Climate Change and the City of Tucson's Greater Southlands Habitat Conservation Plan: Climate Projections and Habitat Workshop

Monday October 17, 2011 from 1:00 to 5:00 p.m.
City of Tucson Housing and Community Development Department, Sentinel Building
(310 N. Commerce Park Loop), Pantano and Santa Cruz Rooms

Transcription from Audio Recording (draft)
(Note: Draft transcripts were sent to each speaker, some of whom made clarifications. Some speakers expressed a desire to clarify or edit their transcript, but do not have time.)

CONTENTS:

ATTENDEES:

Dennis Abbate – Arizona Game and Fish Department
Marit Alanen – United States Fish and Wildlife Service
Lee Alter – Cascadia Consulting
Julio Betancourt – United States Geological Survey
Jamie Brown – City of Tucson Office of Conservation and Sustainable Development
Carlos Carrillo – University of Arizona
Theresa Crimmins – USA National Phenology Network
Francina Dominguez – University of Arizona, Department of Atmospheric Sciences
Doug Duncan – United States Fish and Wildlife Service
Leslie Ethen – City of Tucson Office of Conservation and Sustainable Development
Julia Fonseca – Pima County
Gregg Garfin – University of Arizona, School of Natural Resources and the Environment and Institute of the Environment
Rich Glinski – Arizona Game and Fish Department (retired)
Trevor Hare – Coalition for Sonoran Desert Protection
Kathleen Kennedy – Coalition for Sonoran Desert Protection
Taryn Kong – University of Arizona
Kendall Kroesen – Tucson Audubon Society
Tom Meixner – University of Arizona, Department of Hydrology and Water Resources
Mead Mier – Pima Association of Governments
Asia Philbin – City of Tucson, Tucson Water
Brian Powell – Pima County
Spencer Reeder – Cascadia Consulting
Phil Rosen – University of Arizona, School of Natural Resources and the Environment
Russ Scott – United States Department of Agriculture, Agricultural Research Service
Linwood Smith – EPG, Inc.
Janine Spencer – Town of Marana

TRANSCRIPT:

Topic 1: Regional climate change projections for the next 70-plus years

<u>Gregg Garfin – University of Arizona, School of Natural Resources and the Environment and Institute of the Environment</u>
Just to motivate this, when atmospheric composition changes you end up with big changes in the global energy balance, which could also result in changes in oceanic and atmospheric circulation where heat, energy, and moisture are redistributed. And, of course, the thing we are interested in here is the effect of global processes on our watershed and the Habitat Conservation Plan area. In order to figure out what might be plausible for the future, we use climate models at a global scale that use mathematical equations to represent many different processes. These look at, again, heat and moisture exchange between the ocean and atmosphere, land surface, atmospheric changes, and so on. Depending on the resolution of the model, you get some interesting effects with

topography. At roughly the scale of the global models or GCMs, the Rocky Mountain chain looks like a 9,000-foot blob. At the 25 and 10 kilometer resolutions, you can see individual mountain ranges and peaks. Thus, whereas in the global-scale models, with their 200 kilometer resolution, the Santa Catalina, Rincon, Tucson, and Santa Rita Mountains might appear as a high elevation area, in the finer resolution models, you can identify each of those mountain ranges and even some of their individual peaks.

One of the key things when talking about climate modeling is accounting for uncertainty and there are many kinds of uncertainty. I won't go through all of this in great detail but, just first of all, when I say "uncertainty" I don't mean that we don't know anything. It is accounting for things that we know well and that we don't know well. On the physical science side of things, there is uncertainty just with the measurements that we take to observe biological and physical processes. With the global climate models, there are processes that we know imperfectly that equations can't account for – things that we have to use best estimates from the literature or parameterizations[1]. And, of course, we really want to get down to the details and we have to use other kinds of process models.

Also, in thinking about the future, possibly the biggest uncertainty is what greenhouse gas emissions will be, which is dependent on such things as global economics and policies. When we look at these projected changes in global temperature, rather than try to predict the future, we embody some assumptions about changes in emissions through the use of different scenarios. The key distinction here is between prediction, such as daily weather predictions in which the time scales are such that changes in atmospheric composition do not have an appreciable effect, and projection, where scientists use emissions scenarios, because they cannot predict global economics, etc. on the century-long time scales of climate model runs. These scenarios have different assumptions about population change globally, economics, and other factors. And, depending on which of those emission scenarios you choose, you end up with a different temperature pathway. I'll be referring to the B1 scenario which involves aggressive alternative energy, global cooperation in terms of economics, and so on. The A2 scenario is more "business as usual" in terms of fossil fuel use, with isolated economies that don't cooperate, a higher rate of population growth, and so on.

As you can see, the implications for global temperature don't start diverging until a few decades hence so that they stay pretty well clustered in the first 25-30 years of this century. And, there have been some efforts to estimate different aspects of uncertainty both globally and regionally[2]. An example is for the British Isles. What the investigators did was they looked at many different model runs and tried to estimate the amount of uncertainty – the fraction of uncertainty that was due to different factors like the internal variability of the climate system, the different scenarios that we choose and the uncertainty embedded in the models and how they represent all of those different processes using equations. And, one of the key things here is that on very short time scales, internal

[1] We should probably define this term; I have inserted language from the American Meteorological Society's online Glossary of Meteorology (http://amsglossary.allenpress.com/glossary/browse).
Parameterize: The representation, in a dynamic model, of physical effects in terms of admittedly oversimplified parameters, rather than realistically requiring such effects to be consequences of the dynamics of the system. An example is subgrid-scale processes, which are **a**tmospheric processes that cannot be adequately resolved within a numerical simulation. Examples can include turbulent fluxes, phase changes of water, and chemical reactions. Such processes are often parameterized in numerical integrations (*i.e., model runs*). (italics are Garfin's language)
[2] Reference: Hawkins, E. and R. Sutton, 2009: The potential to narrow uncertainty in regional climate predictions. *Bulletin of the American Meteorological Society*. doi:10.1175/2009BAMS2607.1

variability at the smaller regional scales like the one we're looking at, the Greater Southlands HCP Planning Area, dominates the uncertainty. However, when you get out to the end of the century, it's more dominated by the choice of emission scenario and we saw that with the temperature projections. These are kind of a caveat.

I'll talk a little more about different processes to project climate change and then share some projections for the region. Francina will go into a lot more detail about projections that may be particularly useful for our region. One of the things that the Intergovernmental Panel on Climate Change report said is what GCMs can and cannot do. They say that there is a lot of confidence in these at global and continental scales because they can reproduce physical processes and observed features of climate present, future, and past. They are better for some variables like temperature that are more spatially coherent, than for precipitation. And, overall globally they show a robust and unambiguous picture of significant warming in the future. Again, those are the caveats.

One of the ways to bridge very large spatially scales, like the 200 kilometer per side of the grid scale in the global model, is to use a process called downscaling. Therefore, we take information out of the global models and use statistical equations to bring it down to a regional scale that might produce some information that is valuable locally. Or, we can take the output from the global model and put it into a smaller scale, regional model that has better topography and finer grid cells and better physics for understanding the interaction between the land and the atmosphere at the smaller scales.

With statistical downscaling, equations are used to downscale a historical dataset using things like linear regression that you're familiar with. The advantages to this method are that it is inexpensive, relatively easy to do, you can use literally more than 100 model runs and build up a good statistical sample size, and it's easy to transfer from one region to another region. On the other hand, if you don't have a reliable historical climate record, it's hard to do those calibrations. It depends a lot on the choice of predictors. It assumes that the relationships between the overlap period of the model and the historical data are constant throughout time, and we know that that is not true.

Another con for this method is that it can't account for feedbacks from, for example, the land or water surfaces and the atmosphere. Therefore, one of the implications is that if you use this method, you're basically training the model dataset on the historical dataset and it's going to take on differences that are mostly based on changes in topography, by and large. Just as an example and I know that everyone hates equations, but a typical, very simple equation for doing statistical downscaling for precipitation might be to multiply what comes out of the model for a particular grid cell against a fraction of the observed, historical average in the numerator and the model average for that same place and time in the denominator. And, if the model is too wet, the fraction will be small to correct for the precipitation that is coming out of the model. If the model is too dry, then it will multiply things so that the fraction will be large. You do a similar thing for temperature, but you take the difference. It's a simple method. What it essentially does also is correct for the bias in the model and in the seasonal cycle of precipitation. In the model for roughly our region, that is January and this is December and you would expect the biggest spike in the summer months and maybe a little less in the winter. This kind of method forces the models to look more like what we see in the observed record. Here, we have the historical average for the region, we apply some anomaly to the model and history, and you get kind of a pretty picture for the future. Again, we are taking into account this bias that the model may have; downscaling does not simply use the model results as if, if, for example the model has an unrealistic seasonal cycle (such as if Tucson showed a spring peak and a summer low in precipitation). All downscaling corrects for these types of biases. There is a very well-known and well used dataset put together by Lawrence Livermore National Lab, Santa Clara University, and the Bureau of Reclamation, which we refer to as "Reclamation's" dataset[3]. It is currently considered a standard for this statistically downscaled data.

Dynamical downscaling, which Francina will talk about at length, takes the output from the GCMs and passes it through basically a weather forecast kind of model. The good things about it are that the response is based on physical processes, it captures regional feedbacks between the land and atmosphere, and it can model changes that have never been observed before in the historical record. It is particularly useful where topography is particularly important, such as in our region. On the other hand, there are some limitations that primarily have to do with resources. It takes lots of money and time to do this – it requires significant computational power and so it limits the number of model runs that we can use. There is also a problem with so-called drifting at a wide time scale. Again, the key thing here is that we're assuming that with some improved model physics at the regional level and with finer resolution, these will give us an improved output. This includes better fidelity with historical observations and better representation of the physical processes that are important for our region. You are using the GCM data for a particular grid cell as an input to this regional model and it is also input from the atmosphere to the land surface. And, you're using the regional model as sort of a magnifying lens to create this higher resolution data. You're using the output from the GCM and equations to represent processes, but there are some processes that we can't resolve at the grid cell level. Therefore, we have to use best estimates or what we call parameterization. These are best estimates from physical studies that you can't use equations to get at or dynamical equations to get at. And, that accounts for some of the uncertainty in this process.

The kind of modeling studies that Francina will talk about are at the 35 kilometer grid cell level, and that level will have some realistic topography. With statistical downscaling, there are easily available datasets for our region, such as monthly precipitation and monthly temperature. One of the other advantages of using dynamical downscaling is that there are over 90 variables, some at 6-hour time scales, such as snow-water equivalent, soil moisture, on so on.

