow species to freely migrate. One approach common to natural resource managers and urban planners is to look for "no and low regrets" and "win-win" strategies. No and low regrets strategies examine current climate-related challenges and evaluate whether it makes sense to deal with them now to fend off plausible future risk. An example is forest treatment, such as prescribed fire, to reduce both current and future risk of catastrophic wildfires. A win-win strategy looks for actions that reduce heat-trapping gases, while reducing climate-related vulnerabilities. An example is bicycling to work, which reduces an individual's emissions while improving that individual's health and resilience to adverse effects.

Adaptation planners are concerned with the prospect of implementing climate-related strategies that are inadvertently in conflict with each other; this is referred to as maladaptation. For example, to reduce risks of water shortage during drought, we might construct a desalination plant. The plant would increase the resilience of water supplies, but the energy required for operation would generate more heat-trapping gases, which would further contribute to global warming. To

Above: Dry river bed. Below: Dramatic storm clouds at sunset with lightning.

address uncertainties and avoid maladaptative strategies, adaptation practitioners use systems thinking, a holistic approach to evaluating the connections among parts of a system, such as an ecosystem, or a large city. Scenario planning is a practice that combines systems thinking with flexible management approaches for anticipating multiple plausible futures. Tucson Water has effectively used scenario planning for more than a decade (https://www.tucsonaz.gov/water/waterplan). Many water and natural resource managers have embraced this approach.

Getting regional

Adaptation to current and future climate change has been embraced by numerous cities, federal agencies, non-governmental organizations, and others in the western U.S. and northern Mexico. For example, the city of Denver, Colorado has a climate adaptation plan that identifies short, medium, and long-term activities across key programs, such as transportation, natural resources and water, and articulates measurable goals and strategies. Planners look to implement adaptation strategies that align with smart-growth principles and city development plans. The strategies are implemented through existing or upcoming strategic planning efforts, to reduce duplication of effort.

"Safeguarding California Plan: 2018 Update" may be the most comprehensive plan in the U.S. In this second update to California's adaptation plan, state planners convey key principles, such as considering climate change in all functions of government, supporting research, partnering with vulnerable populations, prioritizing infrastructure solutions that produce multiple benefits, and promoting collaboration and coordination among federal, local, tribal and regional governments. For example, biodiversity adaptation recommendations include strengthening the climate adaptation component of conservation planning. The recommendation is implemented through existing planning procedures, such as the development of Habitat Conservation Plans, and with specific guidance about how to use the best available science in conservation planning—whether at the state or local level.

There are also numerous examples of climate adaptation-like initiatives called resilience, sustainability, or preparedness plans. In common, they express concerns for extreme climate and weather events, and an orientation toward reducing risk and increasing flexibility and capacity to cope, or even thrive, in the face of changes. Boulder, Colorado articulates climate adaptation actions by setting priorities for managing ecosystems within a climate sustainability framework. Priorities like supporting ecosystem transitions, or investing in scenario planning, so that recommendations for land management reflect the potential range of impacts, are part of the common lexicon of adaptation planning. Flagstaff, Arizona commenced a municipal sustainability plan in 2011 that included a goal of increasing "municipal resiliency and preparedness to weather and climate," through specific policies and actions. In 2017, Flagstaff began the process for its first climate action and adaptation plan. Garnering sufficient community interest and support is a key to success.

Adaptation in the Sonoran Desert

The plausible projected impacts of regional climate change have spurred adaptation thinking and planning among organizations in the Sonoran Desert region. In the southern part of the region, the states of Sonora and Baja California have climate action plans, which primarily address emissions of heat-trapping gases. Adaptation strategies are clearly articulated in the plan for Baja California Sur, which focuses on eight core areas, including water, coasts, desertification, biodiversity, and others. All climate change action plans for Mexico assess climate-related vulnerabilities. The Tohono O'odham Nation is in the process of developing a climate adaptation plan, in order to address concerns such as water resource reliability, floods, the effects of high temperatures on homes and residents, and food security (see page 8).

Climate change is explicitly addressed in the Colorado River Basin Water Supply and Demand Study (Bureau of Reclamation, 2012), which integrates concerns about sustainability of future water resources for fish, wildlife and their habitats, along with water allocations and deliveries for municipal, industrial, agricultural, and energy sectors. The plan, developed with the participation of numerous stakeholders in the Basin, offers adaptive strategies developed in anticipation of multiple possible combinations of climate, development, and population growth scenarios. Until recently, workgroups in the Bureau of Reclamation's "Moving Forward Effort" assessed progress and opportunities related to water conservation, improvements in water use efficiency, and non-regulatory solutions to protect or improve ecological resources. Similar basin studies are in progress in the West Salt River Valley (in western Phoenix area) and the Lower Santa Cruz River Basin (Tucson area, see page 14). In the meantime, the Salt River Project has developed strategies to reduce the risks of water supply shortages through changes to reservoir operations and collaborative management of Phoenix-area well fields to safeguard against continued drought and climate change.

Some Arizona state agencies have beefed up preparedness for climate extremes through federally-funded adaptation initiatives. Arizona's Department of Transportation conducted a pilot climate adaptation study to identify hotspots where highways are vulnerable to extreme weather, including high temperatures, drought, and intense storms. The study enumerates next steps for the Interstate 19 corridor, between Tucson and Nogales, such as giving more consideration to potential shifts in biotic community composition, and more robust modeling of wildfire risk. The Department of Health Services (ADHS) conducted extensive studies and exercises to develop integrated assessments and strategies for preparing for and adapting to climate change-related public health risks, such as extreme heat, air pollution, changes in disease vector (e.g., mosquito) ecology, increasing allergens and other factors. The ADHS work is aimed at implementing climate adaptation measures that align with the Center for Disease Control's Building Resilience Against Climate Effects (BRACE) framework.

The efforts of non-governmental and community organizations are essential to climate change adaptation in the Sonoran Desert region. For example, scientists from The Nature Conservancy in Arizona, in collaboration with an ad hoc partnership of community groups, private landholders, and conservation organizations in southeastern Arizona, the Sonoita Valley Planning Partnership, have contributed substantially to efforts by the Bureau of Land Management to manage the Las Cienegas National Conservation Area in ways that anticipate climate change. Las Cienegas adaptive management initiatives now incorporate adaptation strategies, such as monitoring of climate-related indicators, replication of populations of threatened species, creation of refugia, and reduction of non-climate stressors like invasive species. Based on priorities identified through a series of climate adaptation workshops, the Sky Island Alliance has committed substantial resources to inventorying and monitoring springs and seeps, which are known to be biodiversity hotspots and anticipated to be species refugia in a hotter climate.

Other ways of preparing for change

Another way communities in the Sonoran Desert region are preparing for climate change is by investing in human capital through community and formal education, and by convening communities of practice (see page 28). Through such investments, the potential to adjust to changes in climate, to moderate potential damages, take advantage of opportunities, and cope with consequences—can be strengthened. Colleagues at the University of Arizona have institutionalized practices for enhancing the benefits of investments in "engaged research", through improved understanding of the process of co-producing science, knowledge, and policy with the broader community. This is a fancy way of saying that a growing number of citizens, practitioners, and researchers understand the benefits of collaboration, that they have developed guidelines for doing so successfully. Examples include the CLIMAS program, the Southwest Climate Adaptation Science Center, and Cooperative Extension.

