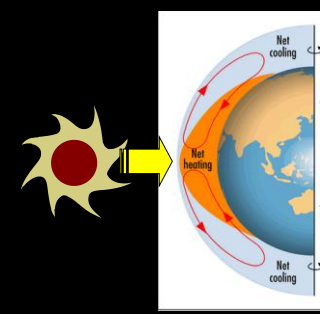
Regional Climate Change Projections for Southern Arizona and the Colorado River Basin

Climate Change and the City of Tucson's Greater Southlands Habitat Conservation Plan: Climate Projections and Habitat Workshop
October 17, 2011 – Tucson, AZ

Gregg Garfin, The University of Arizona

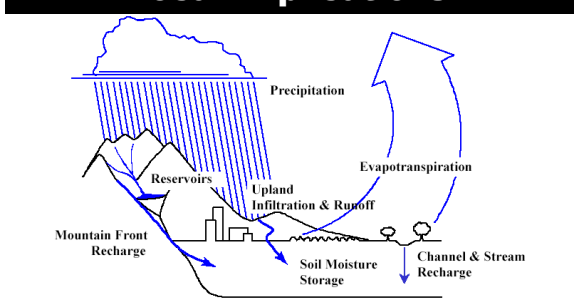
Institute of the Environment · CLIMAS Climate Assessment for the Southwest

Global Energy Balance



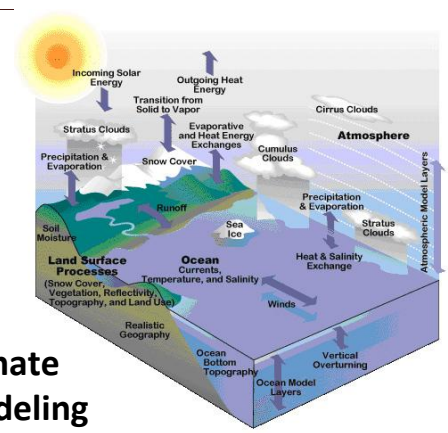
From http://www.bom.gov.au

Local Implications

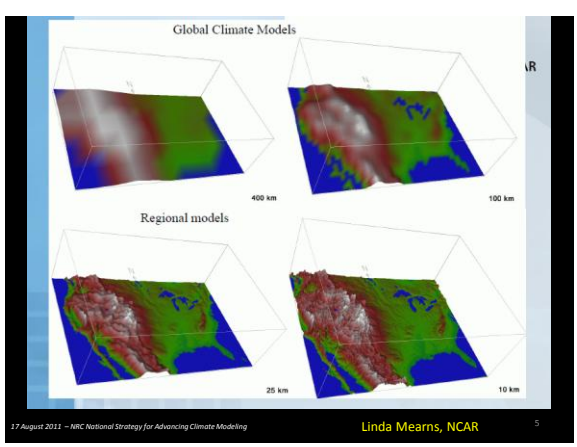


Recharge = Precipitation – Evapotranspiration – Runoff – ΔSoil Moisture

SAHRA *Sustainability of semi-Arid Hydrology and Riparian Areas*



Climate Modeling



UNCERTAINTY

Data

GCMs

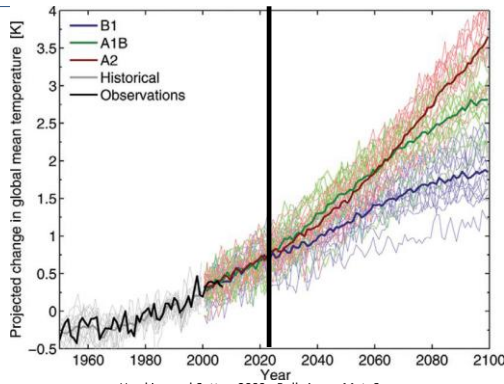
Emissions

Laws, Policies, Institutions

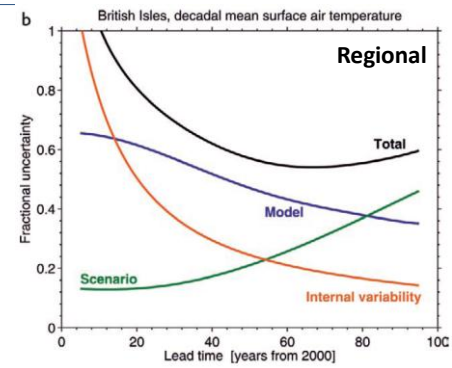
Hydrologic & Vegetation Models

Economics

17 October 2011 – Tucson HCP: Climate Projections and Habitat Workshop



Hawkins and Sutton 2009. Bull. Amer. Met. Soc.



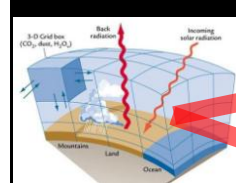
Hawkins and Sutton 2009. Bull. Amer. Met. Soc.

What GCMs **Can and Can't** Do

There is considerable confidence that climate models provide credible quantitative estimates of future climate change, particularly at continental scales and above. This confidence comes from the foundation of the models in accepted physical principles and from their ability to reproduce observed features of current climate and past climate changes. Confidence in model estimates is higher for some climate variables (e.g., temperature) than for others (e.g., precipitation). Over several decades of development, models have consistently provided a robust and unambiguous picture of significant climate warming in response to increasing greenhouse gases.

IPCC 4th Assessment Report, Chapter 8, *Climate Models and their Evaluation*
http://ipcc-wg1.ucar.edu/wg1/wg1-report.html

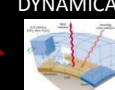
Methodology

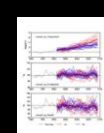


STATISTICAL

$$P_{ds}(x,t) = P_{mod}(x,t)\frac{\langle P_{obs}\rangle_{sea}}{\langle P_{mod}\rangle_{sea}}$$

DYNAMICAL





There are basically two approaches to downscale coupled climate model projections :

Statistical Downscaling

These methods assume a relationship between large-scale atmospheric variables (predictors) and local climate variables (predictands).

- Pro : Cheap and computationally efficient.
- Pro : Can use many different scenarios, model runs.
- Pro : Easily transferable to other regions.
- Con : Requires long and reliable observation data.
- Con : Depends on choice of predictors.
- Con : Assumes stationarity of predictor-predictand relationship.
- Con : Cannot account for feedbacks.

Statistical Downscaling

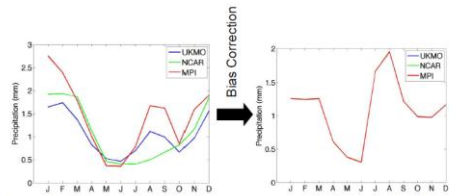
F. Dominguez, C. Castro et al., 2010 University of Arizona

Statistical Downscaling

$$P_{ds}(x,t) = P_{mod}(x,t)\frac{\langle P_{obs}\rangle_{sea}}{\langle P_{mod}\rangle_{sea}}$$

$$T_{ds}(x,t) = T_{mod}(x,t) + [\langle T_{obs}\rangle_{sea} - \langle T_{mod}\rangle_{sea}]$$

It is important to clarify that the Reclamation Data is Bias Corrected, so the observed climatological mean is matched in the historical data.



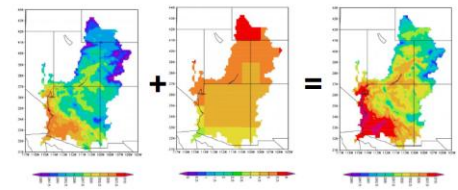
Raw GCM climatology for the three selected models (1950-2000)

"Reclamation" statistically downscaled climatology (1950-2000)

F. Dominguez, C. Castro et al., 2010 University of Arizona

Statistical Downscaling

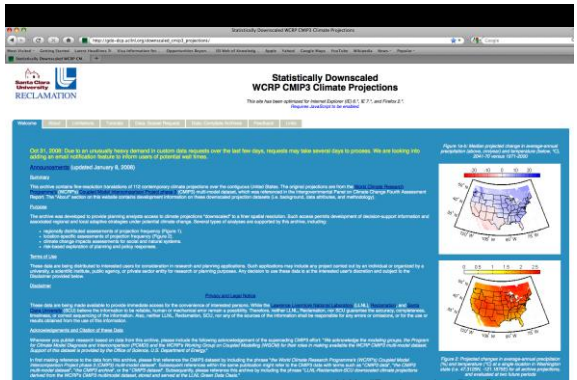
$$T^{projection}_{HR_MEAN}(m) + T_{ANOM_PROJ}(m,e) = T_{HR_PROJ}(m,e)$$



LLNL-Reclamation-SCU downscaled climate projections derived from the WCRP's CMIP3 multimodel dataset, stored and served at the LLNL Green Data Oasis is done using this technique (bias corrected).