This is some work done by Francina, Chris Castro, and others at the University of Arizona with a particular interest in the monsoon season. These are historical observations, (pointing to a map) here's Baja California, Mexico, getting into Arizona here, for June, July, and August. (Again, pointing to maps...) This is the global scale model and this is using dynamical downscaling. Taking it from the global model into the regional scale model, you can see that there is pretty good accordance between the dynamical downscaling and observations. Now I'll just show some results from statistical downscaling because, again, it is relatively easy to use, there is this free and easily available Reclamation dataset, which you'll hear referred to frequently. One recent reference is from a Bureau of Reclamation report for the western United States where they used this

[3] Reference: Maurer, E. P., L. Brekke, T. Pruitt, and P. B. Duffy (2007), 'Fine-resolution climate projections enhance regional climate change impact studies', *Eos Trans. AGU, 88*(47), 504.
Website: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html

statistically downscaled dataset and projected streamflow for major basins, including the Colorado River Basin[4].

Here (pointing at maps) we're looking at three different time periods – the 2020s, 2050s, 2070s – and we're subtracting the difference between those time periods and the 1990s. This is just the temperature climatology for the 1990s. Basically, what we see here all across the Basin with not much nuance is increasing temperatures going from perhaps a 2 Fahrenheit (F) degree warming in the 2020s, to 3-4 degree F in our region by the 2050s, and maybe as much as 5-6 F by the end of the 21st century. This is the same sort of set of maps, but for precipitation. Two key things here: One of these is that this reflects the sort of trend we saw in temperature, with some multi-decade variability, that it may possibly be wetter than the 1990s in the near term (i.e., 2020s), but perhaps drier later on in the upper reaches of the Colorado River Basin. However, by and large, what we see here for annual precipitation average is perhaps on the order of 5-10% drying in the course of the century in our region.

One of the bits of work that Francina and colleagues have done for our region is track and select the best models that most faithfully show the historical climate and also some of the atmospheric processes that are important for our region. Part of that work shows three models. I will refer to those three models and will also refer to the average that I've shown in the Reclamation dataset. This is some work that a colleague, Jeremy Weiss of the University of Arizona Geosciences Department, kindly put together. We looked at these 12 grid cells that intersect the boundary of the City of Tucson limits and took an average of those from the Reclamation dataset. I don't expect you to read these numbers in the table, but we broke things down into 30-year periods – 2011-2040, 2040-2070, and 2070 to the end of the century – and we broke it down by seasons. So, you have annual measures and then winter, spring, summer, and fall.

I'll point out just a couple of things. Regardless of the emissions scenario you use – the 16-model ensemble from Reclamation or the 3 models that Francina chose[5] – by and large we see decreases in winter precipitation. It's not 100 percent consistent, but, by and large, that's a fairly robust result. In every case in spring, you see decreases in precipitation. We don't get a lot of precipitation in spring, but the little we get probably helps sustain species through the super dry period from the end of March through the end of June. Also, maybe it replenishes tanks (small ponds or watering holes used by wildlife) and surface water supplies. In the summer, by and large, we see a trend toward increasing precipitation. Just to look at this in terms of time series, the black line is the average from the Reclamation 16 models, the orange line is the 3-model subset, and the grey line is every single model run jammed together and going from 1950 to 2100. This is annual precipitation for the A2 scenario or "business-as-usual" emissions. By and large, we see a lot of year or multi-year decade variability, with some dry periods, some wet periods, and perhaps, overall, a small decline in precipitation for the Tucson Basin. Then, if we just look at those time series but for the different seasons – winter, spring, summer, and fall – probably the most discernible thing is the potential for decreased winter precipitation in the second half of the century and a big trend toward decreasing spring precipitation.

[4] Reclamation, 2011: SECURE Water Act Section 9503(c) - Reclamation Climate Change and Water, Report to Congress, 206 pp.

[5] Reference: Dominguez, F., J. Cañon, and J. Valdes, 2010: IPCC-AR4 climate simulations for the Southwestern US: the importance of future ENSO projections. *Climatic Change*, **99,** 499-514.

Here is the same sort of thing, but for temperature. Here's annual temperature with the 16 model dataset and the 3-model dataset, and the trend is quite apparent. Here's the same sort of thing for seasons and it literally varies by degree, with the greatest warming occurring in the summer season.

Just a couple of considerations: You can use models to inform your decisions, and you can use and justify either method of downscaling. Some people will throw darts or arrows at you while others will praise you. We can hope that we can get the silver bullet – the magic thing from our climate model "doctor" – but it's important to take the caveats into account and remember that these are projections, not predictions, with the largest uncertainty being emissions. With that, I'll turn it over to Francina.

<u>Francina Dominguez – University of Arizona, Department of Atmospheric Sciences</u>
Hello everybody. Thank you for being here. I'm Francina Dominguez and I work for the Department of Atmospheric Sciences. First I want to acknowledge my collaborators Christopher Castro, Erick Rivera Fernandez, Carlos Carrillo, and Hsin-I Chang.

This is just kind of the picture that I like to show between the GCM projections at that very coarse resolution and, after we perform the dynamical downscaling. This shows the continental downscaling that we do, so when we produce results, we produce them for the continental U.S., northern Mexico, and a little bit of Canada. So, there are slides in my presentation that repeat some of what Gregg shared.

My presentation focuses on dynamical downscaling and what we do is that we take the projections from the global climate model, those coarse projections, and we take a limited area model or regional model over this area that I'm talking about in the continental U.S and we drive the regional climate model, which, in this case is the WRF, the Weather Research Forecast tool. It's a grassroots effort based at NCAR [National Center for Atmospheric Research] and we force it at its lateral boundaries with the Global Climate Model. And, that Global Climate Model can contain information about historical periods and we can use something called reanalysis data, which is analogous to observations, or you can use it to drive these GCMs that have been working in the IPCC effort with future climate scenarios.

So, we have a finer resolution model that can have improved model physics and what we're testing is if these models are more similar to what was observed. We're also trying to gain physical knowledge from these analysis processes at this very detailed scale and so both of these can give us a return on our investments. And, just like the Global Climate Model that has this dynamical core that Gregg talked about, you're characterizing how the atmospheric fluids work and you're also characterizing all of these different physical processes: Radiation, clouds, precipitation, and the land surface boundary layer. Therefore, both the Global Climate Model and the Regional Climate Model work essentially in the same model. It's just that one is at a higher resolution and we can improve some of the physics in the higher resolution model.

I want to highlight a couple of things: The model is a physically consistent model and it captures our best knowledge of how this system works. The primary reason why we are doing this is that it can model changes that have never been observed in the historical record and this goes back to the issue of non-stationarity. There is a lot of this talk and it primarily comes up in the civil engineering world of how we design civil engineering structures based on the climate of the past 50 years. But, what happens in the future? What happens if these intense events are now more intense? How do we design for this new world that is coming? So, with these regional climate models, we can address this issue.

Another thing that I wanted to mention is with regard to the necessary computational power. With one simulation – one GCM/RCM combination – it takes us about five months to complete. We're getting better at it, but it takes 128 processors. So this is a continuous simulation where you send the process out, but someone has to be there and make sure that it is running well. Carlos can tell you all about our current efforts. Therefore, because of these gigantic computational limitations, we can't run as many different scenarios as we would like. So, for the work that I'm going to show you from now on, we're using two different sources of dynamically downscaled data. One we are producing locally at the University of Arizona Department of Atmospheric Sciences. As Gregg mentioned, it is a 35 kilometer resolution run. But, there is also a national effort called NARCAP [North American Regional Climate Assessment Program], which is being spearheaded at NCAR involving a lot of institutions tasked with different model simulations. We are using a total of seven different simulations from the NARCAP effort. What you get is kind of a matrix of Global Climate Model / Regional Climate Model couples, and, therefore, what we have is a larger ensemble than just our simulation. As of this moment, we have two simulations from the University of Arizona and nine from NARCAP. If this set were to be done now, we would have even more ensemble members.

We have eight models and the first work that I'm going to show is about precipitation events in the western U.S. for the winter. Here's what each of these models is showing you and these are all different RCM / GCM combinations. I'm showing mean winter precipitation for the western U.S. for the eight different models. These are observations that we are going to be working with. What we see is that, in general, the Regional Climate Models realistically represent the spatial pattern. You have this clear topographic forcing that is captured by the models, which is their job as they have to do the topography correctly. All models overestimate precipitation and this has been consistent for all of the eight simulations. From what I have seen, all of the models over-represent mean winter precipitation from 0 to 6 inches per year. And, this is only the historical period and how this GCM represents the historical period. Now, when we look at the future and how the models represent the future minus the past – so the change that they're projecting – we see, in general, that the pattern is increased precipitation in the northern part of the region and decreasing precipitation in the south of the western U.S. The axis, if you don't see it is minus 20 to 20. So, actually, we're kind of in the range of the statistically downscaled data and we have that same pattern: Wetter in the north and drier in the south.

What I'm showing here is model agreement: How many of the models agree with the sign of the change. There is this very clear geographical pattern coming out of both statistically downscaled data and dynamically downscaled data which comes from parent GCMs. So, I did this quickly, but I took grid points that correspond with Pima County and took them out of this to see what projections we're getting so that I can compare with Gregg's statistically downscaled data. For temperature you again see this much smaller uncertainty. Each of the thin lines represents one simulation. The bold represents the ensemble, with the historical in blue and the future in green. Results show an increase in temperature for all months and so there is no surprise there.

For precipitation, you see this huge uncertainty in the model, as Gregg was saying. Through these simulations, we're seeing consistent decreases for all months. So, we don't see the increase in the summer that Gregg is seeing. This is the multi-model average. So, as you can see, the changes in precipitation are small and are not statistically significant.

Perhaps one of the most interesting topics coming from these simulations is in the analysis of extremes. Gregg talked a lot about the changes in the mean, but, as he said, from the dataset you can only get monthly temperature and precipitation. Here, we have very high resolution data and what I'm showing you is an example for the Salt River Basin. So, we are analyzing the extremes and the way we are doing this is by taking the historical record, setting a threshold, and looking at the precipitation events that fall above the threshold. Then, we can set a probably distribution to those very high events. So, if we can do that for the historical period, we can do that for the future and see how that probability changes in time from these simulations. What I'm showing you here are just the tails from that distribution and this is the historical period and the future. With this example, what this is showing is that the function is shifting. You're getting that for the same probability of occurrence, you're getting a more intense event. And, we are presenting this data as the events that have a recurrence probability of once every 20 years or once every 50 years.