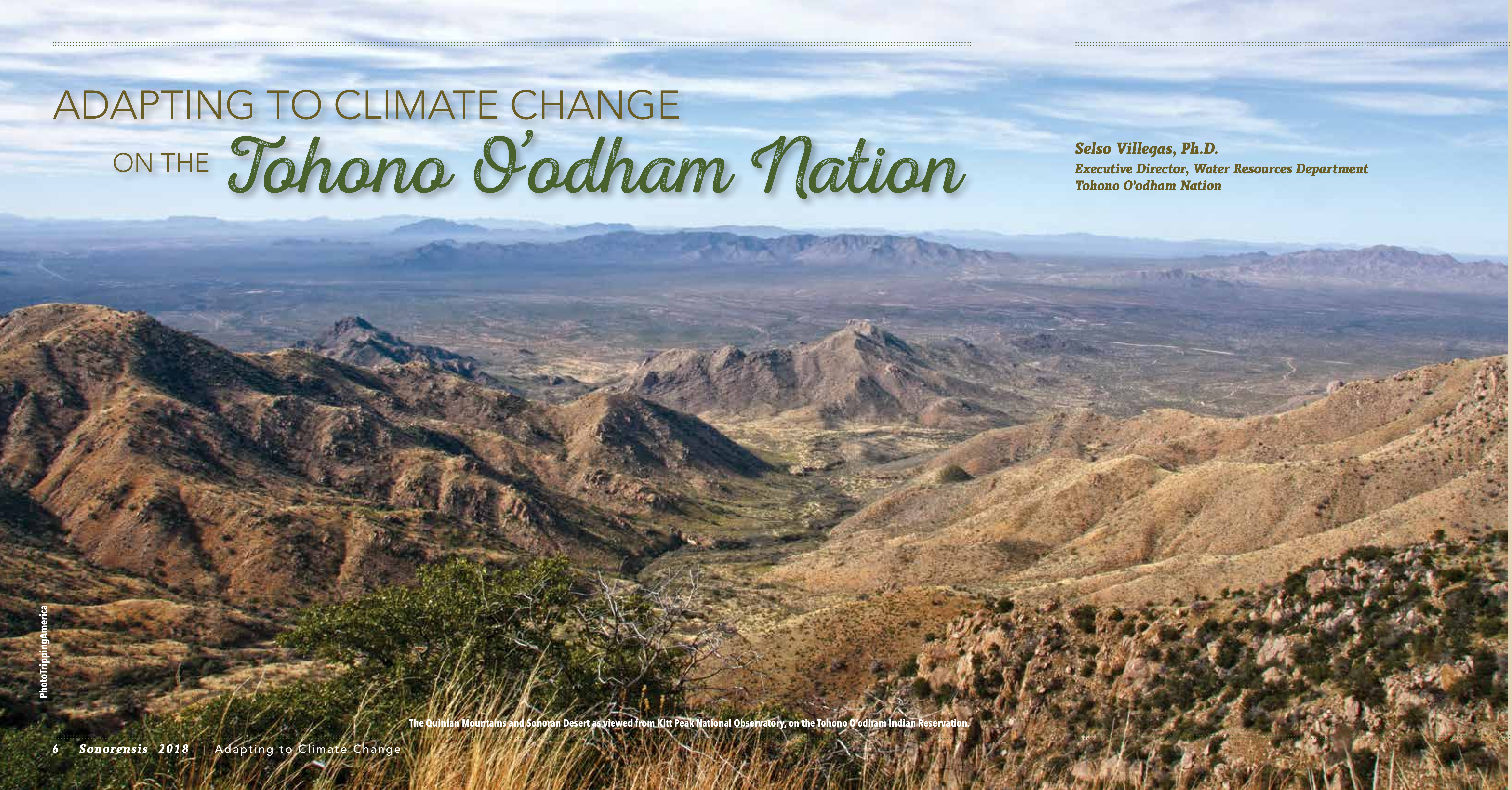
Prospects

What are the prospects for robust climate change adaptation in the Sonoran Desert? My perspective is one of an "apocaloptimist." I described apocalypse (i.e., challenges) earlier in this piece, so I'll wear my optimist hat for this section. In the region, there are already many partial actions to address climate change, resilience, and sustainability. While, in my opinion, we need a combination of individual and collective actions, including legislation and incentives to take actions that will reduce risk, evidence indicates that individual actions add up sufficiently to create meaningful change. One of the greatest challenges is to make adaptation thinking and action part of business as usual for individuals, organizations, and governments. Fortunately, the region has organizations, alliances and initiatives which form networks for raising awareness and developing solutions. By building on shared values and strengthening institutional linkages, these networks can proactively build substantial capacity to plan and act. On the other hand, I expect that we will suffer more extreme climate events—runs of severely dry years, or dangerous floods, or severe fires, or punishing heat waves—which will likely force reaction and, as with the floods of the early 1980s and early 1990s, promote further proactive approaches to address regional climate challenges. The potential regional consequences of climate change demand that we shift the balance toward more proactive initiatives.

Above: Haboob. Below: Community gardens build resilience.

ADAPTING TO CLIMATE CHANGE ON THE *Tohono O'odham Nation*

Selso Villegas, Ph.D.
Executive Director, Water Resources Department
Tohono O'odham Nation



PhotoTrippingAmerica

The Quinlan Mountains and Sonoran Desert as viewed from Kitt Peak National Observatory, on the Tohono O'odham Indian Reservation.

Introduction

The Tohono O'odham Nation is a federally recognized tribe located in southern Arizona. Its lands reach into Pima, Maricopa, and Pinal Counties. The Nation covers more than 2.8 million acres in four, non-contiguous segments of land. It is divided into 11 districts, each of which maintains a district government. The largest section of land is 2.7 million acres and includes the community of Sells, the Nation's capital, which is located in the center of the main reservation. San Xavier District consists of 71,095 acres just south of Tucson. Some of the smaller land areas are the San Lucy District near Gila Bend and Florence Village near the city of Florence.

In 2014, concerns about climate change and its potential impacts on the Nation led the Tohono O'odham Nation Legislative Council to ask the Water Resources Department to explore potential impacts of climate change on the Nation and make recommendations about how to respond to those impacts. The Nation worked with researchers from the University of Arizona to develop the plan.

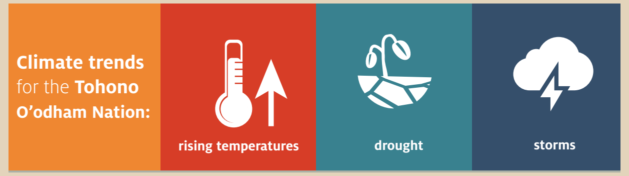
Our Changing Climate

The climate, or the long-term average conditions in a particular place, of the Nation is changing — as are conditions around the globe, across the United States and in the Southwest in particular.

On the Nation, the long-term annual average temperature is 68° F. However, almost every year since 1985 has been above the average. The long-term average annual precipitation on the Nation is less than 11 inches. As expected in the Sonoran Desert, the Nation experiences variable precipitation patterns with years higher than average and years below the average. The highest precipitation year in recent history was 1984 when just over 21 inches of precipitation fell, but the Nation has also experienced several years when only 6 inches or less have fallen. The Nation, along with the whole state of Arizona, has experienced lower-than-average precipitation since the late 1990s. This has contributed to long-term drought in the state.

Using computer models, scientists have been able to project future temperatures. Different amounts of greenhouse gases (GHGs) released into the atmosphere will have different effects on warming temperatures, so climate models are developed for several different emission scenarios. Climate models for this region project a rise in annual average temperatures of between 2° and 10°F by the year 2100, depending on the emission scenario. This translates to annual average temperatures of between 70° and 78°F based on the long-term average for the Nation. The range depends on the rate of greenhouse gas emissions around the world between now and 2100.

Climate models can also be used to project changes in precipitation. However, the precipitation models are not as accurate in this region because it is difficult to capture the dynamic nature of the North American Monsoon which brings us about half of our annual precipitation. The average of all the precipitation projections shows no more than a few percentage points of change in either direction (more or less rain). These projections do not show a trend but reflect the variable precipitation common in Arizona and the Nation. However, even with no change in total precipitation, Arizona could become much drier as warmer temperatures mean more evaporation over surface water and more evapotranspiration, which will further dry soils.



Planning for Climate Change

Climate adaptation planning means adjusting to new or changing environments in ways that take advantage of beneficial opportunities and lessen negative effects. Adaptation planning provides communities with opportunities to develop strategies that will help them adapt to a future where the climate will be warmer than today. The process of climate change adaptation planning is similar to other resource management planning processes and generally includes: identifying risks and vulnerabilities, assessing and selecting options, implementing strategies, monitoring and evaluating the outcomes of each strategy, and revising strategies or the CCAP (Climate Change Adaptation Plan) as necessary.

The Nation's Planning Process

We focused the adaptation planning process on three key sectors: on water resources, human health, and emergency management. We consulted both the scientific literature and knowledgeable community members about how projected climate changes are likely to affect these sectors. Likely climate change impacts on the Nation include higher overall temperatures, especially higher nighttime temperatures; more frequent heat waves; more frequent extreme storms, which can lead to more flooding; earlier and longer wildfire season; and potential changes in water availability from the Central Arizona Project.

Youth Engagement

In collaboration with Baboquivari and Tohono O'odham High Schools, we held a Youth Climate Change Forum to gather students' input on both concerns about climate change and ideas for adaptation strategies. After an opening ceremony led by students who have shown exemplary leadership, the students broke into small groups to discuss how climate change affects them, their families, and their community. Students were most concerned about the human health impacts from higher temperatures and poor air quality. They also asked questions about water shortages on the Nation and food security for their community. The students noted the potential for climate change to affect their environment and negatively impact their culture.

When we asked students to propose adaptation strategies, they enthusiastically generated an incredible list of actions to take as families, at school, and as a Nation. They suggested 28 different ways to conserve resources, such as not wasting food or water, driving less, conserving electricity, and promoting rainwater harvesting. They also shared ideas about using more alternative energy sources (such as solar or wind) and using energy efficient building techniques, including traditional O'odham techniques. The students had a number of suggestions about how the Nation as a whole could prepare for future climatic changes or more short-term emergencies like storms and heat waves. They suggested making sure emergency stores of food and water were available for community members, using more buildings as cooling centers (such as libraries and community centers) across the Nation, and creating a system to check on community members in case of emergency. Finally, they noted a need for more education of community members about climate change and had suggestions about how to engage with people through meetings to gather community input.

Climate Adaptation Strategies for the Tohono O'odham Nation

1. Use traditional building knowledge and practices to make homes cooler
2. Open available community buildings as cooling centers during heat emergencies
3. Plan for flood mitigation
4. Hire additional wildland firefighters
5. Ensure groundwater is treated for more households
6. Educate community members about climate change

Professional Expertise

We also consulted with the executive directors and staff of 25 of the Nation's programs and departments to gain their input on their concerns about climate change and ideas for adaptation strategies. We asked workshop participants to prioritize possible adaptation strategies that had been suggested by the literature, used in other communities, or developed by the participants themselves.

Community Members and Elected Representatives

Finally, the adaptation planning team met with each of the 11 district councils of the Nation as well as community members attending each council meeting. We presented an overview of climate change impacts to the Nation and examples of adaptation strategies. The district council members and community members in attendance were asked to complete a short survey about their concerns about climate change and suggestions for adaptation strategies.

Adaptation strategies recommended by the Nation's employees, elected leaders, and community members included:

- Using traditional building knowledge and practices to make homes cooler,
- Opening available community buildings as cooling centers during heat emergencies,
- Planning for flood mitigation by mapping flood plains, creating rainwater capture systems, and improving immediate response capabilities.
- Ensuring that groundwater is treated for more households,
- Hiring additional wildland firefighters
- Educating community members about climate change

This CCAP includes these strategies with other recommendations and identifies possible sources of funding for the strategies.