Statistical Downscaling

F. Dominguez, C. Castro et al., 2010 University of Arizona



Statistical Downscaling

The second downscaling approach is dynamical downscaling.

Dynamical Downscaling

- Pro : Produces responses based on physically consistent processes.
- Pro : Captures feedbacks.
- Pro : Can model changes that have never been observed in historical record.
- Pro : Useful where topographic controls are important.

- Con : Requires significant computational power.
- Con : Limited amounts of models / runs / timescales.
- Con : Dependant on GCM boundary forcing.
- Con : Problems with drifting of large-scale climate.

Dynamical Downscaling

F. Dominguez, C. Castro et al., 2010 University of Arizona

Dynamical Downscaling

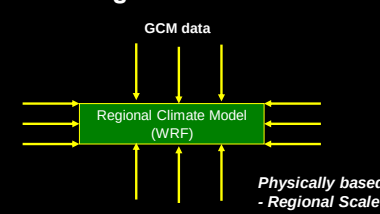
Definition: *Use a numerical model to generate fine-resolution output from coarser-resolution input.*

Implicit assumption: Finer resolution and/or improved model physics (parameterizations) improves representation of regional weather and climate, compared to the driving model (GCM).

- **more fidelity with observations** *and/or*
- **improved representation of physical processes**

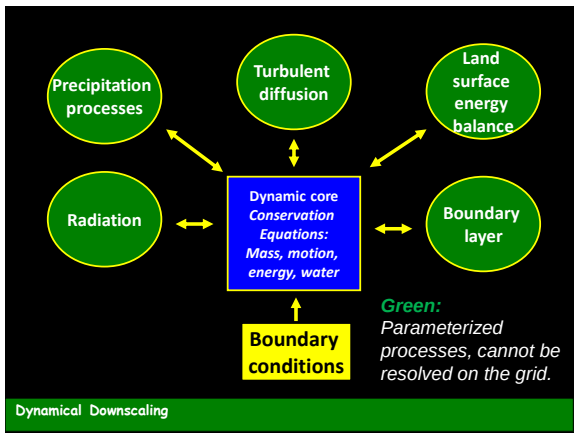
Dynamical Downscaling

Use the regional model as a "magnifying lens" to create higher resolution data…



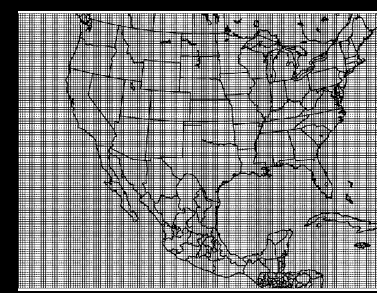
Historical (Reanalysis) → Seasonal Forecast (CFS) → Future Projections (IPCC)

Dynamical Downscaling

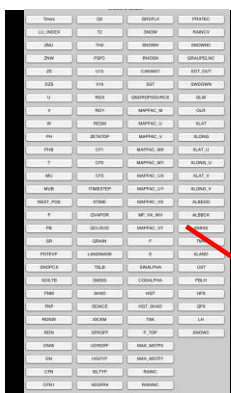


Dynamical Downscaling

Regional Model Grid (35km grid spacing)



Dynamical Downscaling

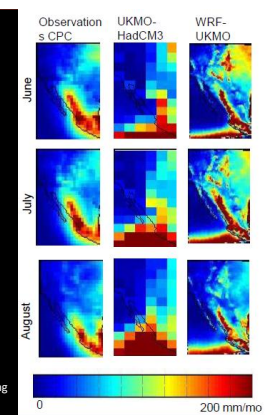


Statistical downscaled output:
Ppt, Tem: monthly

Dynamical downscaled output:
90 variables: 6-hourly

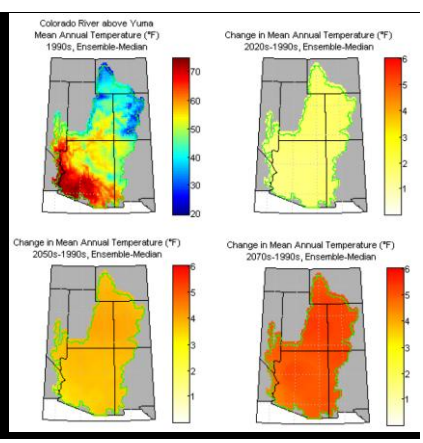
Winds, temperature, humidity, ET, potET, SWE, snow depth, soil moisture…

Dynamical Downscaling



Castro, Dominguez, Chang
University of Arizona

Reclamation, SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water, Report to Congress, 2011



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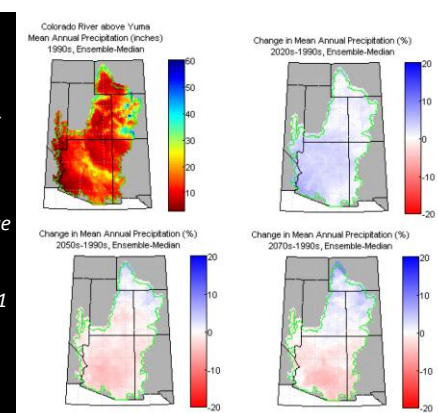
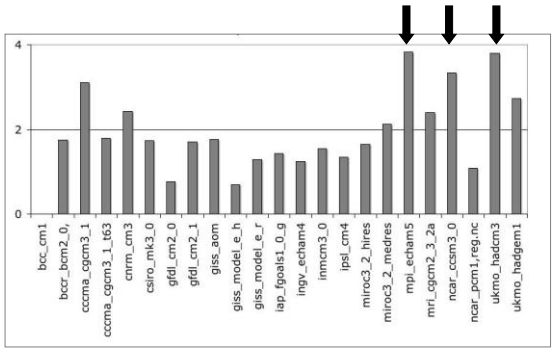
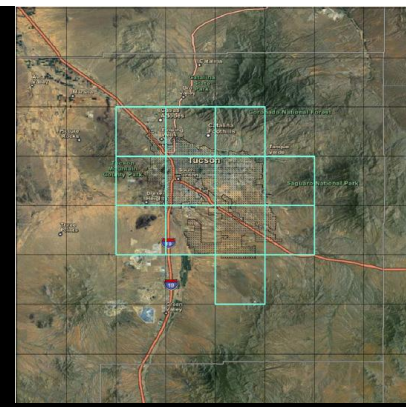




Dominguez, F., J. Cañon, and J. Valdes, 2010: IPCC-AR4 climate simulations for the Southwestern US: the importance of future ENSO projections. *Climatic Change,* ***99, 499-514.***



J. Weiss, University of Arizona (Geosciences)

		16-model ensemble A1b	A2	B1	3-model ensemble A1b	A2	B1
2011-2040	Annual	-0.8	+0.1	+1.9	-0.6	-1.8	+7.6
	DJF	-4.2	-0.4	+4.7	-6.4	-5.3	+10.2
	MAM	-16.6	-13.5	-11.5	-22.0	-24.8	-4.6
	JJA	+3.8	+0.5	+3.8	+3.4	-1.2	+3.6
	SON	+3.1	+5.4	+1.4	+10.8	+10.1	+17.6
2041-2070	Annual	-2.1	-4.8	-2.3	-3.0	+2.7	-0.4
	DJF	-5.3	-4.0	-9.5	-14.8	+6.3	-9.2
	MAM	-27.4	-25.4	-19.5	-27.5	-24.7	-13.9
	JJA	+2.9	-1.6	+3.8	+3.0	+1.3	+2.1
	SON	+5.4	-0.8	+4.0	+14.1	+16.7	+15.0
2071-2099	Annual	-0.6	-6.2	-0.5	-2.6	+4.7	+1.9
	DJF	-12.0	-17.3	-8.2	-9.5	-21.0	-5.9
	MAM	-30.3	-37.4	-19.1	-37.4	-38.8	-12.8
	JJA	+5.0	+2.1	+7.1	+2.8	+7.2	+3.9
	SON	+5.1	+6.3	+4.7	+13.9	+50.2	+14.6

Precipitation. Percent departure from 1971-2000 climatology of BCSD statistically downscaled CMIP 3 climate projections for the 12 cells that intersect City of Tucson boundary. The 16-model ensemble includes the first runs of each of the models available. The 3-model ensemble includes the first runs of the HadCM3, NCAR CCSM3, and MPI ECHAM5 models.