What I'm showing here is the ensemble change in extremes. This is 50-year return period events and I'm showing the mean of all 8 simulations. What we find is that there is a consistent and statistically significant increase in the intensity of future extreme winter precipitation events over the western U.S. Recall that for the mean, you have that clear pattern where the north gets wetter and the south gets drier. But for the extremes, it's just all getting more intense and you'll see in a little bit that there is very good agreement between the models. So, for example, what I'm showing you here are changes in mean precipitation and here are changes in those extremes, the 50-year, and I've subdivided the region into four subregions. This is the average over the entire region and looking at what the change in the average is. In general, even if you subdivide the region, the changes in the mean are small and statistically insignificant. All of the green dots denote statistically insignificant changes. Here, for the extremes, we see that the changes in the extremes are much larger than changes in the mean. Also, when you look at the region as a whole, what we see is that all of the models are projecting an increase in the intensity of extreme events. This is statistically significant for the entire region. So, this gives us confidence in these results.

So, before moving on, what we are seeing for the Southwest is a decrease in mean winter precipitation and increases in extreme winter precipitation. Therefore, our question was, "What is happening in between?" So, what we are looking at is the maximum number of dry days in a year. What we are doing is that for each year, we look at the maximum number of dry days and then average it out for all the time periods. This is for the historical and the future and the legend goes from 0 to 60 days. When we do the same, future minus historical, we see that there is a consistent increase in the number of dry days in the future for the southern part of the region. So, the models are projecting longer, drier periods, essentially. Therefore, in conclusion, we use this dynamical downscaling framework and for the southwest U.S., we have decreases in mean winter precipitation, increases in extremes, and increases in the number of consecutive dry days. That is where we are right now with the analysis of future precipitation. And, I'm glad that Carlos is here because they are now starting the analysis for the summer with these same models. For winter results, you can ask me. For summer results, you can ask Carlos.

Topic 2. Potential effects of climate change on aquatic habitat of Cienega Creek

<u>Doug Duncan – United States Fish and Wildlife Service</u>
I'm going to start with this talk that I put together with Gregg Garfin about five years ago, talking about native fish conservation and climate variability geared toward southeast Arizona. I'll make some references to what is happening specifically in Cienega Creek because that is the main aquatic area that the City of Tucson Habitat Conservation Plan is looking at. Basically, I took out a lot of climate change information because I knew Gregg would cover all of that. So, I'll talk briefly about some of the challenges of native fish and aquatic species in general and I'll frequently refer to native fish. However, herps are also considered too.

For native fish sites, we've had a historical reduction in native fish sites for a number of reasons. Over the last 50 years or so, non-native fishes have been the main source of impact and have led to the endangerment of our listed fishes and also our rare aquatic species. One of the things we are dealing with recently is, even if we have habitat that is suitable, if it's not on federal land you have land owner resistance. Some may say that there is landowner resistance to doing things even on federal lands. One of the issues with native fish conservation is sport fishing because it has a large constituency in the state and the Arizona Game and Fish Department sees that as one of their missions. Most sport fishing sites are not compatible with native fish mainly because most of the sport fish are piscivorous as they prey on our native fish as well as native frogs. One of the things we see in southeast Arizona, especially in the effluent dependent systems, is that we have degraded water quality and we have some other rare aquatic vertebrates, which I'll mention shortly.

In terms of the number of fish in southeastern Arizona, depending on how you classify the species, there are about 21. 16 still occur and the one extinct species is the Santa Cruz Pupfish. It used to occur in Monkey Springs and the Tucson Basin. It was recently renamed as the Santa Cruz Pupfish as it used to be just the Monkey Springs Pupfish. However, genetic research performed by Tony Echelle *et al.* determined that it was all one species. Unfortunately, it is still extinct.

One of the reasons for doing a Habitat Conservation Plan is that 13 of these species are listed under the Endangered Species Act. There are 3 species that occur in Cienega Creek, both the upper and the lower. There's the Longfin Dace, which is probably the most common native species in Arizona. The other two are listed and they are the Gila Topminnow and the Gila Chub. Cienega Creek, both the upper and lower, is designated as Critical Habitat for the Gila Chub. Some of the other native aquatic species we have in this area include a couple of leopard frogs, Tarahumara Frog, and Sonora Tiger Salamander. Cienega Creek has leopard frogs and a garter snake. Cienega Creek also has the Huachuca Water Umbel, which is an aquatic plant listed as endangered. It has pretty good populations in both sections of the Creek and has really been increasing in the upper section on Bureau of Land Management land. I was up there last week helping Jeff Simms with some fish surveys and we were finding Huachuca Water Umbel every place we looked.

I'll talk about what we consider the baseline of the endangered species game and some of the threats to aquatic habitats. As I mentioned earlier, the biggest threat of the past 50 years is non-indigenous species. This is the term I frequently use, which is the same as invasive, non-native, or exotic. A lot of habitat loss mainly occurred in the first half of the 20th century with the great increase of groundwater depletion and dewatering of a lot of the habitats, such as the Santa Cruz River and Rillito River. Also, some habitat loss occurred with damming, although that hasn't been too much of an issue in southeast Arizona. Another issue with both of those together is the reduction in habitat quality. Because they are tied together, there are many studies. Reductions in habitat quality often provide the inroad or a trigger for non-indigenous species to invade. Once they invade, their numbers increase significantly. As you can see from the little quote, those two things are a factor in 98% of endangerment for listed fish species in North America.

In terms of climate change and the baseline of the fish and what might occur in the future, we've been talking about extreme events. I think the enhanced hydrologic cycle is going to be the most problematic for aquatic species, at least fishes mainly. Even though it appears that many of our native species deal better with floods, I think with more extreme floods, that may not be the case. We have lost native species to flooding in places where we reestablished them. The non-native fish species from the Mississippi Basin seem to be washed out by the floods, but that's not an absolute. The other factor with the extremes will be the potential of what happens to the functionality of riparian and aquatic systems. If there is increased downcutting, that will certainly have a big impact on habitats for native fishes and you've seen that at Cienega Creek.

There has been a lot of discussion about whether we have been in a longer term drought, whether it is a drought in and of itself, climate change, or both of them together. However, it doesn't really matter as conditions are drier and it looks like it's going to remain drier. That is going to make native fish conservation in Arizona even more difficult as we only have a limited amount of water. We have a fair number of threatened aquatic species, including fishes, snakes, and salamanders. Some of the species don't mix very well and so we have had some discussions over which species should go where. Also, in the future, we're going to have to look at prioritizing those sorts of sites for the species we're trying to save.

Some of the obvious impacts on fish are that fish need water. If you don't have water, then the fish are gone. I think it was 2004-2005 that the San Pedro actually had zero flow at the Charleston stream gage. There are only two native fish in the San Pedro River, the Desert Sucker which is another pretty common native fish, and the Longfin Dace. Desert sucker pretty much only occur in the San Pedro River in the area of the Charleston gage. Therefore, if zero flows become more common, we will probably lose Desert Sucker in the San Pedro. Another issue with reduced stream flow and that we have seen in other sites is that they can become fishless for at least certain parts of the stream because there is reduced dissolved oxygen. Another factor to consider in climate change, especially with a warmer climate, but also with less flowing water, is water temperature. There has been research at the University of Arizona with Scott Bonar and others. It seems counterintuitive: One would think that species that evolved here in the desert southwest would be more tolerant of higher temperatures than many of the non-indigenous that evolved in the Mississippi Basin and elsewhere. However, that is not the case. So, if we have less water and less vegetation in these areas impacting water temperature, these conditions could actually favor the non-indigenous species.

We've seen this happen at a couple of Gila Topminnow sites. Cienega Creek has Gila Topminnow. This is a spring in the San Rafael Valley within the San Rafael State Natural Area. There is a series of 17 pools in the Cienega system with staff gages in each pool. You can see that staff gage is high and dry. What has occurred in this system, which has had Gila Topminnow historically, is that Mosquitofish were put in there and Gila Topminnow and Mosquitofish don't get along even though they are about the same size. Mosquitofish are more pisciverous and will eat the small Gila Topminnow and harass the adult Gila Topminnow. If you gave me Gila Topminnow from a Mosquitofish inhabited site and a non-Mosquitofish inhabited site, I would be able to tell you which one it came from. This is because 80% of the Gila Topminnow from the Mosquitofish site would have shredded fins. So, over the long term, a lot of our Gila Topminnow sites with Mosquitofish is that, eventually, Mosquitofish take over for multiple reasons. At this site here we think it is a combination of factors. This is one of the sites studied by Gary McVie in the 1980s looking at flooding tolerance by different species, including Gila Topminnow and Mosquitofish. The Mosquitofish got flushed out quicker than the Gila Topminnow. The Gila Topminnow reacted to the flow by turning into the flow or go to the side. The Mosquitofish tried to maintain their position and got blasted out of these experimental flows. In this system, Mosquitofish first appeared in the 1980s. They did relatively well for quite a well with their stronghold in the upper pools of this system, maintained by periodic floods. Once we started getting into drier times in the 1990s, there weren't as many flows through there. Some of the pools went fishless, some of the upper pools were gone, and a few of the other pools became anoxic. This is because there was a lot less flow, so much so that Gila topminnow and Desert Pupfish, which can handle low dissolved oxygen, disappeared from this system. There are basically no Gila Topminnow here and the last time they were seen was about 5-years ago. At that time, one thousand fish were collected and only one of these was a Gila Topminnow. So, we are assuming that they are gone in that system, but we believe that this is due to a combination of the drought and Mosquitofish.

There's a similar story for Red Rock Canyon near Patagonia. It also had Mosquitofish and Gila Topminnow as well as bass at one time, but the bass didn't stay very long. So, it was a story mainly of Gila topminnow and Mosquitofish, which coexisted since the 1980s. However, with increased drying, loss of habitat, greater concentrations of fish, fewer refuges for the Gila Topminnow, and not having the Mosquitofish scoured out periodically, eventually we lost the Gila Topminnow. The last time they were seen was about three years ago.