Next Steps

On January 16, 2018, the Legislative Council approved the Nation's CCAP by resolution.

We hope that this plan becomes a tool that the Nation's elected representatives, departments, and community members can use to help inform decisions about community health, community development, infrastructure investment, and natural and cultural resource management and protection.

The O'odham View of Climate Change

For centuries, the O'odham, like our ancestors, the Huhukam, have endured extreme changes in our climate and our environment. We have experienced extreme heat, extreme drought, and Ice Age conditions. We have adapted through many environmental changes that affected our diet and technology. We have survived three cycles of conquest: the Spanish, the Mexican, and European intrusions to our personal lives and himdag (culture). Many indigenous people around the world have creation and destruction stories. Sadly, we are at the beginning of our destruction story. It was told through oratory that the world would catch fire (get hotter), but we did not know why. We know that the jewed ka:cim (Mother Earth) can be hard on her children. She has taken many lives by extreme weather events. However, the irony of this story is that we (humans) are making Mother Earth sick. We are giving her a temperature with carbon dioxide pollution. Mother Earth may survive the sickness but we may not. As witnesses, we have watched the industrialists lose their relationship and respect for our Mother as well as compassion for anyone else. However, there is always hope that we will not be scared of the few and come to our senses to save our Mother, ourselves, and the things we love. The question is, "Who will speak for Mother Earth?" ■


Anton Foltin

Through the Looking Glass:

Climate Change and the Future of Water in the Tucson Region

Katharine Jacobs, Ph.D.
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'That's the effect of living backwards,'
the Queen said kindly:
'it always makes one a little giddy at first'
'Living backwards!'
Alice repeated in great astonishment.
'I never heard of such a thing!'
'— but there's one great advantage in it,
that one's memory works both ways.'

From Through the Looking Glass,
Chapter 5: Wool and Water
by Lewis Carroll

Sierralara

Toroweap (Sunset) Grand Canyon National Park

The tricky part about adapting to climate change is trying to understand what exactly we are adapting to. Most water managers would appreciate accurate predictions of the future, and many feel uncomfortable making decisions about climate adaptation given the wide range of possible future conditions. Yet the alternative, which is to do nothing, is almost never the prudent option. Fortunately, we do have a general understanding of the trends that are already visible, and can use these to guide our choices.

If, like the White Queen in Through the Looking Glass, we lived backwards, all of our decisions would be much easier. As forward-living characters, we need to use the best scientific information available, along with a good dose of common sense, to anticipate future risks and opportunities. Looking into the future, what can and can't we learn from the past? How can understanding current trends as well as the basic physics of the earth system help us make the best choices? And how well do our current water supply and past actions protect us from future crises?

Until about a decade ago, water managers assumed that the climate since the last ice age had been essentially stationary. Though there was plenty of variability, it was thought to be variability around a stable average climate. What we are now experiencing is a new paradigm: variability around accelerating trends of changing climate. This makes it more difficult to apply lessons from history, but there is still a lot that can be learned from the past. For example, examining the past using tree rings and other natural recorders of climate, we can see that there have been floods and droughts that far exceed what has been experienced since humans began recording river flows. This helps us understand how serious these events can be even in the absence of climate change, and the information about both mega-droughts and floods in the past is sobering.

Climate Change & Water

So what are the trends that we are seeing in the relationship between water and climate change? Virtually all observations of temperature on the globe show increases over the last 50 years, and all recent national and international science assessments have concluded that it is almost certain that global temperatures will continue to increase over the next 50 years, and into the coming century.

Basic physics tells us that higher temperatures will result in more evaporation and less runoff because warmer air holds more moisture and evaporates more water from land and water bodies. In addition, transpiration (use of water by plants) increases when it is warmer. So, in the absence of changes in precipitation, we will face a drier future, and both natural vegetation and agricultural crops will need more water to survive. But for southern Arizona, most climate models also anticipate at least some reduction in overall precipitation. This "double-whammy" in our region is why climate expert Jonathan Overpeck has called Arizona "ground-zero" for impacts associated with climate change.

We already see increased drying of the land surface and reductions, on average, in river flows due to higher temperatures. Ironically, increased flooding is another likely result of warming. How do we know this? The same physical principle that causes warm air to hold more moisture means that when it does rain, it rains more intensely (more rain per unit of time). And this is what scientists have been observing — the intensity of precipitation has been increasing to some degree regionally and quite substantially across the entire northern US and Canada. More intense precipitation often leads to flooding – so increases in both floods and droughts are anticipated as part of climate change impacts in many regions of the US.

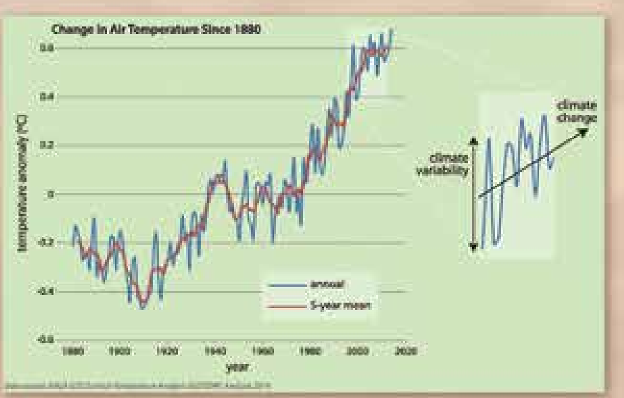
What does this mean for water in the Tucson region? Recent work by Bradley Udall and Jonathan Overpeck (*Water Resources Research*, 2017) shows what higher temperatures mean for our primary source of renewable supplies — the Colorado River. Reduction in total flows could reach 20% by midcentury, and even lower flows by 2100 — even if precipitation increases in the headwaters area. Snowpack volume is also decreasing at lower elevations, and less water stored in snowpack affects runoff timing (when the peak flows occur) and total volume. In addition to the impacts on the Colorado River, this has serious implications for riparian and aquatic ecosystems in tributaries and other rivers and streams across the southwest.

In Arizona and Sonora, where riparian systems are already seriously threatened by water diversions and groundwater pumping, it is likely that heat, rather than changes in precipitation, will drive the largest impacts on natural systems. Increasing water temperature and decreasing water quality are also anticipated, presenting more challenges for biodiversity.

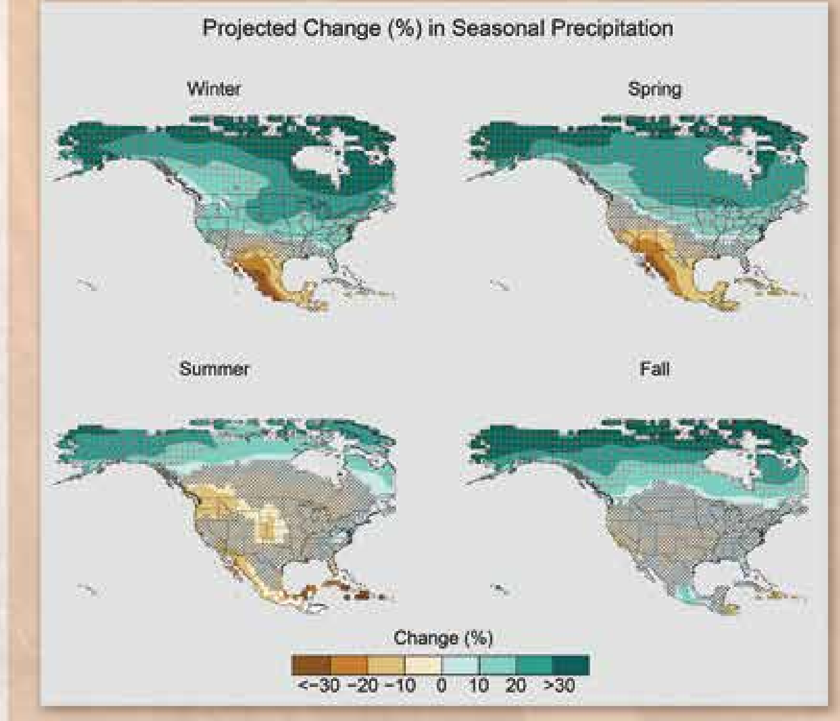
Where will we get our water in 100 years?

Given all of this grim news, we might be tempted to jump back through the looking glass and avoid knowing what the White Queen knows. But on the positive side, those of us in the Tucson basin have already made many investments to ensure future water supplies. Because informed politicians and water managers in Arizona have understood that increasing use of over-drafted groundwater in our desert environment seriously threatens our environment and, ultimately, our economy, Arizo-

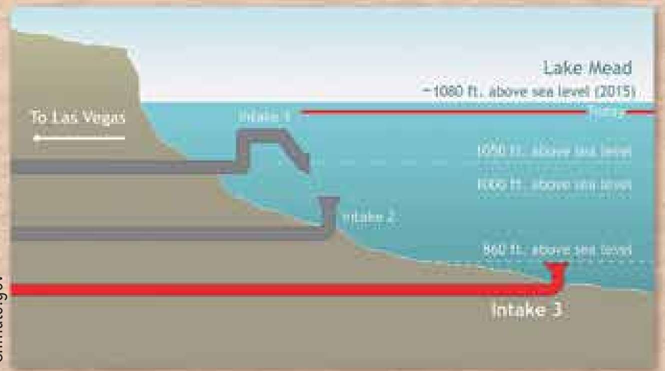
As shown by this graph of annual surface air temperature from NASA, aspects of climate vary from year to year. Without climate change, they would vary around a relatively flat line. When the climate is changing, the varibility is around an upward or downward trend.