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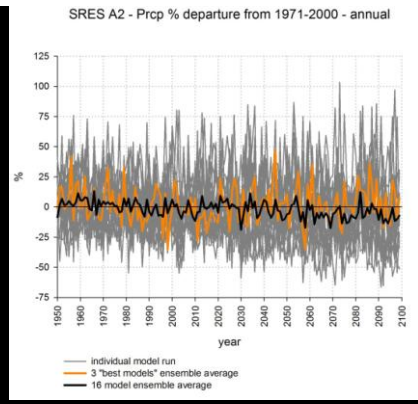

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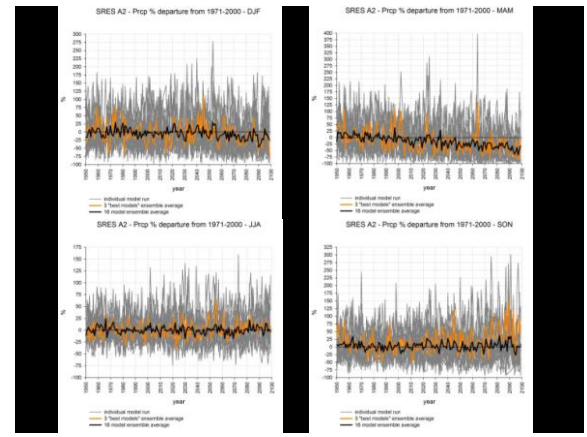

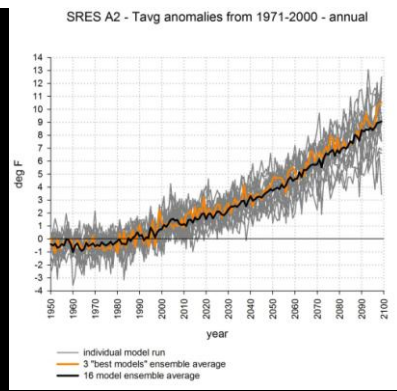

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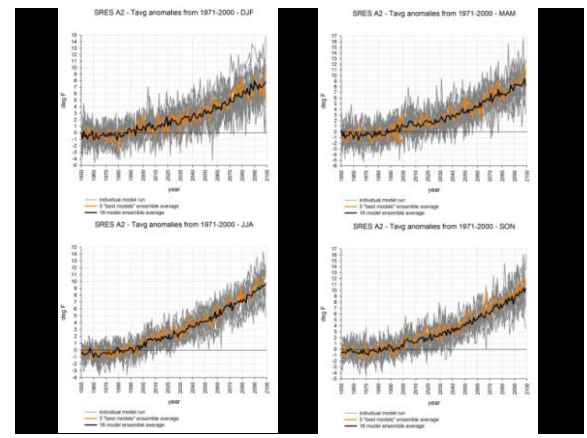
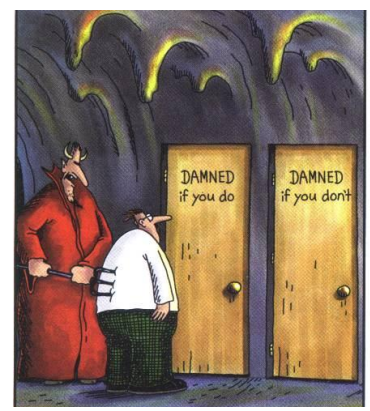


CONSIDER THIS

- What options do managers have?

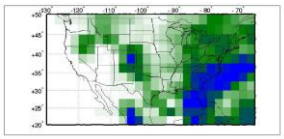


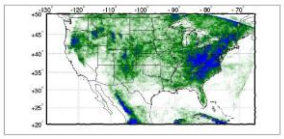
C'mon, c'mon – it's either one or the other

GCMx
4289
USA Today

GCM Pill Dispensary
(IPCC Approved)
Snow Away
B1
A2
A2
Mon-SOON
Warning:
Only Projections.
Use safely.

Dynamically Downscaled Climate Projections for the Southwestern United States





Francina Dominguez

Collaborators:
Christopher Castro
Erick Rivera Fernandez
Carlos Carrillo
Hsin-I Chang

University of Arizona
Dept of Atmospheric Sciences
Dept of Hydrology and Water Resources

October 17, 2011

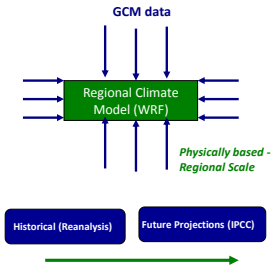
ATMOSPHERIC SCIENCES
UASCIENCE

Dynamical Downscaling

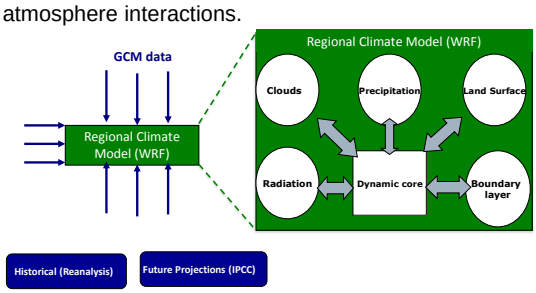
Definition: *Use some kind of numerical model to generate finer-resolution information from coarser resolution information. For the atmosphere, this is a regional climate model.*

Assumption: A finer resolution and/or improved model physics gives a "better" representation of weather and climate than the driving GCM.

"Better" may = more fidelity with observations and/or improved representation of physical processes



RCM is a physically based model with enhanced representation of the terrain forcing and land-atmosphere interactions.

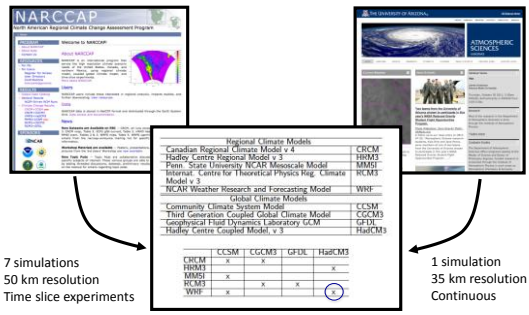


Dynamical Downscaling

- Pro : Produces responses based on physically consistent processes.
- Pro : Captures feedbacks.
- Pro : Can model changes that have never been observed in historical record.
- Pro : Useful where topographic controls are important.

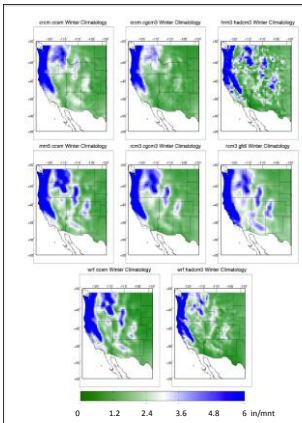
- Con : Requires significant computational power.
- Con : Limited amounts of models / runs / timescales.
- Con : Dependant on GCM boundary forcing.

We use two sources of dynamically downscaled data for this analysis:



7 simulations
50 km resolution
Time slice experiments

1 simulation
35 km resolution
Continuous

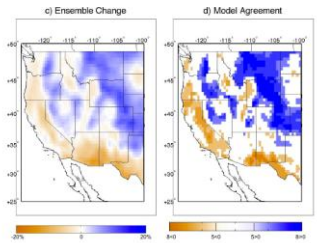


When compared to observations of winter precipitation in the Western US:

1. RCMs realistically represent the spatial pattern.
2. All models overestimate precipitation.

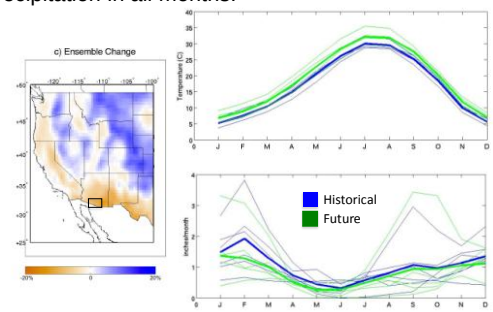
"observations"

The ensemble future projections show increasing precipitation in the north and decreasing precipitation in the south of the western US.