That looks like a great fish site with great aquatic habitat. That is upper Cienega Creek near the headwaters on the BLM land. The story there is that the BLM has reduced the grazing and so a lot of vegetation came in. Vegetation is a "double-edged sword" for two reasons: Increased shading inhibits the exchange of dissolved oxygen and so you want sunlight to help get oxygen into the water. In addition, with all that extra vegetation, a lot of it falls into the water and decays, which also takes up a lot of the oxygen. The third factor in this story is that shortly after they excluded this from livestock grazing, the headwaters actually started to move upstream from where it had historically been. However, once it started getting dry in the late 1990s, the headwaters actually moved downstream. You can see in this photo the film on the water indicating that there are a lot of diatoms, which inhibit oxygen exchange. There are no fish in those headwaters. They have actually come back since there have been some flows there. That's been a factor on Cienega Creek too – the lack of any recent flushing flows. On both the upper and lower Cienega Creek, we don't have the non-indigenous species, but we can see that just the impacts from the drought exacerbated by, in this situation, increased vegetation, have an impact on the native fish there.

Therefore, I have a few recommendations. We need to continue our dialogues about native fish conservation needs. It's something we are doing a pretty good job of. A lot of native fish support in Arizona is funded by the Bureau of Reclamation's mitigation for the Central Arizona Project. We're about to get another big sum of mitigation funds for sport fish stocking and those impacts on native fish. With conservation planning, such as with HCPs, we do address climate variability through adaptive management. In the fish world, we have had some discussions and draft plans for having a fish salvage protocol. This effort started after the large fires in the mid-2000s, especially the Cave Creek complex, but has basically languished. We also need to replicate our important populations. One of the tenets of conservation is redundancy and so we want to make sure that we have these populations preserved in multiple sites. We're doing that with Gila Topminnow and this species is probably the best off in that aspect because it has been listed a long time. It is considered one of the most recoverable. We have a pretty good handle on that, but not so much for the Gila Chub since it was listed more recently. Efforts on the Gila Chub Recovery Plan with the recovery team are going on this year as we speak. One of the other things that we need to continue doing is identifying potential refuge sites as well as wild sites where we can replicate wild populations and aquatic communities, not just for fish but also considering the other native, aquatic vertebrates. Once we have those sites, we need to continue monitoring. We're doing a pretty job of that mainly through a suite of different groups. Phil Rosen does a lot for herp sites. Arizona Game and Fish Department does a lot for the other native fish sites.

<u>Mead Mier – Pima Association of Governments</u>

I'm Mead Mier and I work with Pima Association of Governments in watershed planning. I monitor Cienega Creek in the Pima County natural preserve, but just the lower part of the Creek for the Pima County Regional Flood Control District and for regional benefit. My presentation is on our drought findings and some of our monitoring methods that have been used and also on some of the erosion impacts. Perhaps everyone knows this but I was just looking at the map and noticed that about half of the Preserve lies within the Greater Southlands HCP boundary, from about Marsh Station downstream.

I didn't know who would be here today and so I refer to a lot of you. This is about the water in the system. I don't look at the precipitation data; I look at the base flows and how precipitation effects groundwater levels. There is over 30 years of hydrologic data on the Creek and the Preserve. The first monitoring data is from around 1975 and the Cienega Creek Natural Preserve itself was established in 1986. Groundwater and surface water are monitored monthly and we also do wet/dry mapping every quarter. Our next wet/dry mapping survey is in December and is a good way for people of all disciplines to join us on the Creek. I share my hydrologic data with them and this is generally a good venue for information exchange. We also monitor Davidson Canyon and have conducted an erosion study, as I mentioned.

So, I'm sure that you know that Davidson Canyon flows into Cienega Creek just about at the Marsh Station Bridge. We have consistent long-term data which allows me to submit monthly drought reports to the State of Arizona. This is important because every season we see different impacts of drought. The State finds our data helpful because it represents the natural environment, while a lot of information used in the State drought reporting system has more to do with municipal supplies. A lot of the drought information sent out to the public has more to do with municipal supplies or to agriculture. For example, the City of Tucson and Pima County are in Drought Stage 1 and the next trigger is a decrease in Central Arizona Project supplies. With the drought watch reporting system, the State encourages everyone to participate because it's a good way to see what's actually occurring on the land. I just looked at the recent drought results and drought is present on the Santa Cruz Watershed. For the long-term, it is considered moderate status and, for the short-term, it's already extreme status. In August, the USDA designated Pima County as a disaster area, which relates to abilities to get funds for agricultural needs.

So, this is our length of stream flow from 100 percent to zero. This is stream flow volume and groundwater volume. I just wanted to point out the decline. We consider around the year 2000 to be the start of what we consider drought years. However, you can see that it varies quite a bit. But one thing is that they all parallel each other pretty well. For the same year, you can see length of flow, stream flow volume, and ground water levels and you can see that they parallel one another. The point is that we are in a very acute drought, the groundwater levels in particular.

So I'll go into each of these really quickly so that you know what the current data is. I used to say that our driest year was 2004, but this June we beat that for wet/dry mapping, which showed just 13% flowing. The last time that there were continuous flows was in 1984. Since 1999, the average has been 28% flowing out of the nine miles total. The wettest year since around 2000 was 2001. So, in that drought period, the percent of the Creek with flows has declined since then. There are similar results in Davidson Canyon. In 2005, it was completely dry and although it has had flows since then, we have not seen fish or Lowland Leopard Frogs. Additionally, for management we're concerned by Off Road Vehicles in that area.

During our wet/dry mapping, when we see endangered species, we record them so that we can report to Pima County for the purposes of their Multi-Species Conservation Plan. Therefore, it's a cooperative effort. When fish experts come along on mapping trips, they point out the Gila Chub or Gila Topminnows and we usually see Lowland Leopard Frogs. Groundwater is five feet lower than it was pre-drought. This is significant because it is a shallow water dependent ecosystem. Say the cottonwood tree has the ability to send roots down 20 feet, this five feet is a significant portion of its root's range. For stream flow, I guess they all have similar patterns, but you see high variability. This is a picture of the stream flowing bank-to-bank in Sept. 2008 and here's a picture of zero stream flow in June 2011 at the Marsh Station Bridge. This is another example of variability. In Sept. 2009, we saw the driest September on record and that is usually the wettest time of year. Whereas this September was the wettest September on record and so it varies quite a bit year-to-year. However, we saw very little fish recovery from June through September 2011, even though there was high flow in September. Due to the extremely low June levels, the fish didn't recover and so the lowest point is very important for these aquatic species.

Also, the peak for the time of flow seems to be changing. For the driest years, the highest flows seem to occur in winter and in wetter years, the highest flows tend to be in summer. So, it sounds a little opposite compared to precipitation, but that is what I see with the actual base flow. We coordinate with Sky Island Alliance and we hear their staff and volunteers saying that in the driest months, they see fewer species using the corridor.

We also did an erosion study that showed a correlation between erosion and drought. This is our headcut area, the active zone, and you can see a 12-foot drop since 2004. We're in the bottom of the channel. I'll just go through this real quick. The concept is that you'll see the soils destabilize and the root zone is being dewatered and so you see change in habitats. Some of the trees die-off before the nick point makes its way upstream due to the destabilized soils. That's about 4000 feet that the nick point traveled in 10 years. This is a quick explanation of why we see the erosion happen. Basically, the groundwater levels are dropping and the slope of the groundwater table increases in the driest periods of the year and that creates a dewatered aquifer. That destabilizes the soils and leads to more erosion, but it's also really important to note that the erosion follows the dry periods. It's not the big events that wash the sands down; we saw major erosion happen when we had a major storm event in April after a very dry winter. That creates the same amount of erosion as would a significant rain event during the summer monsoon period. So, it's that dry point before that seems to cause the most erosion. We published a report on this topic that is available on our web site. When we did the habitat assessment, we found more pools in this active zone and so this erosion increased fish habitat temporarily. Loss of sediment exposed the subsurface flow. Therefore, if you're managing for fish, perhaps that is good, but there is a loss of vegetation cover and so if you need shade, those 30-year old cottonwood trees are gone and no longer provide shade.

I don't have recommendations for management as it depends on what you are managing for. The Preserve wants to maintain instream flows, sustain shallow groundwater, and preserve native species. They also look for groundwater pumping, but that is not a major concern in that area as it is pretty well preserved. Upstream in Las Cienegas, however, there are a lot of restoration projects that Sky Island Alliance is involved in. The idea there is to increase resilience through restoration. In terms of urban areas, green infrastructure and low impact development is recommended. One area that PAG works in is green infrastructure and low impact development, with the concept to slow, spread, and sink the water in both urban and natural areas to mimic the healthy hydrologic systems.

Topic 3. Potential effects of climate change on xero-, meso-, and hydro-riparian hydrology and vegetation health in the Tucson region

<u>Tom Meixner – University of Arizona, Department of Hydrology and Water Resources</u>
I'm a professor of hydrology and water resources at the University of Arizona. I'm here to talk about riparian hydrology, and when going through the slides, there will be an emphasis on climate change. Some aspects of the presentation are on biodiversity, riparian hydrology and land use/land cover change as well as riparian cover.

Earlier, Trevor mentioned these other stressors and I think it's also important to remember that there were stressors in the past. This is the classic picture of the Santa Cruz River in 1942 and then in 1989. We had a river with cottonwood trees and then we didn't. In parallel, here's the San Pedro River at the U.S.-Mexico Border in 1930. It's an open grassland landscape. Here's a more recent picture showing that it's now a lush, riparian forest with dense growth. So, we're dealing with these legacies. We have the Cienega Creek Natural Preserve and some of the change we've seen is probably due to the drought, some of it is due to what BLM has done, and some of it is probably due to what occurred 120 years ago when, seemingly, every cow in Texas moved to Arizona.

So, I'll talk a little about the hydrology of semi-riparian areas, the seasonality of climate, recharge, riparian hydrology, and the wet/dry mapping on the San Pedro. And, there may be some discussions *vis a vis* Cienega Creek. So, one key aspect about the hydrology of the southwest that Francina probably already mentioned is the profound seasonality of our precipitation. We're here and the San Pedro is here and we're essentially on that 50/50 line – half of our rain comes during the summer monsoon and half comes the rest of the year, mostly in the winter. Those two things may not move in unison as I imagine Francina covered with respect to climate change. Summer rains may be one thing, winter rains another. That is important because they behave very differently hydrologically for riparian systems. I'm going to talk about the San Pedro River, which is the next basin over, because that is the system that I can talk about competently as opposed to Cienega Creek. I know Cienega Creek is there, I've been there, and I've actually been on the wet/dry mapping that Mead discussed. I don't know as much about the biology and physicality of that system.