Climate variability occurs due to natural changes in the circulation of the air and ocean (like El Nino), volcanic eruptions, and other factors.



These maps show the predicted change in seasonal precipitation from the present to the end of the century from the National Climate Assessment (2017). Changes projected to be larger than natural variability are stippled. If the changes are expected to be smaller than natural variability, the region is hatched. In the southwest, precipitation will decrease in the spring, but the changes are only a little larger than natural variations.



Climate.gov

This schematic shows the elevation of water intakes that move water from Lake Mead to Las Vegas. Shortage on the river will be declared when the water level reaches 1075 feet above sea level, triggering cutbacks.

Phillip Bird

na adopted the 1980 Groundwater Management Act. Arizona (and our Federal Partners) completed the $4 billion Central Arizona Project (CAP) in the 1990s bringing renewable Colorado River water supplies through Phoenix to Tucson.

We in the Tucson region have a more secure water supply due to investments in the largest municipal CAP allocation in the state, in multiple underground storage facilities, in a reclaimed-water system, and in conservation. The question we have to ask ourselves is have we done enough?

Implications of climate change for the Central Arizona Project (CAP)

The majority of the Tucson basin's water use is now supplied via the CAP, and the Arizona Department of Water Resources has declared its "Tucson Active Management Area (AMA)" to now be at "safe yield." This means that the average amount of groundwater withdrawn from the aquifer is now less than the amount being recharged naturally and through artificial aquifer recharge projects (mostly through percolation basins in the Avra Valley and agricultural exchanges). This is quite a remarkable feat given that Tucson's metro area population has roughly doubled in the almost 40 years since the Groundwater Management Act was passed.

Our greatest concern now is no longer groundwater depletion but the supply in the Colorado River system. The major reservoirs on the Colorado are currently at or near their lowest levels since they were filled in the 1950s. There is a more than 50% probability of a shortage in the near term, which poses serious implications for Arizona and the CAP. We could very likely cross the "level one" threshold low water level of 1,075 feet in Lake Mead in the next two years, which will trigger cutbacks in water deliveries. The risk of Lake Mead reaching the even more critical low level of 1,025 feet is significant. If we assume that just the most recent 28 years are most predictive of the "new normal," the probability is 50% by 2026.

Shortages on the Colorado River are a major concern for us because Arizona has the lowest priority CAP allocation among its neighboring states, and the Tucson area's water supply is the most dependent on CAP water. That said, with the current priority system, it is unlikely that Tucson's municipal allotment will be curtailed any time soon because municipal supplies are cut last. The story for agricultural users, many of whom have been using excess CAP water, is very different, since excess water and agricultural supplies will be cut first.

Clearly, increasing temperature and population, and decreasing flow in the Colorado River, are not a good combination. Though we have neither a magic mirror nor a crystal ball, a century from now there will almost certainly be more people and less agriculture in Arizona. Urban land use already is less water consumptive than agriculture, and it would be surprising if we hadn't achieved even more conservation than we have today thanks to continued technological advances. Housing and land use patterns are currently moving towards further reductions in water usage. And it is logical to expect that water will continue to become more expensive. All these factors could help stem the historical trend toward ever greater demands for water.

Adaptation options for those connected to the CAP, effluent and municipal delivery systems are dramatically easier to achieve than options for those who are dependent entirely on groundwater. This is a very significant challenge for the region: the "haves" and "have-nots" in Southern Arizona are rather clearly demarcated by the service area of the CAP and the boundaries of the Tucson AMA. For the rest of southern Arizona and northern Sonora, there are no significant protections from groundwater over-pumping, and no access to imported sources of renewable supplies.

As this article is being written, Arizona is embroiled in historic negotiations about how it will handle possible future shortages on the Colorado River. We will either fight it out internally, leaving winners and losers, or we will come together (the current "haves" and "have-nots") to creatively address a future with leaner water supplies.

Top left - clockwise: Wildlife crossing bridge over the CAP. Central Arizona Project (CAP) near Picacho Peak. Agua Caliente Park, Tucson, AZ.
Middle left: Diagram of Lake Mead.
Bottom left: Colorado River flows into Lake Mead.

And what about future water supplies for our unique natural environment?

It is hard to imagine ways to adequately prepare for the impacts of climate change and drought on riparian habitat and vegetation in general. It is one thing to protect the urban system from the implications of severe drought, and quite another to protect the desert and mountain ecosystems that add to our quality of life and that support the intricate network of biological assets of the region.

The implications of climate change for river and stream flows and riparian habitat have received very little public attention, but may be the most visible and irreversible impact of climate change in our region. The Queen would likely not be impressed by our failure to anticipate the multiple consequences of failing to protect what riparian and aquatic systems we have left.

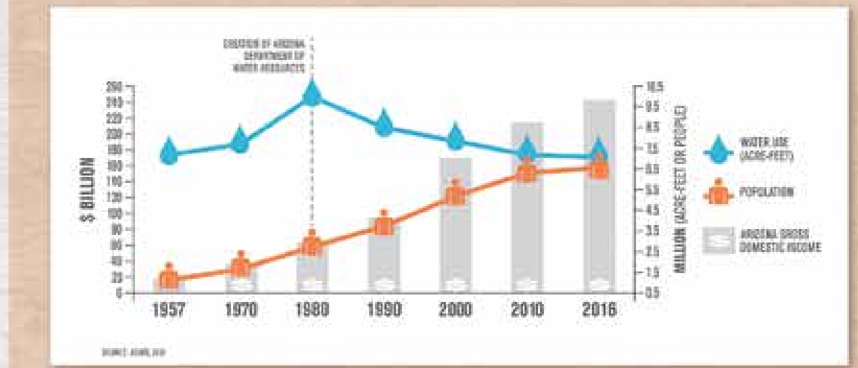
Limitations of our regulatory systems

If we were living backwards, we would likely already know that the Groundwater Management Act and other Arizona water laws, the Recharge and Recovery Act, and the associated Assured Water Supply rules (that require a 100-year supply of renewable water for new subdivisions) were giant steps forward in protecting developed areas from the impacts of climate change—even though climate change was not a motivator for those investments. Living in a desert, we already recognize water scarcity and benefit from the foresight of prior governors, businesses, farmers and members of Congress who recognized the value of water. Arizona is an example for others, but we still face dramatic challenges, and our environmental assets are at the top of the list.

With 20-20 hindsight, we now see that the provisions of the Groundwater Management Act were totally inadequate to protect water supplies for our natural environment. The Act focused on safe yield and on water for human use, not streamflow or environmental benefits. Arizona has no overarching regulation that protects environmental assets. Other than the Santa Cruz Active Management Area (the Santa Cruz River basin north of Nogales and south of Amado), where protecting the flows of the river from pumping is a goal, no provisions explicitly focus on preserving river flows or habitat. Furthermore, the provisions of the Groundwater Management Act are largely limited to the Active Management Areas, which cover less than a quarter of Arizona's lands.

What is the landscape of the future going to look like?

Climate change impacts on ecosystems in our region are already substantial. We have seen very large wildfires destroy significant forested por-



Due to water conservation measures introduced in the last few decades, Arizona has managed to decrease its water use, inspite of increasing population and economic activity.

Top: Central and Southern Avra Valley Storage and Recovery Project (CAP). Middle: Arizona water use trends.
Bottom: Horseshoe Bend.

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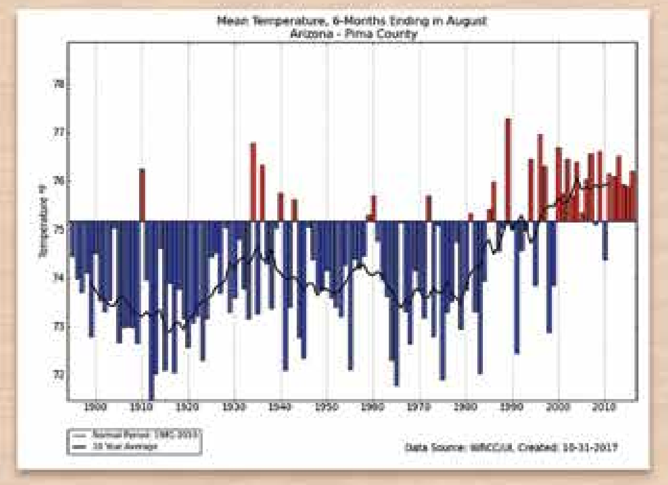

For Pima County, Arizona, average spring/summer temperatures have been steadily increasing for the past 30 years.

tions of the Sky Islands. The regional drought that has gripped our area since roughly 2002 has had a big impact on the potential to support ranching in the area. Perhaps of greatest concern is the impact on the few flowing streams that still exist in our region. A large percentage of biodiversity in southeastern Arizona is dependent on riparian areas that are drying up. This past year, Sabino Creek stopped flowing for the first time in recorded history. Over the past several decades, the cottonwood canopy in the Tanque Verde area has diminished considerably. The San Pedro River's plight has received national and international attention.