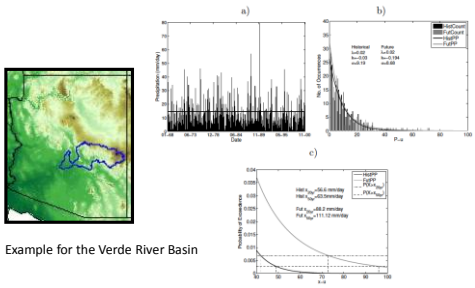
Mean winter precipitation change future (2038-2070)- historical (1968-2000)

Pima county in is projected to have decreasing precipitation in all months.



However, mean precipitation changes are small and generally statistically insignificant.

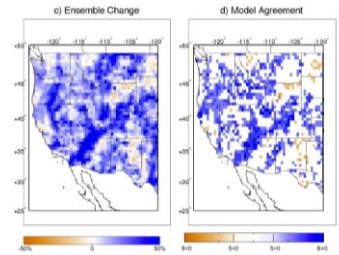
We have also evaluated changes in future extreme precipitation for the Western US.



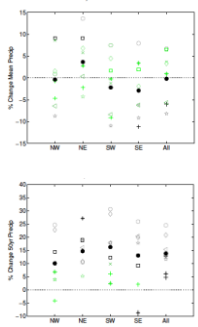
Example for the Verde River Basin

Changes in historical and future 20-year and 50-year daily winter precipitation events.

We find a consistent and statistically significant increase in the intensity of future extreme winter precipitation events over the western United States,



The models project deceases in mean winter precip. and increases in extreme winter precip. for the SW.



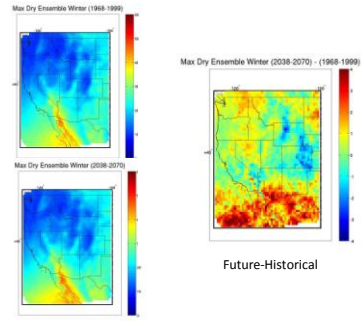
Changes in the mean are small and generally statistically insignificant.

Changes in the extremes are large and generally statistically significant.

The maximum number of dry days is also projected to increase in the Southwestern US.

Historical

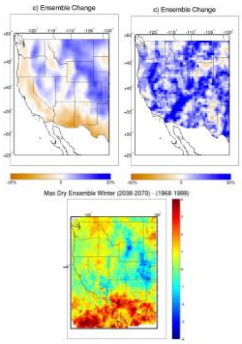
Future



Future-Historical

In conclusion…

We have used a **dynamical downscaling** framework to evaluate climate projections for the Western US.



In the Southwest, the models project:

1. Decreased mean winter precipitation.
2. Increased extreme winter precipitation.
3. Increased number of consecutive dry days.

Native Fish Conservation & Climate Variability in Southeastern Arizona

Doug Duncan and Gregg Garfin

US Fish & Wildlife Service and **University of Arizona**

Native fish sites

- **Unsuitable**
  - nonnative fish
  - landowner resistance
- **Unusable**
  - sport fishing
  - degraded water quality
  - other rare aquatic vertebrates

FISH STATUS

- **21 species in southeastern Arizona**
- **16 still occur in the area**
- **4 are extirpated**
- **1 is extinct**

- **13 species federally listed under the Endangered Species Act**
  - **9 are listed as endangered**
  - **4 as threatened**

OTHER NATIVE AQUATIC SPECIES

- **3 ranid frogs**
  - **lowland leopard**
  - **Chiricahua leopard**
  - **Tarahumara**

- **1 salamander**

- **several garter snake species**

THREATS

- **nonindigenous species**
- **habitat loss**
- **reduction in habitat quality**
  - Habitat destruction and the introduction of nonindigenous species are responsible for the decline of 98% of North American fishes listed as endangered, threatened, or of special concern

KEY PROJECTIONS:

enhanced hydrologic cycle - in a warmer world an enhanced hydrologic cycle is expected; flood extremes could be more common causing larger floods; droughts may be more intense, frequent, & longer-lasting

INTERSECTION OF CLIMATE & FISH

- drought and climate change, plus historical and continuing threats, will make native fish conservation in SE AZ even more difficult

INTERSECTION OF CLIMATE & FISH

The impact of site desiccation is obvious

- Less obvious effects can occur with drought and a warmer climate.
- Sites with reduced streamflow, or ponds or pools with low water could become fishless from reduced DO

INTERSECTION OF CLIMATE & FISH

- Bonar et al.
  - NIS have higher thermal tolerances
  - Many natives have lower tolerances than expected
  - Warmer waters will mean less habitat for natives, and favor NIS
  - Once again, the 1-2 punch of NIS and habitat loss and degradation hits

INTERSECTION OF CLIMATE & FISH

- We have seen these occur at important natural Gila topminnow sites

RECOMMENDATIONS

- Natural resource managers should be informed about climate variability

RECOMMENDATIONS

- Constructive dialog about native fish conservation needs, and how drought and climate change will affect it

RECOMMENDATIONS

- Conservation planning should address climate variability through adaptive management

RECOMMENDATIONS

- Complete and implement fish salvage protocol

RECOMMENDATIONS

- Important fish populations should be replicated
  - Genetic information crucial in determining important populations

RECOMMENDATIONS

- agencies should begin work on identifying & creating potential replication and refuge sites

RECOMMENDATIONS

- monitor important aquatic sites & fish populations
  - expand monitoring programs to enhance drought preparedness

Effects of drought on aquatic habitat of Cienega Creek

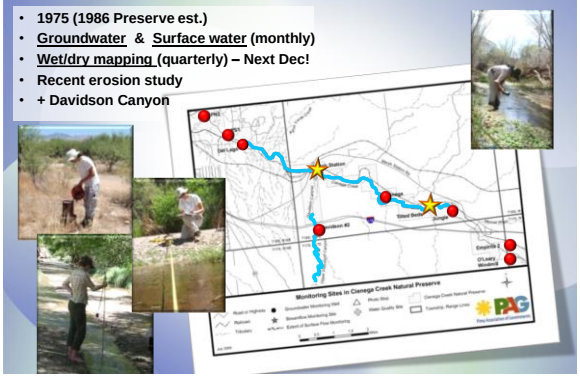
Oct. 2011

City of Tucson's Climate Projections and Habitat Workshop

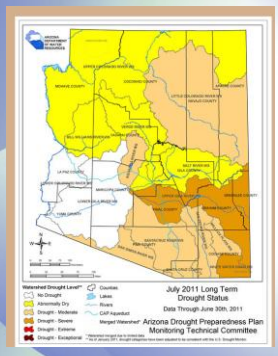
Importance of Long-Term Consistency

PAG – 30 years of Hydrologic Monitoring on Cienega Creek

- **1975 (1986 Preserve est.)**
- **Groundwater & Surface water (monthly)**
- **Wet/dry mapping (quarterly) – Next Dec!**
- **Recent erosion study**
- **+ Davidson Canyon**

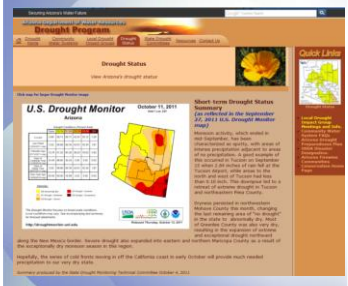


Drought Information Sharing



- Long term
- Consistent
- Impacts to Natural Environment

Drought Information Sharing



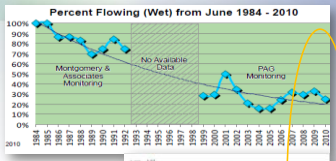
- Local Drought Impact Group (municipalities)
- Pima County & City of Tucson in "Drought Stage 1" (public notice)
  - Next trigger is CAP supplies
- DroughtWatch reporting (everyone encouraged)

Drought is Present on the Santa Cruz Watershed
(Oct. 2011)
Long Term -"Moderate" status
Short Term -"Extreme" status

U.S.D.A. designated Pima County a contiguous disaster area, Aug. 2011 (Agriculture)

Cienega Status: Acute Drought

Wet/Dry % wet



Streamflow Volume (cfs)