With these riparian systems, whether it's Cienega Creek or the San Pedro River, we have systems where there is mountain block and mountain front recharge that occurs at the highest elevations. In the case of Cienega Creek, I believe that the Whetstone Mountains have been shown to be important but, oddly enough, there is no robust data on the Rincon Mountains and what their influence may or may not be in Cienega Creek. However, it rains a lot more on the mountains and there is excess soil moisture, in particular, in the winters. That allows recharge to occur through the mountain blocks themselves or streams run out onto alluvial fans. Anyone who has been to Sabino Creek can see that when you walk into the canyon, there is water; you walk down below, there is none. Where that water goes, it went into the groundwater system. In addition to those two mechanisms, there can also be basin floor recharge, which in much of the region is negligible. But with Cienega Creek though, particularly in the BLM lands of the upper part of the Preserve, there is some amount of recharge that is occurring there that is supplying the groundwater system because it is at 5,000 ft. of elevation. There can also be recharge from ephemeral run-off events. The washes are sandy and so the water percolates and some of it may or may not reach the groundwater system and I'll touch on that as well.

A lot of my work on the San Pedro has focused on a revised description of the hydrology of these systems. We know that when floods occur, these streams can go from ankle deep to chest deep in a matter of minutes. That change in stream stage can drive a significant amount of water into the subsurface. With the San Pedro River, about half of the flow of the river is actually the summer flood recharge. With Cienega Creek, it is probably not going to be as important because of the geologic nature of the system. The Tanque Verde Formation is not all that deep and presents essentially a confined layer of depth. There is, of course, a linkage between the water sources here and availability to what Julie Stromberg at ASU – she has done work at Cienega Creek as well – has shown to be the condition class. If we want to have cottonwood/willows and riparian wetlands, you've got to have sustained, perennial flow. Once you don't have perennial flow, you lose water necessary for herbaceous species from the system that a lot of herps and other things depend on. Once you go dry part of the year, you lose some of the cottonwoods and then when you get completely dry, you just get mesquite bosque in these systems. In this way, I don't think that Cienega Creek is too different from the San Pedro at Charleston. You have this profound pre-monsoon dry period where streams dry out and will go to zero flow. Then you have a profound flood season and higher base flow after the flood season than you had before because of all of this flood driven recharge that happens. You may get further recovery during the winter when trees drop their leaves and evapotranspiration (ET) shuts off. So, the stream flow continues to recover and then the cycle is repeated.

Some of the material I'm presenting shows the legacy of past extremes. In the late 1800s, many cattle from Texas moved to Arizona and denuded the landscape. For the San Pedro River and Cienega Creek, you had this big flush of sediment off of the landscape and into the valley bottoms, raising up the bed level. Subsequent to that you get downcutting after the erosional process ended. And, on the San Pedro, we've been able to look at aerial photos essentially from the 1930s through today and look at what the system was like in 1955 and what it is like today. The main thing that has happened is that areas that were bare ground in 1955 are now, over half of them, in cottonwood/willow. What was a big, wide, sandy floodplain has narrowed and is now dominated by cottonwood/willow and so there has been this replacement. My understanding is that similar processes have happened on Cienega Creek – from a fairly sandy system years ago to much more of a gallery forest, at least from what I've observed today. So, I think this is something to keep in mind. This system we see today is still a system recovering from past insults even though we are preparing for new insults to that same system. So, sometimes the response we are seeing is because of the past and some of it is because of what we've done today.

So, that ephemeral channel recharge and these floods: Where do they come from? Some of the best research comes from Russ's team at the USDA Agricultural Research Service. They've done a lot of work at Walnut Gulch. You see these relatively defined, very intense events. I think the peak amount of rainfall is about 60 mm of precipitation in 30 minutes. This is a classic, summertime "gully washer." It rains here and flow occurs at this scale, flume 6, and then essentially, water is disappearing. There are 246,000 cubic meters here, 200,000 here, and only 150,000 here. All of that water is percolating into the sands of the wash and the sediments underneath it. Because of the long-term data they have at Walnut Gulch, they've been able to quantify this. So, this 300 mm of precipitation that happens at Walnut Gulch is pretty similar to what would happen in the southeast corner of the Tucson Basin. Almost 330 mm of it essentially soaks into the ground. For the most part, plants use it and it evapotranspires back to the atmosphere. Twenty-three mm runs off that individual spot and goes into the channel network, where 20 mm more is lost in these transmission losses. Now, we don't have a really good handle on these transmission losses. It is only, I'll be generous, 5-10% of rainfall. However, once it soaks into the sediments, it's not clear how much of that goes to the channel evapotranspiration back to the atmosphere and how much goes into sustaining groundwater recharge in these ephemeral channel systems. Two millimeters in the case of Walnut Gulch, sort of the biggest scale here, about 100 square miles, goes out as runoff into the San Pedro River itself.

When and where does the groundwater in our systems come from? This is going to be important *vis a vis* climate change. If winter and summer precipitation change, how is that going to affect the system? This is again data from the San Pedro Basin, but Tucson looks remarkably similar, if not even more shifted to the winter component I'll be talking about. What you're looking at here is elevation at which rainfall occurs. On the x-axis is the isotopic composition of that precipitation. You can largely think of this isotopic composition as more and more negative values are colder and colder clouds from which the rain originated. So, not surprisingly, with elevation there is a slope. Higher elevations yield colder precipitation and there is also the difference between summer and winter. Winter is colder, summer is warmer (less negative). The key is that since we have this thermometer of what the temperature was in the cloud, we can maybe identify the elevation or the season in which the precipitation occurred. Things I'm not showing here deal with noble gases, dissolving water work to tease this out. So, winter precipitation can be more negative, colder. Negative in the San Pedro Basin would be negative 10 and summer would be negative 5. If we go to actual observations in the San Pedro Basin, we have springs in the mountains. We have riparian groundwater down here and we have, say, wells underneath Sierra Vista, the City of Tucson, the Catalina Foothills, and the Tucson Foothills. Then we have wells in the mountain park. These lines here are sort of two different models. I prefer model 2 because it represents that elevation gradient, but it doesn't matter too much which one we use. But what we get when we use all of this is that the basin groundwater here is 75 percent winter precipitation component and 25 percent summer. Now, this is in the San Pedro Basin where summer precipitation is 60 percent of annual rainfall and winter precipitation is 40 percent. This is compared to Cienega Creek in the Tucson Basin where it is closer to 50/50 percent or almost flipped (40 percent summer/60 percent winter). So, even here where winter precipitation is a relatively small component of the overall precipitation budget, winter precipitation is three-fourths of the recharge that goes to sustain the groundwater system. Now that is the groundwater system as a whole. When you get to the San Pedro River itself, there is a much larger component of summer precipitation in the water that we actually see in the River. This graph shows it better. Here's that basin groundwater component, which was 75 percent winter and 25 percent summer and here is monsoon runoff that is observed in the river channel network. These are the riparian wells and the different symbols here are base flow. This is Charleston down here, which is a relatively perennial site versus Palominas, which is an ephemeral site. So, sites with more ephemeral flow that might go dry for some years or extended periods of time are more dependent on this monsoon runoff component than the perennial sites. So, you're most perennial sites are dependent on this basin groundwater, largely winter precipitation. In contrast, the more transient condition sites are more dependent on monsoon precipitation. Writ large on the San Pedro, about half of the water in the stream is from summer precipitation and about half of it is from this basin groundwater. Therefore, to the River itself, the summer is pretty important. To the basin groundwater, winter is important. So, if you are trying to sustain the system on a long-term basis though, factors that change the winter component sort of determine the overall state and wetness of the system. Then, the summer runoff component determines that boom or bust that you can get from strong or weak monsoons.

Similar to Cienega Creek, The Nature Conservancy and BLM, with a host of volunteers, have been mapping the wetness and dryness of the River. And I think you see fairly similar things on Cienega Creek. There are these notable reaches that are always wet. Just upstream of the control structure on Cienega Creek, it is always wet along a fairly substantial reach. Another traditionally substantial reach is at the Marsh Station Road crossing, although maybe not more recently. But there are also these sporadic spots with sustained wet and there are these oddities. You come across these springs and the stream is wet for 20 meters and then it is dry again. This sporadic nature speaks to refuges of species that can exist, but, in general, you want to focus restoration, recovery, and preservation on reaches where it has been reliably wet year in and year out throughout time.

There is a link, obviously, between this riparian hydrology and the species diversity and invasiveness, invasiveness being the ability of these systems to be invaded. This is a graph showing the percent of time that flow is present along the x axis. Of the trees out there, what basal area is represented by Tamarisk, Salt Cedar? And we can see that if it is wet most of the time, you don't have that many Tamarisk. Whereas, if it is dry half the time of observations, Tamarisk invades. In terms of the invasibility of the system, Tamarisk is essentially filling a niche that the existing species aren't filling and has a competitive advantage in this near perennial / turning intermittent zone. In contrast, here's some data from Cienega Creek. If the stream is always permanent, you do have that herbaceous wetland perennial cover, but once you get below perennial, it's just dry for 25% of the time, essentially your herbaceous cover, small wetland species, disappear.

In terms of climate projections, these slides have probably been superseded by what Francina talked about today, since she has more recent data, but we do unfortunately have some disagreements among the models. This disagreement is in terms of whether the winters will get wetter or drier or whether the summer will get wetter or drier. We're starting to get better indications. As Francina probably told you, the extremes are likely to occur more often, particularly very wet, big storms. On the one hand, this means bigger floods and perhaps more downcutting. On the other hand, it may mean better recharge opportunities during those situations. And, notably on both the Cienega Creek and the San Pedro River systems, there have been established patterns. One notable one on the San Pedro is that the overall volume of stream flow has declined over time. Compared to the beginning of this record, the teens through 1950s and before the most recent 5 or 6 years since this dataset was created, which is 2000, the monsoon was not nearly as intense over the last 40 years as it was over the prior 40 years. During the 1950s, in particular, there were a lot of large, intense floods. You see that again in the past couple of years. So, there's something there with regard to larger climatic cycling, perhaps. But the point is that there is this larger pattern of smaller runoffs and since flood recharge is an important component that has implications to the system. So, in terms of hydrological implications of climate change, I think based on what we know, whether or not there are changes in winter or summer precipitation is critical. I touched on it before, but one of the things I've seen in the data so far are that even if the winters are just warmer the trees in the mountains will be more active and will use more soil moisture and you'll get less recharge as a result. So, just the warmer factor showed up in our analysis as a bigger factor than those subtle changes in precipitation. So, it's one of those things that a colleague at the University of New Mexico reminds me – temperature is a hydrologic variable as it drives the growing season and evapotranspiration as a result. And, as we get better knowledge of the winter versus summer dynamic, we'll have a better idea of that direction. I think it's important to remember that floods are a critical component of the perennial system hydrology. Low Impact Development was mentioned earlier and you sort of have to balance it out. More floods may have some benefit because if you catch the runoff at the headwaters as opposed to letting it runoff into the channel, you are changing the hydrology of the system. I can honestly say that I don't think we have a good answer for you right now about what would be the right thing to do. My bias would be to say capture the water as soon as you can and get it as deep into the ground as you possibly can because the longer you leave it at the surface, the more likely it is to evaporate as opposed to transpire. At least if the water transpires, we get some green leafy things. If it just evaporates, it's just a waste. And, I think critically, we need to have data on what the current conditions are, what's affecting them, to minimize those effects, but also to understand when we are seeing a climate signal.