These issues are not unique to our region and the implications are not limited to biodiversity. What we also know – beyond broad, general statements of concern — is that water-related impacts of climate change will vary by basin. For example, if natural recharge from surface water is not a big part of the water budget in most years, changes in flows may not have a big impact (e.g. in the Pinal AMA). By contrast, the Santa Cruz AMA water budget changes dramatically based on precipitation and flooding events because surface flows are highly linked to shallow groundwater. For the San Pedro, where sustainability of surface flows is an important goal, slight changes in seasonality of precipitation (e.g. changes in the monsoon) could have big impacts. This means that the risk to water supplies and environmental assets varies dramatically from one basin to the next, and therefore the adaptation options that we must consider will not be "one-size-fits-all" solutions.

What we don't know

Obviously, it would be great to have perfect knowledge of what is at risk and what the best adaptation options might be. But there are still many gaps in our knowledge of existing and future trends. Scientists and water managers are still working answer these and other questions:

- What are the implications of changes in seasonality of runoff on groundwater recharge rates?
- Will there be increased recharge during large flood events, and might that be enough to offset the overall losses in recharge that come from increased drought and heat?
- What changes might there be in availability of alternative supplies (e.g., municipal effluent)? Could we go to direct potable reuse of effluent, which would reduce its availability for landscaping and riparian flows?
- What might the effect of changes in energy supplies and costs be? Will a transformation to renewable energy or new cooling technologies change the demand and use of water?
- Will surface water shortages result in more groundwater pumping at a time when energy costs are increasing?
- How will global economic trends, such as shifts in agricultural production or economic downturns, affect water demand and supply?

Top left: Rain storm over the Grand Canyon.
Middle left: Graph of Pima County Spring-Summer temperatures.
Bottom left: Flooding at Stone underpass in downtown Tucson.

The Lower Santa Cruz Basin Study

To address some of these gaps in our knowledge, a regional effort is underway to understand the implications of climate change on water supply and demand. The project is led by the US Bureau of Reclamation, in partnership with Pima County, the City of Tucson, the Arizona Department of Water Resources, and the Central Arizona Project, along with numerous other water utilities, agricultural, tribal, and mining interests. The University of Arizona, through its Center for Climate Adaptation and Solutions, is also a project partner, providing technical and scientific support.

The Lower Santa Cruz Basin Study (LSCBS) is a technical assessment of supply and demand imbalances in the Tucson Active Management Area through 2060; it will not produce recommendations for action, but will establish a foundation for future action by local entities. It will evaluate the costs and benefits of adaptation options to enhance water security for water users and the environment.

The LSCBS is the first study supported by either the state or the federal government to look at climate impacts on the water supply in the Tucson region. By using the latest version of a regional climate model developed at the University of Arizona, it will generate more accurate and relevant insights for this region than currently available. In addition, there is significant effort to study the impacts of climate change on riparian areas and other environmental assets, and to evaluate the effectiveness of adaptation options for environmental protection. Information on this study can be found at https://www.usbr.gov/lc/phoenix/programs/lscrbasin/LSCRBStudy.html; the public is invited to attend briefings on progress and provide input.

What adaptation options are there?

Now that we have at least a partial view through the looking glass – what are the responses we can consider? Fortunately, we do have many options, and several are practices with which we are already familiar. They include integrated water management – which really means thinking about all water supplies as part of a portfolio of resources and matching quality to use. Recycling of municipal effluent, and matching the quality of that water with specific uses such as landscape irrigation, is a good example. Although Tucson is already a leader in conservation, even more can be accomplished without significant impacts to our quality of life.

Another option that is already in place but may be expanded is using the groundwater aquifer to store surplus water during wet years in order to "bank" it for later use. Understanding where it is most beneficial to store water, and where it is best to pump it, can be a powerful tool for protecting environmental assets.

Storm water capture and storage, also known as rainwater harvesting, has received substantial attention and should be part of a package of strategies. But it is challenging for a number of reasons. First, it only works when it rains; higher temperatures and more extended droughts reduce its viability. Second, if we have more intense precipitation, flood control is more challenging – even though it means more water is available on a temporary basis. Third, there are health issues if retention ponds or water harvesting systems are not managed to control mosquitoes and other disease vectors.

An adaptation option that is receiving significant attention across the US, including in Pima County, is the use of green infrastructure. For instance, natural greenways can be developed for flood control as opposed to cement-lined channels. Such projects provide co-benefits, including environmental enhancement and recreation, while also reducing flood risk.

Conclusion

In contrast to the White Queen, whose memory goes in both directions, we have to use our own imperfect understanding of future conditions to manage climate-related risks. The good news is that we have a very firm water management foundation. The not-so-good news is that we have many challenges ahead, and though we have a broad solution set, it is not clear whether our current and future decision makers will be as motivated, congenial, and innovative as their predecessors in overcoming those challenges. Investing in the future, in light of all of this complexity can "make one a little giddy at first." But nothing is more reassuring than peering back through the looking glass, and appreciating the way Arizonan's came together in the past to solve the grand water challenges of their day.

Top: Santa Cruz River near Canoa.

Right: Santa Cruz River in the Tohono O'odham Reservation.

Below: Water storage tank at Vallee Girl Farms, an organic farm in Oro Valley.

Michael Landrum

Climate Change, Forests and Fire

in the southwestern US and northern Mexico

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Long before there was a border, long before "Mexico" or "the United States" existed, fires roamed across the mountains and deserts of southwestern North America, including our Sky Island bioregion. Jaguars, bears, pronghorn, bats, and hummingbirds were on the move, and people moved with them through forests, grasslands, and deserts. Some of these fires covered enormous areas, thousands of square kilometers, but burning with short flames and low temperatures that recycled fine fuels – grasses, leaves, small branches – into nutrients that enriched soils and retained organic matter. In dry years these fires would often smolder through the winter, rising up again in the winds and dry weather of the arid foresummer.

People lived with these fires, coexisting with long familiarity, understanding that they enriched and renewed the ecosystems that people depended on. At other times, people used fire as a tool for agriculture, warfare, or spiritual practice, recognizing its power and its ability to shape landscapes and regulate key resources. People lived with fire continuously through the long transformations of southwestern landscapes from the end of the last ice age, over thousands of years as cool forests and woodlands reorganized into the grasslands, savannas, and dry forests we see today.

These days, of course the situation is far different, although it is instructive to recall just how recent this transformation was. The current border between the two countries was set in 1854 after the Gadsden Purchase/Venta de la Mesilla treaty signed between the US and Mexico. Nowadays, this part of North America is divided into nation states with hardened and militarized borders, fragmented land use, and levels of resource extraction that appear far beyond sustainable. And looming over the region, as it does over the entire planet, are the uncertainties of human-caused climate change and the transformations it will bring to both ecosystems and people over the next century.

Given this context, how should we understand and plan for fire in the Sky Island bioregion? What is its past, present, and what might the future look like in the places we now call the United States and Mexico?

DEEP-TIME FIRE HISTORY

Grasping the long presence of fire, and its deep evolutionary relationship to the biota of what is today the Borderlands region, is crucial to understanding the role of fire in the past, present, and future of the landscapes found here. Wildland fire can be expressed in many ways and take many forms, some benign and others profoundly destructive. Thus, to understand fire as an ecological process in the US-Mexico Borderlands, a lot revolves around how and under what conditions fires burn, how large they become, and the conditions that prevail during their recovery.

The tree-ring record shows us in great detail that most fires that occurred in forests, woodlands, and grasslands of the southwest US and northern Mexico prior to the 20th century burned as relatively low severity events, meaning that there was typically little mortality of overstory trees, and little persistent damage to soils. These fires were characteristically ignited by lightning during the arid fore-summer (May and June) prior to the onset of the North American Monsoon in early July when increased fuel moistures tend to inhibit fire spread. These historical "frequent-fire" regimes in grasslands and most forests, except for those at the highest elevations, were integral to their function and dynamics.

Human residents of the region almost certainly contributed ignitions in some areas, associated with hunting, improving conditions for culturally important plants, and warfare (humans also played a role in suppressing fire near their settlements, as has been demonstrated by archaeological studies in the Gila and Jemez Mountains of New Mexico, where Puebloan peoples reduced fuels through land use and fuelwood collecting). Given the long history of human occupation in this part of North America, people learned to understand and live with fire thousands of years ago.

As we are all aware, fire today has a distinctly different – and more perilous – role in ecosystems of the Borderlands. As Europeans moved into the region, especially in the US, the native fire regime was viewed with skepticism and even hostility as a "primitive" force to be suppressed. The importation of millions of grazing animals transformed grasslands and woodlands from frequent-fire to virtual no-fire zones, as the fine fuels that carry spreading fires were consumed. The relentless campaign against indigenous cultures on both sides of the border also contributed to the decline of the original fire regime. Thus, by the late 20th century, more than a century of woody fuels had accumulated in dense forest stands unlike the characteristic state in historical times. The region's forests became a ticking time bomb, which finally exploded into massive megafires when the extended 2000's drought made these dense forests flammable. It is important to keep in mind that the huge, and hugely destructive fires that we see today are nothing like the more sustainable long-term fire regime that existed until relatively recently.

FORESTS AND FIRE IN NORTHERN MEXICO

The landscapes of the Borderlands include deserts, grasslands, woodlands, and many types of forests. These include the short and dry tropical vegetation found at the bottom of canyons in northern Mexico, tall and majestic old growth conifer groves found in the Sky Islands of the Arizona-Mexico border, as well as magnificent riparian forests that still line river corridors throughout the region.