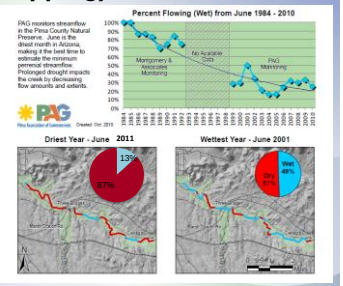
Groundwater Annual rise and fall

Drought

Flow Extent Decreased (Wet/Dry Mapping)

- Cienega perennial segments decreasing in length since 1980s
  - 1984- Continuous flow
  - Since 1999 – avg. 28% flowing
  - Currently- Peak Drought 2011

Davidson Canyon
- Similar declines
- 2005- channel and pools completely dried
- No longer see native fish or Lowland leopard frogs
- Additionally stressed by ORVs

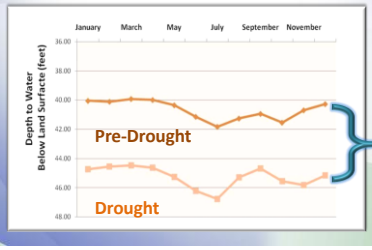


Cienega Creek – Report to MSCP

Clear Drought Effects on Groundwater

Shallow Groundwater:
Currently significantly below pre-drought levels

- 2002 - Drought impacts noticeable
- 2004 - Severe
- 2005 - 2008 some recovery
- 2009 - 2011 - Severe



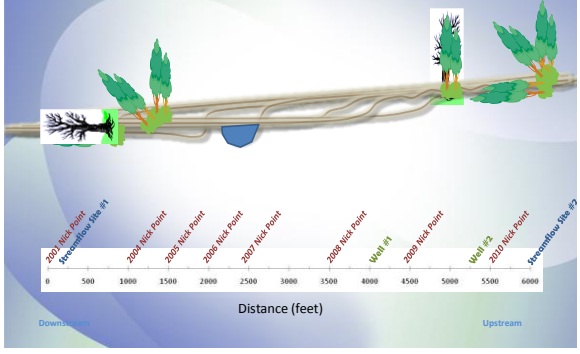
Streamflow Variability

- No Flow June 2011
  - (2nd time on record, also 2003)
- Sept. 2009 <10% of pre-drought flow
  - Normally Wettest time of year
  - 2011 Wettest Sept. on record (10th wettest monsoon- NOAA)- Little fish recovery
- Peak changing winter/summer

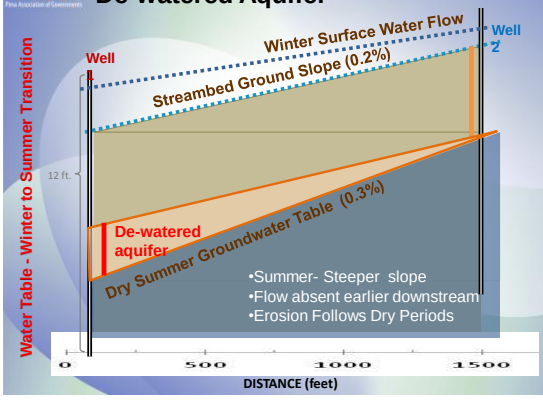
Corridor and Erosion effects

Headcut – Erosion Feature

De-Stabilized Soils
De-Watered Root Zone
Change in Habitat



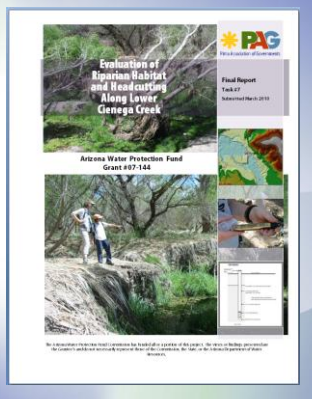
De-watered Aquifer



Erosion/Drought Connection

Trade-Offs in Habitat

- Headuct increased in fish habitat diversity in short term
  - More pools in active headcut zone (10 years)
  - Loss of sediments exposed subsurface flows
- Loss of vegetation cover and composition (20-30 year old dense riparian tree canopy)



Carefully balanced system

Management Recommendations

- Management Goals (County Natural Preserve):
  - Maintain in-stream flows, preserve tree-sustaining shallow groundwater, and preserve natives
- Monitor and address contributing human factors:
  - groundwater pumping, roadways
- Increase resilience:
  - Upstream: arroyo restoration (Las Cienegas)
  - Urban: Green Infrastructure/ Low Impact Development

Low Impact Development/ Green Infrastructure:

Urban Stormwater Harvesting / Restorative Rainwater Harvesting in Natural Systems

Slow
Spread
Sink

Roughen
Meander
Grade
Soil Moisture
Start at Top

Geomorphology
Hydrology
Biology

Mead Mier
PAG Watershed Planning Program
(520) 792-1093
MMier@pagnet.org

Riparian Hydrology

Tom Meixner
Julie Stromberg, Arizona State University
David Brookshire
Francina Dominguez
Enrique Vivoni
Jennifer Duan
Paul Brooks
James Hogan
Carlos Soto
Scott Simpson

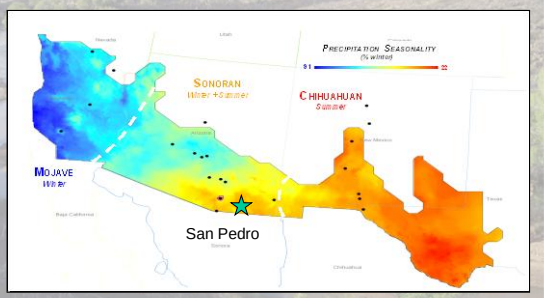
University of Arizona, SAHRA and
Department of Hydrology and Water Resources

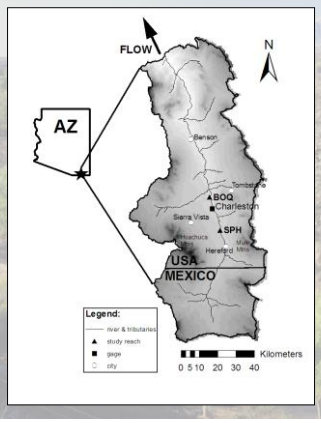
Legacies from the past shape the present

Outline

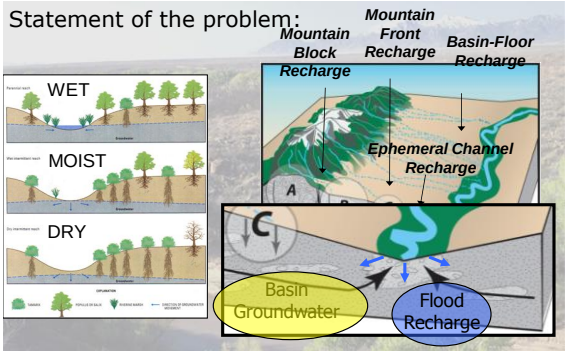
- Hydrology of arid and semi-arid systems
- Seasonality of climate and recharge
- Riparian hydrology
- Where does the river run?
- Implications

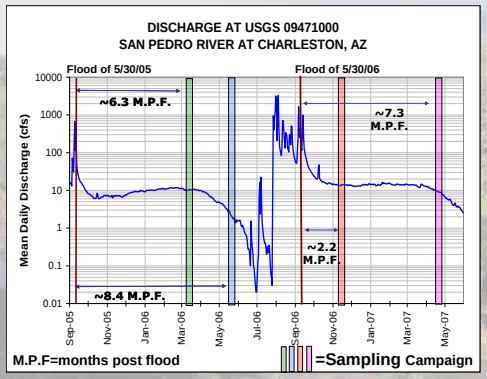
Precipitation Seasonality





Statement of the problem:



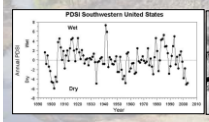


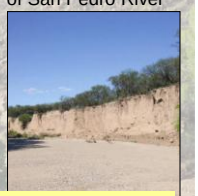
Personal Communication – Carlos Soto

7

Problem statement: Legacies of past extreme flood events may be shaping current vegetation trajectories and response to climate change.

Climate extremes + land use extremes ➡ Historic entrenchment of San Pedro River

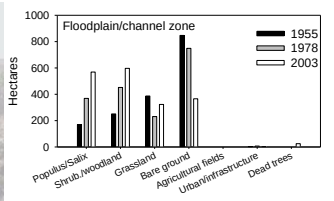




"It was probably during the 1896 flood that a channel almost 244 m wide and 6 m deep developed…" (Hereford and Betancourt 2009).