Russ Scott – United States Department of Agriculture, Agricultural Research Service

My interest is basically the vertical exchange between ecosystems and the atmosphere. That is exchange of energy, water, and carbon and I've worked in both riparian ecosystems and upland ecosystems. You wanted us to address the consequences of climate change on riparian ecosystems and I would look at these exchanges. One of the questions is really "What will be that climate change that we see here?" and so one of the salient projections that Francina was showing was that changes in extremes in wintertime precipitation are coming through. Several other recent published studies have shown more predictable effects in terms of changes in wintertime precipitation. Generally wintertime precipitation decrease and then summertime projections are all over the board. This is due to the complexities of trying to model the monsoon and general circulation models, which are much too coarse a resolution to resolve those things. But if you look at the last ten years, some people are already saying that this is a harbinger of death. Projected climate changes in terms of seeing lower than normal precipitation in winter most of the years and summer monsoons have been, besides the turn of the 21st century, where we also have low monsoon precipitation, have been all over the board.

Just to reemphasize what Tom said, you can't get through the University of Arizona Department of Hydrology without hearing Tom Maddock talk about how changes that happened in the 1930s – mainly the Rural Electrification Act and the development of high capacity ground water pumps – will dwarf any changes that we might see in climate. The effects of those two things on riparian ecosystems are probably much bigger than we'll ever see in the effects of climate change – mainly dewatering of the riparian ecosystems that we have seen throughout southern Arizona. Fortunately, riparian ecosystems are buffered from year-to-year changes in weather generally because of their access to groundwater. If you have an intact riparian ecosystem where there is water available, those plants are more immune to changes if it's been a low precipitation year. What we're seeing, for example, on a mesquite bosque that we're monitoring in the San Pedro River over the last 10 years is that the riparian evapotranspiration is the same almost every year. There's very little change whether or not it is a wet monsoon or a dry monsoon, high or low precipitation winter. Working with Aleix Serrat-Capdevila of the University of Arizona, we took those GCM projections to the San Pedro River and looked at how that might change riparian evapotranspiration (ET). We found in that study that ET will go up. If the groundwater level stayed the same, ET will go up mainly because of the increase in growing season length. So, the biggest effect is the growing season length and that the evaporation itself did not tend to go up from a higher atmospheric temperature. This is because a lot of these riparian plants, even if they are not well watered, already limit their water use to some degree. During the hot dry afternoons that we experience here, these plants have to close their stomata to prevent hydraulic loss in their stems and roots and so on. So, they generally do shut down in the afternoon, even if they have access to water right there. Thus, they are already regulating themselves to damage from too much ET demand. However, it is really this extension where they can leaf out earlier and senesce later that results in the greater ET.

Of course, there are going to be some feedbacks when we increase ET. For example, we are going to demand more water from the alluvial aquifer, which will draw down the water levels. This will especially affect those low flows that are important to the aquatic species because the trees themselves are also groundwater users in those riparian systems. I've seen a lot of evidence in the San Pedro River system where mesquite has increased its density along the old alluvial terraces up the River. Mesquite is fairly deep-rooted and can access groundwater to at least 45-50 feet deep. So, that has really expanded the zone of vegetation that is using groundwater along these riparian corridors. That is basically just like an increase in the number of wells and pumping away. Each one of those mesquite trees is extracting water and is going to affect the streamflow in the River.

Just to jump ahead to the next topic and expand a little bit on the subject of potential climate change effects on upland vegetation, is that we have also seen effects of the extremes in the wintertime precipitation or temperature in grassland over in the San Pedro Watershed, up in Walnut Gulch. There, in the turn of the 21st century drought years of 2003, 2004, and 2005, that grassland transformed. In 2006, after that really dry series of years, most of the natives (e.g., gramma grasses) died in that particular watershed and nonnative Lehman's Lovegrass flourished in that watershed after a transition year of just annual forbs. What's really interesting is that this transition also feeds back into the hydrology and erosion that we saw. In 2007, we found that about 70% of the total erosion in that watershed over a 30-year time period occurred in two storms. Following that extreme drought and vegetation change, big erosion events happen episodically. With these transitions of species due to extreme weather events, hydrology can be unpredictable, especially in terms of erosion. What's interesting is that the freezes in early February of this year were even colder up there. We went back out to the grassland this summer, looking for all the green grass, but all of the green grass was gone. About 70% of the Lehman's Lovegrass bunchgrass that had grown since they replaced the natives died during that extreme cold period. However, we didn't see that kind of mortality down at the Santa Rita Experimental Range, which is just a few degrees warmer in the minimum and the period of the cold snap was shorter. So, these extreme events really shake up the system and that's going to impact non-native species invasions and big changes in hydrology, possibly.

Topic 4. Potential effects of climate change on upland desert scrub and grassland vegetation in the Tucson region

Theresa Crimmins – USA National Phenology Network

Julio and I were charged with summarizing anticipated changes under climate change for upland desert scrub and grassland communities, so basically our low elevation terrestrial communities in this area. I'm sure all of you are aware that there has been a whole variety of types of changes to plant and animal communities that have been documented as a function of climate change in systems around the globe. However, there is not that much that we have documented for this area and so I will give you examples of the kinds of changes that we might be able to anticipate here locally and then I will talk about some of the things we have documented with Dave Bertelsen, which I am most familiar with. I will primarily focus on phenology, which is the timing of seasonal life cycle events, such as when birds migrate or when plants put leaves on. Phenology has been identified by the IPCC and others as one of the best and easiest indicators to track and look at how ecosystems are changing and how individual species are changing in light of climate change. However, we have also documented things like changes in species distribution in terms of spatial extent, invasion of non-natives species, and changes in the composition of native communities.

So, just a quick of examples of the types of changes that we might anticipate in this area. This is a change in phenology for a temperate community in Great Britain. This has resulted in major changes in population numbers and community organization. In this example is a relationship between birds and trees. English Oak, which is a tree species, is leafing out earlier in the spring in temperate Great Britain because spring temperatures are warming earlier in the season. This is something that is being documented almost across the board in most communities, where spring temperatures are warming earlier in the year and plants are doing their thing earlier. As a function, other species are doing their thing earlier in the year, too. So, the Winter Moth, which is an obligate species for feeding on the English Oak and also lives in temperate Great Britain is beginning to hatch out of its eggs earlier in the year, too, tracking the changing climate. However, the Pied Flycatcher, a bird that overwinters in the southern hemisphere and is cued to migrate to the northern hemisphere and its feeding grounds and it feeds primarily to the Winter Moths, is appearing in Greater Britain at the same time every year. This is because it is being told to fly north when the sun is at a certain angle and that is not changing along with climate. As a function, the Pied Flycatcher's food source is no longer available as it's not at peak availability when these birds arrive in their breeding grounds. In some cases, where they are being monitored, they are seeing up to 90 percent decreases in population numbers as a function of this mismatch. You can anticipate that this is probably having amplifications for community organization and opening a niche that the Pied Flycatcher used to fill in Europe.

We don't have anything like this specifically documented locally, but we should probably keep our eyes open. Here's another type of change that we might begin to anticipate. This is an example from the Rocky Mountains and a subalpine community there. On this graph, the x-axis is the day of year, with early spring going to summer as you go to the right. And the number is the abundance of individual flowers. They have been counting the number of flowers in individual plots for several decades now and what they observed early in this record, perhaps in the late seventies or early eighties, was that these two species of *Mertensia* put on their flowers at slightly different times during the spring and peaked in abundance a couple of weeks apart. However, there was a bit of an overlap and so pollinators would always have something to feed on as soon as they hatched and began flying around and needing a food source. But, what is happening now under a warmer climate, warmer temperatures are causing earlier snowmelt, which has cued some of the species to flower earlier in the year and others not. This species, *Mertensia fusiformis,* has advanced its phenology and put on flowers a lot earlier in the year where as *Mertensia ciliata* isn't changing at all. So, what this is resulting in is a significant gap, timing wise, for those pollinators. Some of the other implications that you might be able to anticipate is that there is an open niche there and perhaps another species can take advantage of that. There are also ripple effects of those pollinators not having a reliable food source available and so they may no longer be around. Again, we don't have a good example of changes like this being documented locally, but it is something that we might want to keep our eyes open for.

Some of the things I can talk about here that we have begun to document are things like changing elevational ranges of where species are flowering. From this, we may draw conclusions that species are probably changing their ranges as well. We may also draw conclusions about changes in the timing of the onset of the spring and summer seasons for flowering plants here as well. I'm not sure if any of you are familiar with this dataset, but I'm going to talk about one that I know really well. A fellow named Dave Bertelsen, who calls himself an amateur naturalist, has been hiking a particular trail for about three decades now at approximately a weekly interval. When he hikes the trail, he keeps a record of every species that he sees in flower. This has resulted in an enormous dataset that I've had the pleasure to help interpret and try and tease apart what has been happening here. He had the foresight to attribute his observations to segments of the trails. This shows plant communities that are essentially associated with these different miles, more or less, along the trail. I'll focus primarily on the results from the bottom two miles because those are the communities that are really relevant for the area that you need to manage – the desert scrub and grassland – and there is a bit of riparian in mile one and so we get some mixed results in mile one.