Evidence from tree-ring studies and climatic reconstructions helps to reveal long-term patterns that we can link to archaeological and historical evidence to understand the interactions between climate, ecosystems, and humans. In the Borderlands, this evidence helps us connect continental and regional climatic patterns, such as the El Niño Southern Oscillation (ENSO) and the yearly North American Monsoon, to fire regimes and the role of humans in them. Before the current US-Mexico border existed, "cool" fires moved through the landscape at intervals of less than 10 years, preventing fuel accumulation. The tree-ring record, paired with other ecological evidence, has allowed us to establish that historically, the rainy phase of ENSO in the Borderlands caused increased plant growth during years of higher precipitation, increasing fuel availability and thus the flammability of landscapes.

These "cool" fires are an important component of ecosystems throughout the Borderlands. They maintain habitats that are important to key wildlife, such as Thick-billed Parrots (*Rhynchopsitta pachyrhyncha*), in ecosystems that are of great conservation value and at high risk of disappearing as global temperatures increase. In the 20th century, disruptions to fire regimes in the Borderlands have had dramatically different expressions on the two sides of the international border. In the United States, fires became increasingly severe during the century as a result of fuels that accumulated for over eighty years of federal fire-suppression policies. In Mexico, fires continued to burn through the landscape, maintaining their historical cycles until the new century in many areas.

In the middle of the 20th century, the great US conservationist, Aldo Leopold, identified this stark difference in similar ecosystems found at either side of the international border, and attributed it partially to the fact that fire suppression was not an active policy in Mexico. Even though sites with maintained fire regimes became more rare as the country's development progressed, they can still be found in isolated and remote mountains of the Mexican Sky Islands and the northern end of the Sierra Madre Occidental.

The United States and Mexico share 3152 km (1959 miles) of a terrestrial border along the Mexican states of Baja California, Sonora, Chihuahua, Coahuila, Nuevo León and Tamaulipas. The area of these states comprises about 41% of México's total surface. Modern fire records in Mexico go back to 1970. For the period 1970-2017 we know that on average, about 12% of the total wildfires reported at the national level occurred in Borderlands states. However, the total area burned in the Borderlands represents about 31% of the total burned at the national level, with an average fire size (77 ha) more than twice the average for the country (34 ha).

Previous page: Wildfire on Black Peak, Arivaca, Arizona, 7/30/2016
Right: Thick-billed Parrot.

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Left: *Pinus strobiformis,* commonly known as Southwestern white pine, Mexican white pine or Chihuahua white pine. Right: Douglas Fir reaching for the sky.

Right: Ponderosa pine forest on the steep slopes of Roaring Springs Canyon North Rim, Grand Canyon National Park, Arizona. Cut out right: Pine cone.

The data for area burned by vegetation type goes back to 2006, and for the period 2006-2017 we know that most of the area burned in the Borderlands occurred in grasslands (39%), scrub (37%) and forests (24%). These proportions differ significantly from national patterns, where 46% of the area burned by wildfires affects grasslands, followed by 43% occurring in scrub, and only 11% in forests.

1998 and 2011 were peak fire years in Mexico which had very different patterns across the country. Smoke from the 1998 fires that burned mostly in the southern part of the country affected air quality across Texas and the Midwest, triggering an emergency assistance program from the United States Government. Most of these fires (90%) and burned area (89%) were reported outside the Borderlands. In contrast, 2011 was particularly intense in the Borderlands, where 66% of the country's burned area was registered. Fires in 2011 in the Borderlands affected large areas of scrub and grasslands to the south of the Big Bend, throughout the state of Coahuila. Even though it was expected that the recovery of the Yucca-dominated scrub would take a long time and perhaps change its successional pathway, a field visit in 2012 showed resprouting and recovery in some of the areas affected by the wildfires. It is difficult to assess whether fires have increased in number and area given the short data frame, but there is consensus around the fact that increased temperatures paired with increased drought will bring changes to fire regimes, which will affect the vegetation of this ecoregion, unavoidably affecting the livelihoods of its inhabitants.

FORESTS AND FIRE IN THE US SKY ISLANDS

Like northern Mexico, fire north of the border occurs in grasslands, woodlands, and forests of the Sky Island bioregion. Fires may occur once or twice per decade in productive grasslands such as the San Rafael, Cienega, and Sulphur Springs Valleys that lie between the major Sky Island mountains. Although each range is different, in general as elevation increases, open woodlands and savannas appear, with grassy understories forming the matrix around fire-adapted trees and shrubs, such as the Madrean oaks. Some oak species are fire resisters, with thick bark that helps to protect the sensitive growing cambium cells. Other oaks are fire responders, which can resprout from the base even when the aboveground portion of the tree has been killed by fire. Among the mid-elevation pines above this zone, Chihuahua Pine *(Pinus leiophylla)* is exceptional among conifers for its ability to resprout following fire; the persistent closed (called serotinous) cones which open only after fire are another clue to the long evolutionary adaptation of Chihuahua Pine to fire.

Mid-elevation montane forests of the Sky Islands can vary from virtually monotypic stands of ponderosa pine *(Pinus ponderosa)* to mixed-species stands with multiple types of pines, fir, Douglas-fir, aspen, locust, and several species of shrubs. These forests support relatively frequent low- and moderate-severity fires every 10-20 years at any given location, and again the evidence that fire was part of the evolutionary environment of all these species is on full display. Most of the long-lived conifers tolerate or resist low-intensity fire with thick bark, and canopies that are lifted above the characteristic scorch height of surface fires. Productivity peaks in the montane forest zone, producing abundant fuels, but the cooler damper climate maintains higher fuel moistures in both soils and vegetation, with the result that fires may not spread easily except under unusually hot, dry, windy conditions.

Of course, anyone who lives in the region knows that hot, dry, windy conditions are not so unusual as they once might have been. Following the onset of the 2000s drought, the size of the largest fire each year in Arizona increased by a factor of ten, from 20,000 – 50,000 acres in the 1990s and earlier, to 200,000 – 500,000 acres in the last 15 years. These megafires, such as the 2002-2003 Bullock and Aspen Fires in the Santa Catalina Mountains, 2004 Nuttall Complex in the Pinaleños, and the 2011 Horseshoe 2 and Monument Fires in the Chiricahua and Huachuca Mountains respectively, dominated our attention and media coverage for months. Long after the camera crews have gone home, the ecological consequences from these fires may extend over decades as soils and vegetation recover.

LAND USE AND MANAGEMENT

As Aldo Leopold recognized more than a half-century ago, the binational landscape of the Borderlands represents a singularly unique opportunity to understand the effects of diverging management philosophies. The ecosystems contained in the Borderlands are similar in origin but reveal unique characteristics resulting from public policies aimed at different objectives. In the US, the logic that pervaded management for most of the 20th century was fire suppression, aimed at maintaining or increasing logging and grazing productivity, as well as fulfilling conservation goals. We now know that fire suppression was not appropriate for the ecological conditions of ecosystems in the US West, and land managers are still dealing with the unintended consequences of those policies today. It took many decades for researchers and managers to gather data to understand the underlying reasons for the failure of this policy. Meanwhile (and paradoxically), on the Mexican

Pritha Photography

Sun shining through the aspen trees.

side of the Borderlands, fire regimes were maintained, perhaps by a combination of chance, less effective policy implementation, and a lack of financial and human resources, and perhaps due to more decentralized land management in the ejido system.

The 1970-2017 fire dataset for Mexico speaks eloquently about an important factor that keeps ecologically healthier landscapes than those in the US Borderlands. Most fires in Mexico in this period burned mostly grasslands and scrublands, which are vegetation types that are often at the interface with agriculture or grazing land-use types. These land uses require fire to facilitate regrowth, in the case of grasses, or clearing, in the case of agriculture.

LOOKING AHEAD

Fire is as natural to forests of western North America as floods are to rivers, as common as hurricanes on Caribbean islands. Forests, woodlands, and other types of vegetation like chaparral and grasslands have developed with fire as a shaping force throughout their ecological history. The species that comprise these ecosystems have evolved with fire – and fire has evolved with them, over longer spans of time. Fire will not be leaving the Borderlands.

Archaeological evidence, such as terracing, metates, building foundations, and even ancient corn husks, cobs, and grains, found in the foothills of the mountains of Sonora and Chihuahua demonstrate unequivocally that people have lived with fire in the Borderlands for millennia. The connection between fire, agriculture, and landscape management has been well-established for our continent, and fire has been an inherent part of these landscapes.

With every passing year, the manifestations of climate change, such as extreme heat, and severe fire seasons around the world, are becoming increasingly evident. In this context, it is important to understand this particular disturbance and its intricate connections to ecological, climatological, and human-driven cycles. Recent research confirms that climate change will bring more fire to our landscapes in almost every part of the world.

As Leopold recognized, our two countries must continue to learn from each other, building on each other's strengths. The effects of climate change will not stop or begin at international borders, and in shared landscapes like those of the Borderlands we must see beyond our national differences and build management practices that help us maintain healthy ecosystems where human populations thrive. Current adaptation strategies, such as forest thinning and prescribed burns, are designed using lessons from both sides of the border. We must continue to work together in developing policies that build resilience. S

TAKING THE LONG VIEW:

Ecological Monitoring Helps National Parks, and All of Us, Prepare for Change

Andy Hubbard, Ph.D.
Alice Wondrak Biel, Ph.D.
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Sonoran Desert Inventory & Monitoring Network of the National Park Service

Incremental change is notoriously hard to see. It's why you might go back to a place you once lived and be viscerally, utterly shocked at how different it seems—yet find that people who lived through those changes seem barely aware of them. In the absence of a daily record, gradual change can elude our detection—especially if our lives keep us focused on other things.