Methods: Aerial photographs of the Upper San Pedro River from 1935, 1955, 1978 and 2003 analyzed to assess temporal and spatial trends in vegetation cover type abundance.

Results: As a legacy of past extreme disturbance, pioneer woody vegetation has been expanding over past ½ century.

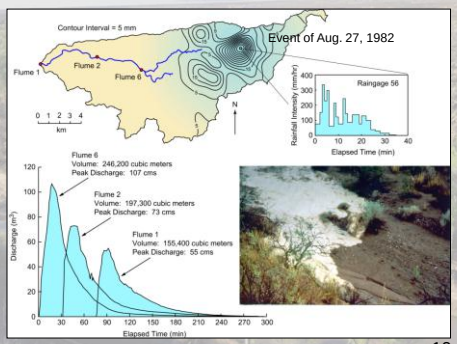


	Status in 2003				
	Populus Salix	Shrub./ wood.	Grass-land	Bare ground	Farm +urban
Status in 1955					
Populus/Salix	15%	3%	7%	9%	0%
Shrub./wood.	10%	46%	4%	23%	0%
Grassland	19%	22%	41%	18%	0%
Bare ground	56%	29%	48%	50%	0%
Farm + urban	0%	0%	0%	0%	0%
Sum	100%	100%	100%	100%	100%

Most *Populus/Salix* points mapped in 2003 arose from bare ground (as mapped in 1955)

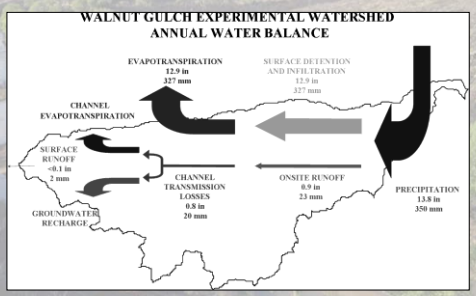
9

Ephemeral Streamflow



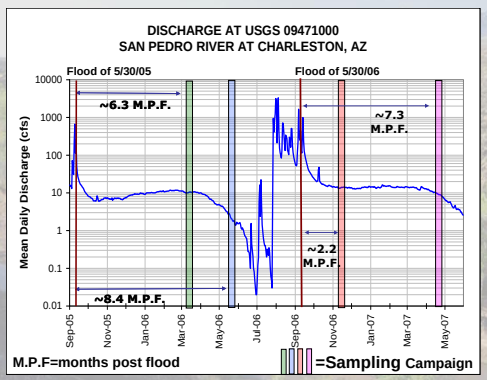
10

Water Balance of Uplands



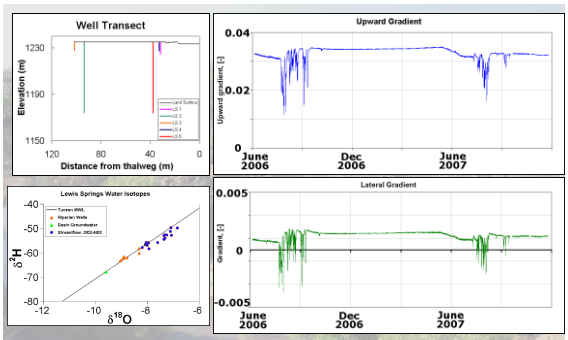
Renard et al. 2008

11

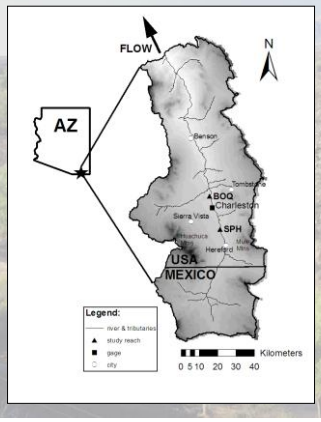


Personal Communication – Carlos Soto

12

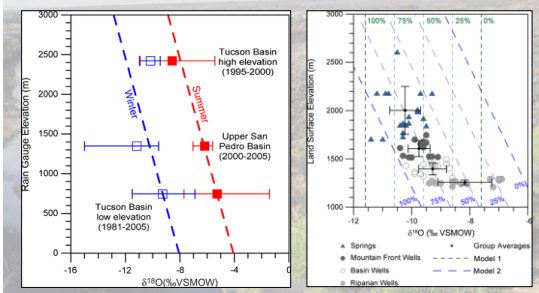


13



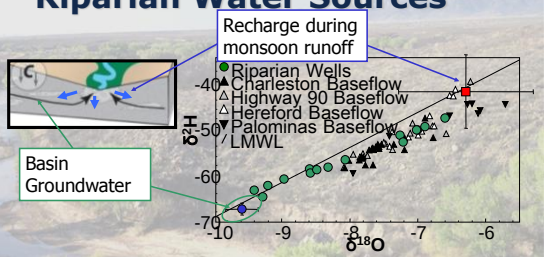
14

Recharge Seasonality



15

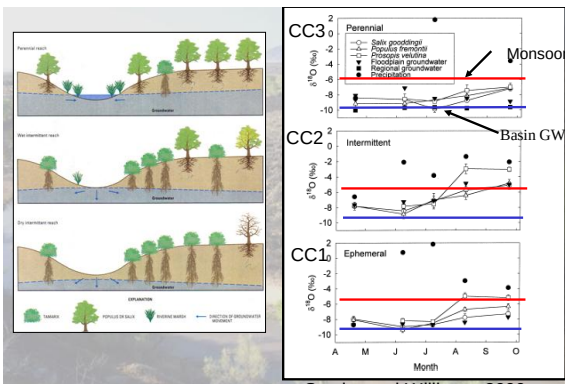
Riparian Water Sources



- Isotopes of water – natural tracer of source
- Riparian wells span range between end members
- Baseflow skewed toward monsoon runoff
- Quantify % using simple mixing model
- Uncertainty associated with runoff end member

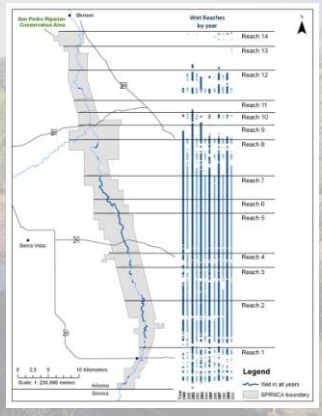
Baillie et al., 2007 JGR

16



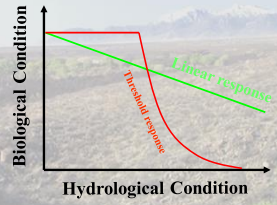
Snyder and Williams, 2000

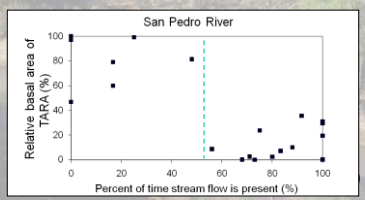
17



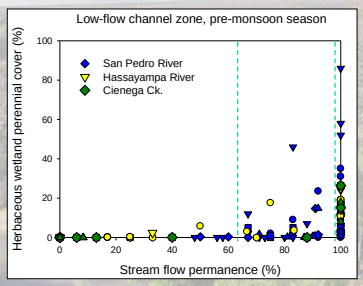
18

We will use empirically-derived threshold values to model abundance changes within the pioneer forests in response to changes in stream intermittence.