Now I'll talk about some of the things that we have documented for this particular dataset. Dave said to me "I think some of the species that I'm seeing in flower are higher and higher in elevation." Right away, that was a warning bell for me and my response was: "We know that species are expected to track climate change by going further up in elevation or latitude." Indeed, we are seeing certain species expand their range to higher latitudes. They are basically tracking climate change and the conditions that are supposed to be most important for them, which for these are basically temperature-driven. So, I said "Let's test that" and so we did. What we saw was that of almost 400 species that we tested, approximately 26 percent did show some sort of significant change in their flowering range. Since, we only have data on species when in flower, not presence, we can only talk about the range when they are flowering. However, one can infer that this may represent changes in their ranges as well. In the data, we saw a number of species shifting their ranges up slope where the band of elevation that seemed most suitable to them, moved up slope. We saw a number of species expand their ranges and that was really more at the higher elevation where we think a temperature limitation was being removed since this is associated with a significant increase in warmer summer temperatures as well. For the last category of species, we saw a contraction of their ranges where whatever elevation band they were seen at before, more recently, they have only been seen at the upper elevation of that initial range. What we think might be going on there is that with warming temperatures, it is increasing evapotranspiration, making conditions probably less suitable for these plants to complete their reproductive cycles. These plants may still be there, but are not flowering.

Another thing that we looked at was the onset of the seasons, with the question "When does spring start for these plants?" This was driven primarily because this is what everybody tests in every other part of the world. Many who study the onset of the seasons have been saying that spring is coming earlier and phenological events are happening earlier. While that may be the case in temperate systems, we are water limited in southeast Arizona. In terms of what the Bertelson data show is occurring here, these results are for the whole elevation gradient and so we probably want to focus on mile 1 species and this is mile 2. However, the results hold across the gradient. Basically, what you are looking at here along the y-axis is the change in the first date that a particular species was observed in flower, or first flowering date, for the year. How you interpret that is that if a species has a bar going in this direction, then the first day that we see it in flower is happening later in the year and if it's going this way, then we are seeing it advancing. This is what is happening in almost every part of the world and this is what we are seeing here. The magnitude, or how long the bar is, is how major that change is. What you see is it's pretty much happening later along the gradient except in mile 1, where it is a mixed bag and I think that is because we have mixed communities there.

However, what we did was try and tie this to climatic drivers too with questions like, "What's happening with the temperature and seasonal temperature and seasonal precipitation that might help explain this?" What we found was that for spring, especially, in the low elevation communities, when things flower is really a function of what precipitation conditions were like in the previous fall. So, if we have less precipitation in the fall, then we see a later onset to the start of the spring flowering season. Also, if it gets dry enough, a lot of species don't bother flowering in the following spring and so that's something that we anticipate may continue in that direction. However, I'll defer to the climate experts about what we think will happen. My understanding is that we might get drier as well as warmer. It is widely accepted that temperatures are increasing in our region and will continue to increase. That can lead to greater evapotranspiration, which can cause greater stress for plants, even plants that are adapted to dry, hot, conditions.

Then, we did a similar set of analyses for the summer season also. This is because the spring and the summer are such unique and separate seasons here, unlike other parts of the world where there is a smooth increase to spring and kind of grades into summer. Here, the seasonal onsets are more sudden. What we saw was, as you might expect, that the timing of when plants start flowering for summer is a function of when the monsoon starts and that is true, again, across the gradient. It really doesn't matter where you are on the mountain, plants do not start flowering until the summer precipitation starts. The trends were less of a concern for that, but what is probably more important to consider is what we might expect going into the future. Yet, we don't know what to expect with changes in the monsoon as the models don't appear to converge on what will happen with summer precipitation over time. However, it is likely to get hotter, and so, again, that can result in less soil moisture available. Therefore, we may expect later starts of flowering and perhaps fewer species in flower in the summer. So, to summarize what I currently think might happen here is that species will respond individualistically. We have some general patterns that I've tried to summarize briefly, but individual responses are erratic and so it's hard to know how things are going to change. However, the general pattern that we did see is that if species ranges are changing, and it looks like species are moving up slope as we might expect under warmer temperatures, for these low elevation habitats that we are talking about today, we can probably expect some delayed onset to the spring season associated with changes in the winter precipitation patterns. Also, warmer temperatures seem to be linked to, perhaps, insufficient winter chilling although this is not something we were able to test. However, it has been documented in other parts of the world, where if plants require a certain number of chill hours before temperatures begin warming in the spring, and they don't get that, it causes them to delay their initiation of spring phenological events and that, too, might be something that might be happening here, too.

Some other things, these are directly from Dave, but I draw from him these anecdotal observations because he's out there every week and has been for three decades now. Along the trail, he has documented notable die offs of many saguaros, Foothills Palo Verde, and Velvet Mesquite in the low elevations, and other tree species higher up, too. He has also observed the continuing spread spatially and upslope of nonnative grasses including, Lehman's Lovegrass, Red Brome, Buffelgrass, Soft Feather Pappusgrass, and Natal Grass.

In terms of phenological changes in our region, while we don't have good, concrete examples in our system, we can definitely anticipate changes in community composition. This may include reduced biodiversity, floral mismatches such as with the Pied Flycatcher example, and increased competition for fewer resources. Could these kinds of changes affect flower size or seed set? I've seen some recent research, where the earlier on-set of spring temperatures is causing insects to have more rapid life cycle changes. However, this is all really preliminary research. Another potential result of these changes is the opening of niches to invasion by non-native species.

Lastly, changing topic briefly, since I am from the USA National Phenology Network, I want to say that phenology has been identified as one of the best, easiest ways to document how species and ecosystems are responding to climate change. I'm not sure if you're aware that we have been working hard to develop rigorous protocols for tracking this for both plants and animals. We've done this for over 400 species of plants and animals. We offer the long-term archive of these data so that one doesn't need to worry about building one's own database and, we can make the data readily available. We also have online visualization and decision support tools and are currently working to enhance those. If you are thinking about initiating long-term monitoring and phenology might be on the table as one of the metrics, we would appreciate the opportunity to talk with you. With that, I'll let Julio talk.

Julio Betancourt – United States Geological Survey

Okay. I had difficulty zeroing in on what I was going to talk to you about today. But, I decided to focus on some of the work that I have been doing with others on invasives, for a couple of reasons. One is that it is probably the most complicating thing in front of us and probably the most near term risk that most of these ecosystems face, particularly in places like the Arizona upland and even in the grassland. Also, with or without climate change, invasions would be a problem. With climate change, it becomes less predictable and perhaps, a little more problematic and confusing.

I put up this slide here to remind us how climate change might actually impact invasives. One, it's going to impact the suitable surfaces for invasives because it will basically change the geography of the invasion. For example, with something like Buffelgrass, it will actually increase the elevational range of Buffelgrass as well as allow it to migrate even further north. So, it will change the climatic envelopes for invasives. Also, you have changing climate variability. It isn't like climate change is the only thing that is happening. In fact, some of the changes that we have had in terms of climate variability might be a lot more significant than what we'll see with climate change in the immediate future.

A lot of what we see on the landscape is the result of things that have happened either in the near past or far past. I'm working on a paper that summarizes the Saguaro census data since the 1950s in the northern Sonoran Desert. And, it turns out, that once you look at the residuals of age distribution curves over time, particularly with censuses that go back to the 1950s, a lot of the Saguaro population that was the inspiration for Saguaro National Park, those populations actually got started in the late 1700s and early 1800s. And, when you see those pictures that Ray Turner shows without Saguaros in the 1960s, it's basically without those Saguaros that got established in the late 18th century and early 19th century, which was the result of a really wet period that also resulted in surge in regeneration of Ponderosa Pine that we see. You can match up the two curves – 1780 to about 1860 – and this is exactly the same period for Ponderosa Pine regeneration. This period from about the mid-1960s to the about the mid-1990s was extremely wet, by all accounts, not just for the 20th century, but also going back several hundred years. Therefore, it had a lot of impact, for example, on riparian communities where you got a lot of establishment through that period. So, climate variability is still probably as significant, if not more significant, than climate change and it tends to modulate invasions. Theresa didn't mention this, but actually there's almost a near step change in springtime temperatures right around the mid-1980s in Pima County and, actually, throughout the West. Also, even though the Bertelson data is excellent, it doesn't go back far enough to see this step change and there hasn't been that big of a trend in springtime temperatures since the mid-1980s. It could be that the mid-1980s ended up resulting in the acceleration of Buffelgrass invasion. So, climate variability could be important although we don't know how much. We have some good guesses that probably half of the change that we have seen in wintertime and springtime temperature warming may be due to greenhouse gases and the other half may be due to Pacific variability. So, there is this complication of climate change and climate variability that might modulate how these invasions progress. If you plot Red Brome invasion over the Sonoran and the Mohave Desert and you look at the residuals from the logistic growth curve, the residuals are actually the Pacific Decadal Oscillation over the last century. So, it speeds up as you might imagine for a winter annual and slows down when it's dry. Therefore, the opportunities for managing Red Brome are during these dry, negative Pacific Decadal Oscilliation periods. So, climate variability is extremely important along with the changing fire danger, because with changes in temperature, you get changes in the coefficients that usually describe fire danger worldwide and in the West. So, this is important because all of these things actually modulate invasion potential and also wildfire potential. Those things can actually make irrelevant what we do on a landscape like the Southlands. If we get big fires on a landscape like that which resets the system, then we will be talking very differently in this room after that fire than we were before.

This is a paper by a couple of friends of mine who are now at the University of Idaho in Moscow, John Abatzoglou and Crystal Kolden. What they have actually done is use the same kinds of approaches that Gregg and Francina have been talking about, but for fire. What you can see here are three metrics. The first is the frequency of extreme fire danger, which is actually a metric used in fire management. The second metric is the advance in the fire season start date, much like phenology. So the fire season is going to start much earlier. The third metric is the advance in the median date of the fire season, which is also going to shift. And you can sort of see these things shifting in the negative for us meaning, joining invasions particularly in the lowlands. With these kinds of fire predictions, we're going to have an increased risk of wildfires in all of these areas due to climate change.