It can be even harder to tease out what's driving that change. In ecology—as in everyday life—change and circumstance tend to result from multiple factors and forces pushing, pulling, and intercombining to create a particular situation. Some are more impactful than others, underpinning the very stability and limits of the system we recognize as our own.

In the Sonoran Desert ecosystem, life as we know it is sustained by a bimodal precipitation regime. Intense summer rainstorms provide a welcome reprieve from the hot and dry pre-summer period, while gentler, longer winter rains soak deeper and recharge the aquifers. The desert flora works in concert with these patterns, responding with vigorous growth and flowering, sometimes within mere days of rain. Yet because the rains are somewhat unpredictable, plants have also evolved ways to prevent water loss, store water, and survive extensive periods of extreme heat.

Annual variability in precipitation is normal. But predicted larger shifts in temperature, and in the timing, duration of rainfall, may effect dramatic, lasting changes. Species distribution patterns are strongly tied to factors that mitigate temperature and water stress. Increased elevation or northern exposures can reduce heat exposure and water loss. Warmer, southern exposures allow some keystone species, such as Saguaro cacti, to avoid deadly frost episodes.

As we anticipate changes in the climate underlying these patterns, we ask: what happens when plants can't move quickly enough to adapt to changes in when and how much it rains? Do some species have an advantage over others in these challenging times—and will that mean a shift toward dominance by invasive plants and the loss of iconic species? What will happen to desert soils, insects, and vertebrates when the vegetation changes?

Federal land managers need scientific information to make sound management decisions. And now more than ever, they are looking to ecological monitoring data for the answers to questions like these. Although many scientific studies are short-term and focused on a singular question, the National Park Service (NPS) has been monitoring a suite of key ecological resources in the Sonoran Desert and Apache Highlands for 11 years. These resources include vegetation, wildlife, water quality and quantity, air quality, and climate. By going back to the same parks and taking the same measurements again and again over time, the Sonoran Desert Network is able to establish a baseline of natural variability, analyze resource conditions, and perhaps explain what's driving those conditions. This allows us to act as canaries in the coal mine, alerting park managers to potential oncoming trouble so they have a chance to act before it arrives.

Bernadette Heath

These long-term data allow us to map ecosystem change in response to variables such as climate, disturbances, and historic management actions. We can see changes across the landscape and across taxa, rather than focusing on a single species and possibly missing changes elsewhere.

The data reveal several emerging issues. One is the occurrence—and ecological consequences—of unusual and extreme weather events. For example, warmer winters and springs have caused more "cool-season" precipitation to fall as rain instead of snow. At Gila Cliff Dwellings National Monument, we have observed many more "rain-on-snow" events over the past decade than the long-term climate record would predict. Snow can't absorb rain as well as vegetation and soils do, and warmer rain can increase the rate of snowmelt. Intense flooding can result. Short-term impacts of flooding typically include soil erosion, increased streamflow, and damage to riparian vegetation and park infrastructure. But we also documented massive quantities of logs, branches, and other woody debris strewn throughout the West Fork of the Gila River in 2011. A few months later, this unusual riverside fuel load supported extreme fire behavior during the Miller Fire. There was extensive damage to the riparian corridor, with consequences for plants, amphibians, fish, and other wildlife that are still evident today.

Broader-scale effects of climate change are also evident. Over the past 11 years, we have observed fewer freezing events than normal (compared to the historic record). Along with this change, we have seen frost-sensitive plants expanding into higher elevations. Consistently monitoring several parks across the Southwest allows us to detect broad-scale geographic shifts in plants and animals. The best-known example has been the repeated detection of nesting elegant trogons *(Trogon elegans)* at Montezuma Castle National Monument—more than 200 miles north of their previous known range. This stunning bird is normally associated with the tropics and subtropics—not the northern fringes of the Sonoran Desert.

What does this kind of information mean for park managers? For one thing, long-term data like these provide insights used to predict future scenarios—a valuable planning tool. Understanding broad-scale weather and climate conditions can help guide NPS activities related to fire management and habitat protection, suggest the likelihood of exotic plant invasion, track the availability of surface water, evaluate potential plant die-offs and recruitment, and indicate the potential success of disturbed lands restoration—all of which helps ensure that tax dollars are wisely spent.

In some cases, NPS managers are also considering interventionist techniques on a scale that wouldn't have been considered in decades past. Starting in the late 1960s, the National Park Service adopted policies prioritizing "natural regulation" of park ecosystems; the idea that if park landscapes were properly protected, the ecosystems therein should be able to regulate themselves, with human tinkering largely limited to removing exotic species and encouraging the controlled use of fire (to correct many decades of fire suppression).

But what happens to a concept like "natural regulation" when human influence is changing the very nature of nature? In recent years, park managers have come to see and anticipate change precipitated by climate shifts that are outpacing evolutionary adaptation. In response, many have moved toward a paradigm of adaptive management—a kind of wait-and-see method that posits a variety of possible actions triggered by a range of possible outcomes.

As research increasingly points to the potential for localized extirpation of key species, another idea is to establish refugia in parks that have (and are projected to maintain) the right conditions to sustain those species, and to pre-emptively relocate species most at risk to areas where they may be preserved. This idea of using national parks as an ark for preserving native species raises an important question with broad-reaching implications for NPS policy: Is it more important to try to preserve park landscapes in the state they were in when they were established (or at some earlier, more ecologically complete period), or to try to preserve our ecological heritage, regardless of its historical geographic context? What goals are realistic and attainable under current and future climate scenarios? How do a park's size, ecosystem, and boundaries facilitate or constrain our ability to meet those goals? Consistent ecological monitoring paired with thoughtful, question-based research permits us to better answer these conservation questions.

Scaling the walls between agencies and disciplines is another strategy for success. Climate change and other ecological threats do not stop at boundary fences, and in recent years, agencies have found efficiencies and unity through common goals and challenges. For example, species recovery and native-plant restoration efforts must occur across agency borders to be successful. SODN uses a shared protocol and field crew to monitor vegetation and soils on parks, wildlife refuges, and Pima County lands. This approach permits us to examine ecological conditions across boundaries, assess the effects of land-management actions and disturbances (such as wildfire), and provide a broader understanding of local conditions for each neighbor. Consolidating these efforts also conserves tax dollars.

Agencies and partners are also working together to combat invasive species and manage wildfire. The most high-profile target is buffelgrass *(Cenchrus ciliaris),* an aggressive, non-native bunchgrass that directly competes with native flora and introduces wildfire into fire-sensitive Sonoran Desert scrub. Conservation partners throughout the region, including the Desert Museum, closely coordinate weed treatments, prevent seed spread, and foster educational campaigns to maximize efficacy and improve the odds for success against this desert threat.

Finally, NPS scientists and resource managers are working across disciplines to protect resources. Climate and soil scientists are partnering with archaeologists and preservation specialists to protect historic and prehistoric structures at parks throughout the region. Using a rainfall simulator and high-precision laser-scanning technology, we are simulating historic and predicted rainstorm events on adobe test walls. This will help us develop better preservation methods and materials for protecting finite earthen and masonry structures in a changing climate.

Public land managers are doing what they can to monitor and maintain ecological health. But the job is too big for them to do on their own. With the help of individual citizens, our ability to make a positive difference improves immeasurably. To meet its scientific mission, the Sonoran Desert Network relies on interns, students, volunteers, and citizen scientists. The network also operates the Desert Research Learning Center (DRLC; see next page), an educational facility with its own dedicated set of volunteers. The DRLC provides space and support for visiting researchers and interns, hosts hands-on experiential learning for local student groups, and displays examples of sustainable practices and native horticulture. It also gives visitors the tools they need to implement conservation practices on their own land—however big or small their corner of the world may be.

Because they were created, in part, out of a desire to keep things as we found them, it may seem ironic that America's national parks are ideal places to detect and study change. But their protected status eliminates some of the statistical "noise" introduced by human influence, allowing us to more clearly see ecological interaction and impacts. In addition, NPS recordkeeping often provides a rich body of baseline data to contrast against recent and ongoing changes. But it's important to remember that what happens in parks doesn't stay in parks. It's indicative of what's happening in the broader ecosystem that we all inhabit outside park boundaries. Detecting change in the parks, where the noise of everyday life is reduced, allows us to more clearly see what's coming, so we may face it together. S

Parks where the Sonoran Desert Network monitors key resources: Casa Grande Ruins National Monument, Chiricahua National Monument, Coronado National Memorial, Fort Bowie National Historic Site, Gila Cliff Dwellings National Monument, Montezuma Castle National Monument, Organ Pipe Cactus National Monument, Saguaro National Park, Tonto National Monument, Tumacácori National Historical Park, Tuzigoot National Monument.

Left: Elegant Trogon. Below: Saguaro National Park West.

Alice Wondrak Biel

The Desert Research Learning Center (DRLC), located adjacent to Saguaro National Park, promotes the scientific understanding, protection, and conservation of Sonoran Desert Network parks. Visitors may enjoy a self-guided tour of the DRLC courtyard, available online at https://www.nps.gov/im/sodn/ct_intro.htm. The tour showcases the desert environment and demonstrates the kinds of sustainable practices that can help to maintain and restore life in arid lands. Tour stops include an artificial tinaja and flowing stream, a heritage orchard, a pollinator garden, and a variety of native plants and foods, all sustained by a rainwater collection system. The webpage for each stop includes information on how users can incorporate the displayed techniques at their own homes.

"MOVIN' ON UP!"