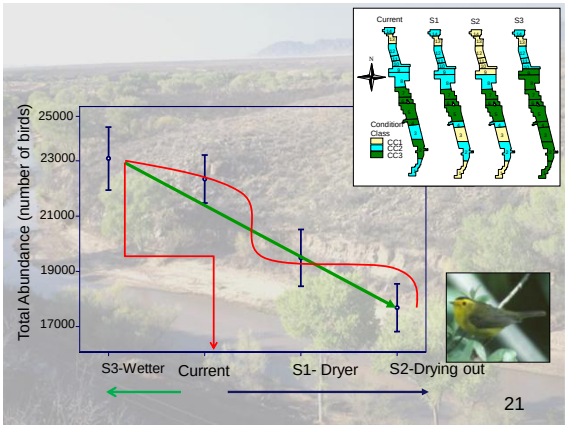




We will use empirically-derived threshold values to model changes in abundance of riverine marshlands



20



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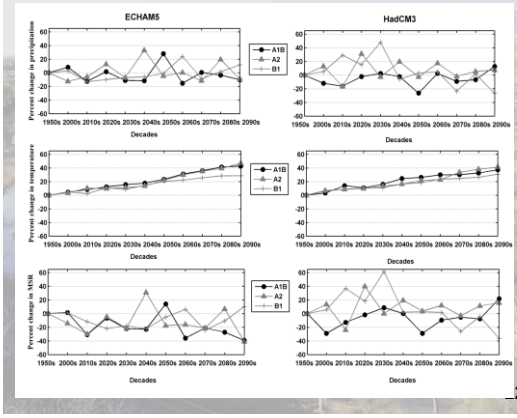


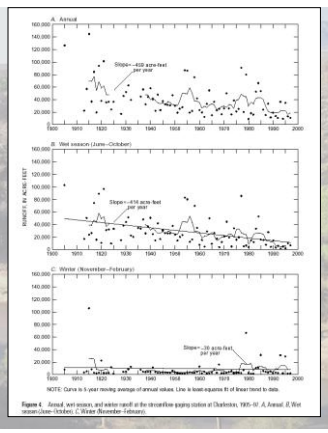
22

Pool and Coes (1999) →

Demonstrate decrease in summer flows over 20th century

Little change in winter flows

Flood recharge of riparian aquifer increasing? decreasing?



Implications

- Changes in winter versus summer precipitation
  - As important as overall precipitation change
  - Important but still unknown direction
- Floods are a critical component of perennial hydrology
- Data on effects of current conditions needed
  - On hydrology
  - On biology

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Acknowledgements

- Bureau of Land Management
- The Nature Conservancy – Holly Richter
- UA- Water Resources Research Center

This research is funded by US EPA - Science To Achieve Results (STAR) Program Grant # R833025

USA npn National Phenology Network

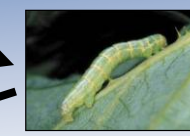
What are expected changes in upland desert scrub and grassland communities under predicted climate change?

- Phenology (timing)
- Species distributions (spatial extent)
- Invasive species
- Native communities

A three-way mismatch

EARLIER

English Oak



Winter Moth

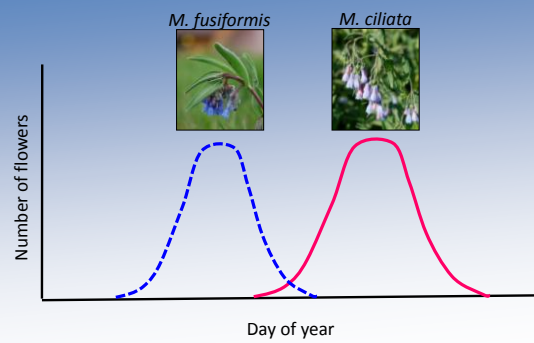
EARLIER

SAME TIME EACH YEAR

Pied Flycatcher

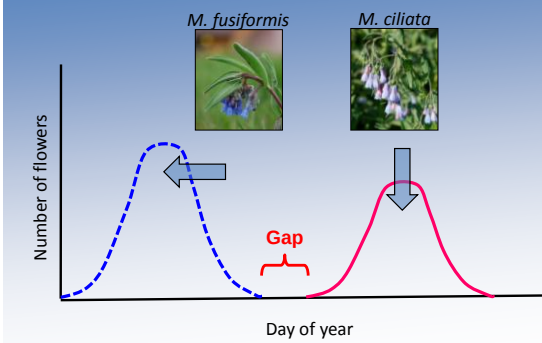
Both et al. 2006 Nature

Resource gaps for pollinators



Miller-Rushing and Inouye. 2009. American Journal of Botany

Resource gaps for pollinators

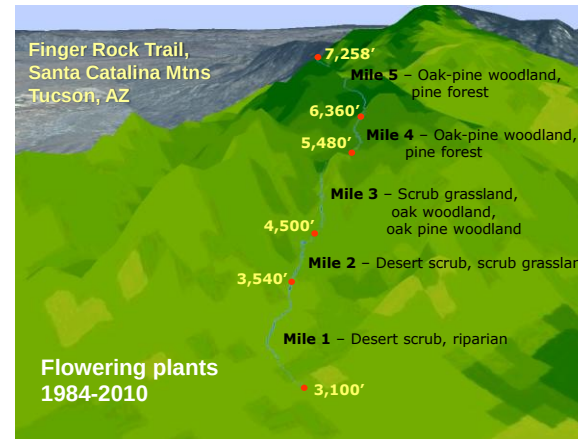


Miller-Rushing and Inouye. 2009. American Journal of Botany

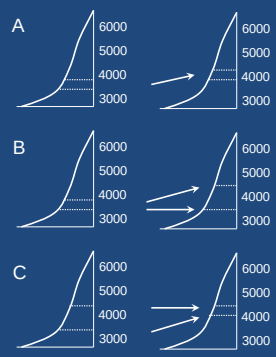
USA npn National Phenology Network

Local changes in phenology

- Species flowering range changes
- Onset of spring season
- Onset of summer season



Finger Rock Trail Phenology : 93 species (26%) show change in flowering range with elevation with warmer summers

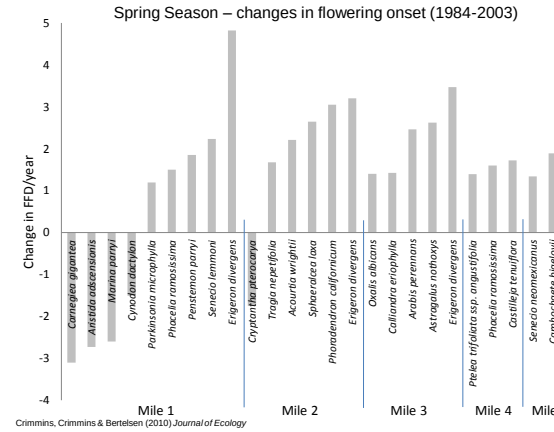


12 species exhibited flowering range shift upslope

34 species exhibited flowering range expansion upslope

23 species exhibited flowering range contraction upslope

Crimmins, Crimmins & Bertelsen (2009) *Global Change Biology*



Crimmins, Crimmins & Bertelsen (2010) *Journal of Ecology*

Local changes in phenology

- Species range changes - upslope
- Low elevation habitats:
  - spring season: delayed onset associated with changes in winter precip, insufficient winter chilling
  - summer season: higher temps, less available soil moisture
- Bottom line: some clear patterns; individualistic responses!

Additional changes documented…

- Notable die-off of saguaros, foothills palo verde, velvet mesquite
- Continuing spread of non-native grasses: Lehmann lovegrass, red brome, buffelgrass, soft feather pappusgrass, natal grass

Implications

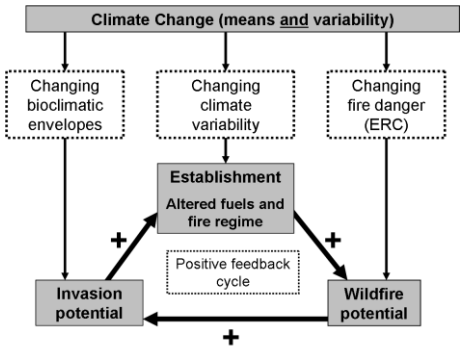
- Change in community composition, reduced biodiversity?
- Temporal mismatches?
- Increase competition for resources?
- Affect flower size, seed set?
- Allow invasions by nonnative species?

Supporting Decision Making & Management

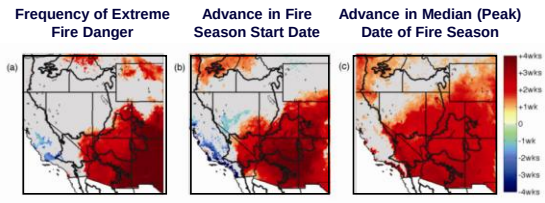
USA-NPN can offer:

- Rigorous protocols
- Long-term data archive
- Raw data
- Visualization/decision support tools

nature's notebook
a project of the USA-NPN



Abatzoglou, J. and Kolden, C. 2011. Climate Change in the Southwestern U.S.: A recipe for increased wildfire and spread of invasive grasses. Rangeland Ecology & Management.