So, I want to switch gears here because I want to make an observation that I think is pretty important for all of us. We can sit and talk about a particular landscape and what's going to happen under climate change or what's going to happen under invasions or what's going to happen with urban development. However, the truth of the matter is that we have to manage across mixed jurisdictions. I was in the Mayor of Oro Valley's office the other day and he asked me directly: "We're doing a lot in Oro Valley and so why should we invest to a much larger effort?" The problem is that things like Buffelgrass, and invasives, and climate change are all spatially extensive environmental problems that have a contagious element to them. So, whatever happens next door can affect what happens in your jurisdiction. And, as it turns out, we don't have – across the governments – a way of managing across jurisdictions. There is no separate agency that herds us together and so this has fallen to non-profits. Whether it's your non-profit or my non-profit, it's really fallen to non-profits. The Southern Arizona Buffelgrass Coordination Center (SABCC), is a partnership basically established to overcome this. So, whether it's invasions or climate change, we're probably going to rely more and more on these non-profits and they're teetering because of economic issues. So, I just wanted to mention this because this is the wave of the future, to have this as the glue across jurisdictions, whether we're talking about the federal government or Oro Valley, this is going to be problematic. We're relying more and more on organizations to manage these spatially extensive contagious problems and, you know, it's funny because I think we're getting a lot more attention at the national level than we are at the local level. SABCC just got this Department of Interior award for partnerships in conservation, people recognizing that, in fact, this is a template for managing these spatially extensive environmental issues, whether it be invasions or climate change.

Another point that I want to make is that we have always been kind of passive in management about the science. In other words, we take what we can get. We're not driving the science and so one of things that has happened with the Buffelgrass issue, and I think that it should happen more with these other issues like climate change, is that we have to specify what science it is that we need in order to make decisions and make things happen on the ground. If you just leave it up to scientists, basically, they're going to do what they were trained to do and what they are interested in doing for other values, not for making management decisions. So this requires quite a bit of organization. We've been doing this with the Buffelgrass issue by trying to interact more and more across science and management to actually set priorities so that we have tools that we can use that are well informed by good science. So, if you ask right now for a series of priorities for the Southlands or any other entity in the Tucson Basin or all of them together, and you said, "For climate change issues, give me a list of priorities of the things that would be absolutely critical to have" We're starting to do this more and more with Buffelgrass, but the problem is that we don't set priorities very well and, therefore, we give scientists very little direction on what's really important. Not only is this about giving them direction, but also about engaging them fully so that the things that we get are actually critical. I don't know if you know this or not, but we're not going to solve any of these invasions without biological control and biological control is a really hard nut to crack. Therefore, right now in the background, we're having these conversations across the country about how to do biological control, whether it's Cheatgrass or Buffelgrass. That's a critical tool and a critical research need because we don't know very much about it. So, it's very important that we start prioritizing the science that we need in order to make decisions not only locally in one piece of property, but in these regions.

Theresa said this, which is actually a pretty critical thing. It's not like we have all these data management systems where we can enter information about distribution and about the impacts of treatments, for example. Data management systems aren't out there that we can just use. They've got to be customized to a certain extent. So one of the things that we've done is build a data management system to bring in Buffelgrass information, such as distribution data or information on the treatments that you have done following the life cycle to decide whether or not they were useful. This is to help answer the question of "Did they did do what you wanted them to do and how long did the treatment last?" Therefore, these data management systems are going to be fairly critical and they are not inexpensive. We don't have a lot of these data management systems for climate effects, for example. So one of the things that is hard is that we have to actually sit down with stakeholders, figure this out, and put together products by which we can make decisions.

This, for example, is a study we did with Logan Simpson, a local environmental firm, where we mapped the Tucson Basin and looked at everything from land cover, ecological impacts, Buffelgrass suitability, pathways for future spread, treatment difficulty, and so on. We put together this fairly big assessment and I'll tell you how climate change complicates it. If a lot of this is actually based on the suitability of Buffelgrass, and if Buffelgrass changes, then all of these change. So, one of the things that we have to be aware of us is when we put together these assessments, we have to have a process for updating these layers given climatic changes or given land use changes. And, we don't do that. In reality, it's more of a snapshot and then we run out of money, get distracted, and go on and do something else. But this is going to be really critical to have these bases where we can actually change the climate, vary the climate, and look at these risk surfaces over time. So, we've been doing a lot of this stuff and I'm not an invasion biologist; I dabble in lots of different things. I realized that I needed to get involved as a scientist and so I've been working with students and colleagues on some of these issues.

One of the studies that we did was on the south slope of the Catalina Mountains where Aaryn Olsson, a University of Arizona Ph.D student at the time and now a post-doc at Northern Arizona University, set-up all of these plots and then, with aerial photography, he mapped the invasion through time. It just so happens that, in the Tucson Basin, there is so much aerial photography through time that you can basically do time lapse photography and map out the invasions. You can then look at a lot of things from invasion rates to how the invasions themselves affect species richness and diversity. So we've done this. This is an example at the bottom, Soldier Canyon in the Catalinas. One of the things that Aaryn found out almost immediately is that there is ecosystem transformation with or without fire. In other words, yes, there is a grass fire cycle, but Buffelgrass can outcompete other plants. Red Brome can't do that and Cheatgrass can't do that. In contrast, Buffelgrass is pretty much a shrub and can actually outcompete other plants. So, one of the important things that Aaryn did as part of his dissertation is that he used Buffelgrass cover and time since Buffelgrass invasion to go through all of these plots and measure the impact on plants and on diversity and richness through time or through cover. He also created a helpful graph of the probability of change in species diversity and richness as a function of cover and time since invasion. It turns out that once there is about 43 or 44 percent Buffelgrass cover, the change is difficult to stop. At that point, the diversity is already in decline and you won't really be able to do very much about it without a lot of money. Many of you are probably familiar with the Soldier Canyon area and know that the watershed has been completely transformed. Large areas of native vegetation within the watershed are pretty much gone now.

Therefore, we need to figure out at which point is the landscape considered beyond treatment and, therefore, focus attention elsewhere. For example, "What is the importance of competition, for example, for space, nutrients, and water as opposed to fire as a medium for changing the environment?" Aaryn was able to track spread rates throughout this whole area. It turns out that all these spread rates across 11 plots on the south slopes of the Catalina Mountains converge. When you add them, there is not much difference between this rate and a logistic growth curve for an invasion. So, it turns out that there is enough summer precipitation across this whole area that the spread rates are more or less constant across time. However, if you go to the other side of the Tucson Mountains, such as, for example, to Ironwood Forest National Monument, the spread rates vary between there and the Catalina Mountains. In the Catalina Mountains, there is a doubling every two to four years. However, at Ironwood Forest National Monument, it's probably every four to eight years. So, if we're talking across jurisdictions, do we spend the money on treatments where the spread rate is so high that basically we treat something and it's right back again? Or, do we go to the outskirts of urbanized areas where the spread rates are slower and treat those because, ultimately, there is much more lasting effect for the money. That's a decision that you have to make across jurisdictions, not one that we can make in the Greater Southlands; it's one that we make as a group.

So, the other thing that we have done is start the work on decision support simulation models. These are basically state-transition or Markov Chain models to simulate how the invasion is going to progress, to simulate the cost effectiveness of treatments, and to determine the effectiveness of treatment over time. So, we actually built this for the south slope of the Catalina Mountains with all of the information that all of us had sitting around the room, whether we were scientists or managers. This information included important algorithms, like spread rate as you actually need to know the spread rate to run these models. This is a very important thing and an important concept that people are missing nowadays, which is that climate variability, climate change and climate heterogeneity are going to modulate invasion rates. It is not like for a single species there is one spread rate; the spread rate may vary in the range of the species. Therefore, to do this kind of modeling, you actually need lots of empirical data on spread rates and you need to be able to understand spread rates. However, there are not many data for invasives. There are even fewer data for native species and I actually work on that quite a bit, on the invasions in the past. So, I can tell you that I don't have a look-up table of invasion rates through space and time. So you can do these kinds of simulations on the south slope of the Catalina Mountains under all kinds of scenarios where you have no management or some management, where you have really good detection or really poor detection and look out 20, 40, 50, 60 years in advance. Then, for the whole area, you can see what the impacts are, such as the difference between investing a lot of money versus not investing very much. It turns out that if you invest a lot of money, you can keep Buffelgrass under control. However, if you invest half of that money, you're going to lose. So there are, in fact, thresholds on the amount of money that you can spend and be effective. These are critical decisions that have to be made, whether it's invasions or climate change.

Another issue is that we may have these tools and, all of a sudden, the person who knows how to run the models is gone. So, with these tools, you have to keep several people trained on their use. This isn't that hard, but, to sustain the effort, you have to have enough people in the community to train them on these tools, whether it's looking at downscaling climate model output for your area or another tool. The other thing that you have to have is resources and we don't have a lot of resources for something like invasions. You may think that we do but we don't. Climate change is sucking the air out of the room and there are resources there, but all that has to happen is for our current U.S. President to lose the next election and efforts like Landscape Conservation Cooperatives and climate change science centers will likely shut down abruptly. An example is that we almost had a congressional field hearing on Buffelgrass here in Tucson, put together by Raul

Grijalva. The U.S. House of Representatives actually passed a million dollar appropriations request last summer and then the mid-term election occurred. The U.S. Senate shelved it, the money was lost, and we had to start from the beginning. It should be noted that this was for doing Buffelgrass demonstration projects across 14 different federal units and 5 different federal agencies and not like doing something for the City of Tucson, Pima County, or Oro Valley. This was doing something on federal lands and we lost the money almost overnight. So, you actually have to keep these things going and build capacity to do these things. Again, whether it's climate change or invasions, you have to have the capacity to actually do treatments across jurisdictions. After this funding setback, FEMA and the Department of Homeland Security partnered with Pima County Emergency Management and wrote a 3.4 million dollar grant that actually got really high scores and it looks we might get funded. In addition, we almost immediately submitted another grant application to do work at the Pima County jail complex and then at the Tucson International Airport (TIA).

This summer, in June, a guy that we work with was mowing at TIA and his mower threw a rock that started a fire. The fire moved very quickly toward two fuel tanks and a helicopter. All of a sudden, he realized what we were talking about. This moved really fast and this guy was scared. So, this fire helped TIA to understand the problems that they have. This is not just about bushes and berries. This is about wildfire in a community like ours that hasn't had to deal with wildfire. A one acre wildfire can occupy 36-37 firefighters and 14 fire engines to put it out. This happened with the bus yard where they were saving bus parts for a museum. But, this is a huge issue. It's fire on the landscape and not just a conservation issue. It is also that we're dealing with a risk that wasn't there before and so we have to build capacity. These are not things that we have been doing all along and that we have the capacity for. One of things that we are looking into is using helicopters to spray on landscapes that we can't get to on foot because they are too far away on too steep of terrain. These are the kinds of decisions that ultimately we are going to have to make. It's really interesting and I'm really interested to talk about climate change and impacts to ecosystems, but we have multiple stressors. We can't really do that much about climate change locally. But one of the things we can actually do is manage the other stressors that interact with climate change like these invasions.