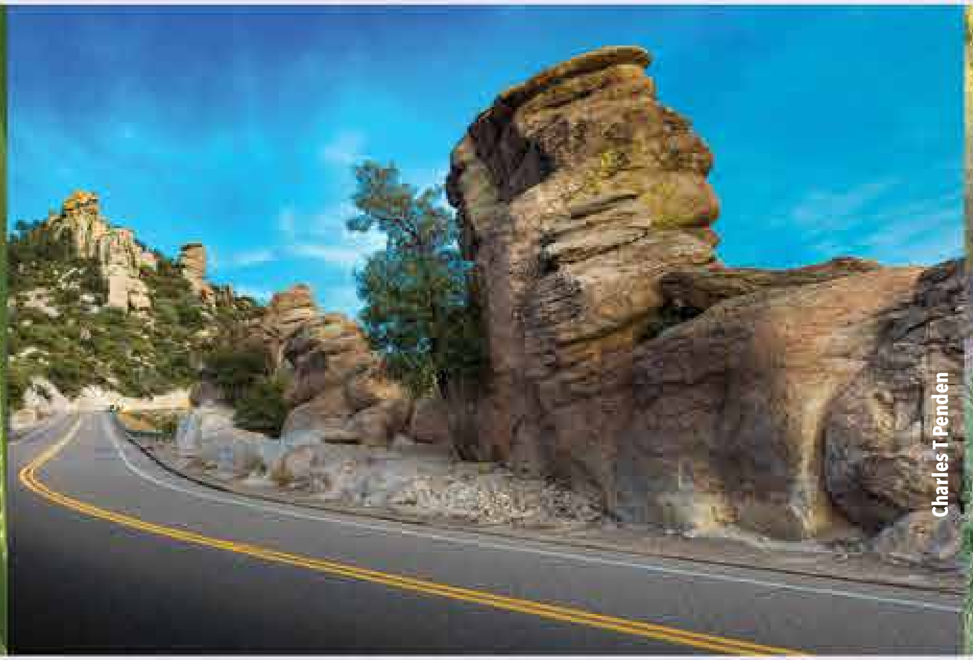
***Catherine Bartlett,** ASDM Education Specialist*

vagabond54

Richter Mach Thunder

Left: Sotol plant with a flower stalk. Right: Juniper tree overlooking valley.

Boulenger Xavier



Charles T Peden

Jolanta Sokol

Peggy Hazelwood

Left: Close up outdoor view of sotol, also called great desert spoon. Middle: Mt Lemmon Hwy. Right: Bear grass. Cut out: Alligator juniper.

Plant species have a few options for adapting to climate change, including evolutionary change (individuals with traits that are best adapted to the new conditions thrive and reproduce at higher rates) or shifting ranges in elevation and/or latitude over generations. A recent study (July 2013) tells the story of range shifts in our backyard – in the Santa Catalina Mountains. Plant species ranges are moving upward in elevation in response to climate change. Scientists from the Desert Museum, the University of Arizona and Pomona College teamed up to compare the current elevational ranges of 27 species of plants along Catalina Highway to their historical ranges, which were documented in 1963 by Robert Whittaker, who's been described as the "Father of Modern Plant Ecology."

The research team followed approximately the same 20-mile stretch of the Mt. Lemmon Highway as the original 1963 sampling transect to allow for direct comparison over the 49 year time span. Over the last five decades in Tucson, mean annual air temperature has increased by 0.25°C/ decade and over the past two decades mean annual rainfall has decreased, reflecting a widespread drought in the Southwest. The researchers found an upslope shift in the lower range limits for 56% (15 out of 27) of the plant species in the study. For example, alligator juniper was recorded at Molino Canyon Overlook and Babad Do'ag Trailhead in 1963, which are between 3000-4000 ft, however, they now start appearing at 5000 ft. Similar trends are seen for other common and recognizable species, bracken fern, sotol and bear grass. The elevation ranges of 16 out of 27 of the species studied had contracted over 49 years. Changes in the upper elevation limits of species occurrence were mixed, with some species having shifted up (4), some down (8), and others showing no change (15). Overall, plant species appear to have adjusted their upper and lower elevational limits separately and individually, as predicted by some ecological models.

For more information and a detailed look at the article, please visit: "Dramatic response to climate change in the Southwest: Robert Whittaker's 1963 Arizona Mountain plant transect revisited." Richard Brusca, John Wiens, Wallace Meyer, Jeff Eble, Kim Franklin, Jonathan Overpeck and Wendy Moore, https://onlinelibrary.wiley.com/doi/full/10.1002/ece3.720 S

Climate Change and Buffelgrass

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Charles T Penden

Above: Buffelgrass, an invasive species growing north of Tucson, Arizona in the Catalina Foothills.

Over the past three decades, buffelgrass *(Cenchrus ciliaris)*, a highly flammable African grass, has rapidly invaded the Sonoran Desert of southern Arizona. Those Tucsonans who live in the Catalina Foothills have been watching this invasion take place from front row seats. By now, most residents can easily spot yellow stands of this disheveled, tinder-dry grass that have come to dominate more than 10,000 acres on the southern slopes of the Santa Catalinas. Buffelgrass has become a dominant species in our urban environment too. It's abundant in alleys, vacant lots, washes and along roadsides across the Tucson Basin.

Buffelgrass is transforming our desert into an ecosystem that looks more like an African savanna. Although the negative effects of buffelgrass are not immediately apparent, the devastating impact of buffelgrass-fueled fire became apparent in July 2017 when fireworks ignited a buffelgrass infestation on the south slope of Sentinel Peak. The fire killed or injured nearly 500 foothills palo verde trees *(Parkinsonia microphylla)*, a keystone species, and 276 saguaros *(Carnegiea gigantea)*, many over 100 years old. Fire can transform the desert overnight, but even in the absence of fire, the transformation from desert to savanna is taking place, just at a slower pace, as the seedlings of our iconic species will not survive in a sea of buffelgrass.

What do we stand to lose in a buffelgrass savanna? First to go would be the spring and summer wildflowers, as well as the pollinators that rely on them. Next would be the diverse desert understory vegetation, the grasses, forbs and shrubs that feed most of our herbivorous desert creatures, everything from seed harvesting ants to the desert tortoise to mule deer. Last would be our long-lived saguaros and desert trees, keystone species that feed and house so many others.

The climate changes we expect in coming decades are likely to exacerbate this problem. Over the past decade, we have observed fewer freezing events than normal (compared to the historic record). Along with this change, we have seen frost-sensitive plants, including buffelgrass, expanding into higher elevations. Moreover, in the past buffelgrass remained in its dormant state throughout the winter months, but in recent years, winter rains accompanied by unusually warm winter temperatures have provided buffelgrass new opportunities for growth and reproduction. Other changes, such as greater concentrations of atmospheric CO_2, could also potentially favor buffelgrass over native plant species.

Although it may sound like the cards are stacked against us, in reality we are well-positioned to take back the places we cherish most from buffelgrass. Effective means of control are well-established. Both manual removal (digging it up!) and treatment with herbicide have been used by Saguaro National Park for over two decades, with great success. Moreover, teams of volunteers under the direction of Pima County and the Desert Museum have been removing buffelgrass from much of the Tucson Mountains, maintaining Gates Pass and the area around the Desert Museum buffelgrass-free. In 2017, the combined efforts of both groups totaled approximately 3600 volunteer hours!

Despite this success, more research and an increased investment in monitoring and control will be required to keep up with a rapidly changing climate and other environmental changes expected to alter the dynamics of the buffelgrass invasion. For example, in addition to rising temperatures, changes in precipitation and extreme weather events (eg. more frequent or severe drought) will almost certainly affect the population dynamics of buffelgrass and the outcome of competition between buffelgrass and native species. Other environmental changes, such as nitrogen deposition on desert soils as result of the burning of fossil fuels, will also have impacts on the performance of both invasive and native species. Increased levels of soil nitrogen often favor plants that evolved in nitrogen-rich environments over plants that evolved in nitrogen-poor environments. Over the past decade scientists with the U.S. Geological Survey have been developing landscape-level simulation tools for buffelgrass that take into account landscape structure, pathways of dispersal, climate change, and other environmental factors to predict the outcomes of different management strategies. These tools can help land managers who face trade-offs in allocating limited resources to the management of vast tracts of public land facing an increasing number of threats.

Despite our best efforts, buffelgrass is not going away. Buffelgrass control must become part of the everyday practice of land managers in southern Arizona. Is it worth it? We live in one of the most beautiful places on Earth, and the cost of protecting this place is small, whereas the costs of allowing the buffelgrass invasion to continue unabated are immeasurable. Can we put a price on the saguaro forests that blanket the slopes of the Tucson Mountains? Can we accept a future in which spring wildflower blooms are just legends of the past, and desert fires have become commonplace? What goals are realistic and attainable under current and future climate scenarios? These are questions facing our community as we move into a future of rapid environmental change accompanied by great deal of uncertainty. Despite this uncertainty and the challenges that lie ahead, our chances of success are high. On the other hand, if we fail to act, I believe that thirty years from now we will be asking ourselves, "What happened to our desert, and why didn't we do something?" S

Julia Rowe

Julia Rowe

Pacifica Sommers

Top right: One of the most effective ways of controlling buffelgrass is to remove it manually with picks and digging bars. These volunteers are working in Pima Canyon.

Middle right (Inset photo): Saguaros badly burned by buffelgrass fire on A mountain on 4th of July, 2017. Outer photo: Same area a month later after rains. Buffelgrass is amazingly lush and green compared to the buffelgrass on the rest of the mountain as a result of the influx of nutrients after the fire.

Bottom right: Buffelgrass survived whatever killed these saguaros.

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