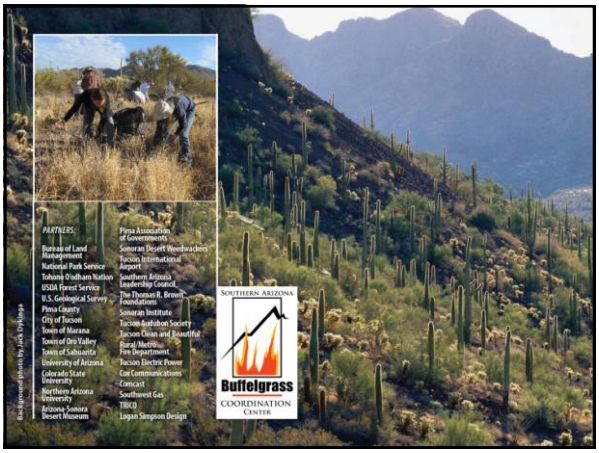
Multi-model Mean Projected Changes by mid-21st century (2046-2065) compared to historical conditions (1971-2000)

Abatzoglou, J. and Kolden, C. 2011. Climate Change in the Southwestern U.S.: A recipe for increased wildfire and spread of invasive grasses. *Rangeland Ecology & Management*

SOUTHERN ARIZONA
Buffelgrass
COORDINATION CENTER

A non-profit partnership across the public and private sector entrusted with educating, planning, and coordinating mitigation of buffelgrass invasion and its impacts across multiple jurisdictions

www.buffelgrass.org



SOUTHERN ARIZONA
Buffelgrass
COORDINATION CENTER

Science and Management Priorities for Mitigating the Impacts of Buffelgrass Invasion and Novel Fire Regimes in the Sonoran Desert

First Annual Workshop, May 4-6, 2010 Tucson

LOGAN SIMPSON DESIGN INC.

USGS
science for a changing world
Fort Collins Science Center

Invasives Species Science Branch

i. **Novel ways of repeatable mapping using remote sensing**

ii. **Empirical evidence for spread rates and degree to which they are variable or constant in time & space**

iii. **Decision support based on dynamic vegetation models**

iv. **Statistical and deterministic habitat suitability models**

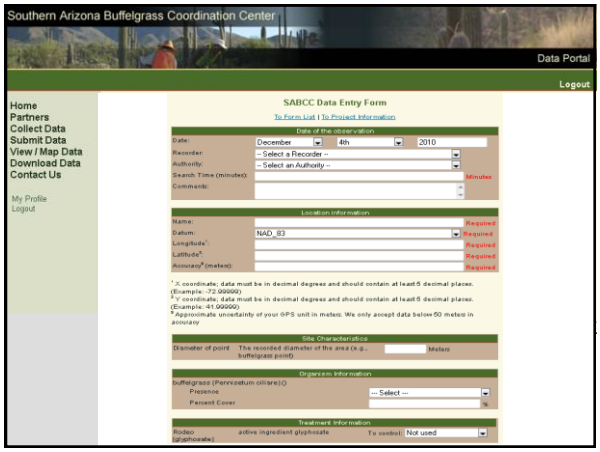
v. **Life cycles for conventional control methods**

vi. **Microorganisms with the right specificity for use in biocontrol**

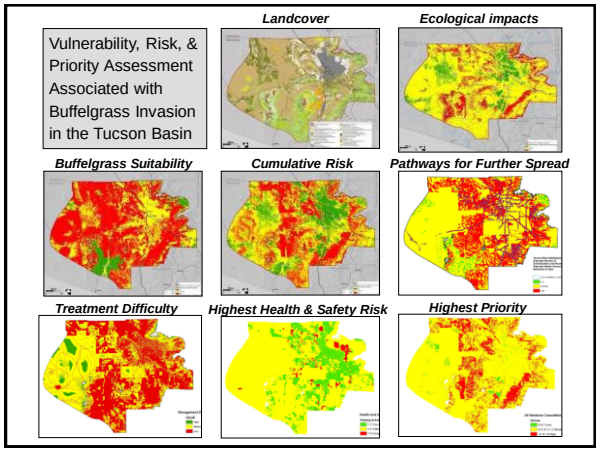
vii. **Landscape models capable of identifying when and where the largest fires tend to start and spread**

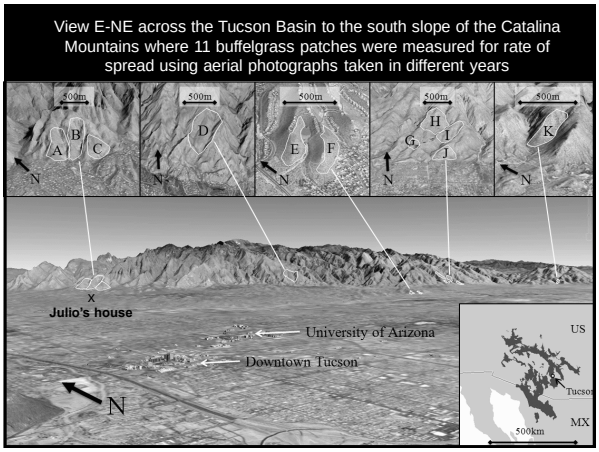
viii. **Post-fire and post-treatment restoration**

ix. **Long-term forecasting of environmental consequences should mitigation fail**

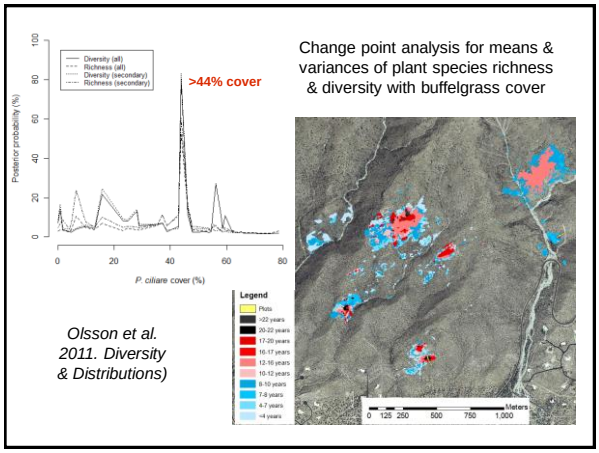

Southern Arizona Buffelgrass Coordination Center
Data Portal
Logout
Home
Partners
Collect Data
Submit Data
View / Map Data
Download Data
Contact Us
My Profile
Logout
SABCC Data Entry Form
To Form List | To Project Information
Date of the observation
Date:
December
4th
2010
Recorder:
-- Select a Recorder --
Authority:
-- Select an Authority --
Search Time (minutes):
Minutes
Comments:
Location information
Name:
Datum:
NAD_83
Longitude*:
Latitude*:
Accuracy* (meters):
Required
*X coordinate; data must be in decimal degrees and should contain at least 5 decimal places.
(Example: -72.99990)
*Y coordinate; data must be in decimal degrees and should contain at least 5 decimal places.
(Example: 41.99990)
*Approximate uncertainty of your GPS unit in meters. We only accept data below 50 meters in accuracy
Site Characteristics
Diameter of point buffelgrass point)
The recorded diameter of the area (e.g.,
Meters
Organism Information
buffelgrass (Pennisetum ciliare)()
Presence
-- Select --
Percent Cover
%
Treatment Information
Rodeo (glyphosate)
active ingredient glyphosate
To control:
Not used

Vulnerability, Risk, & Priority Assessment Associated with Buffelgrass Invasion in the Tucson Basin
Southern Arizona
Buffelgrass
Coordination Center
Logan Simpson Design Inc.

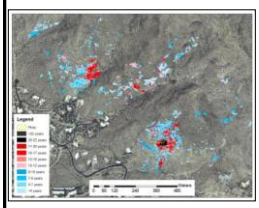

Vulnerability, Risk, & Priority Assessment Associated with Buffelgrass Invasion in the Tucson Basin
Landcover
Ecological impacts
Buffelgrass Suitability
Cumulative Risk
Pathways for Further Spread
Treatment Difficulty
Highest Health & Safety Risk
Highest Priority

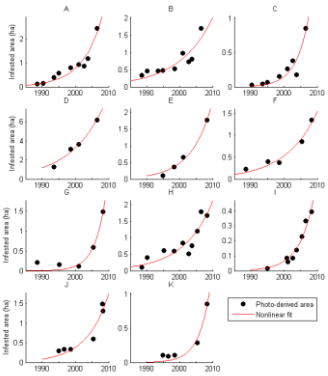

View E-NE across the Tucson Basin to the south slope of the Catalina Mountains where 11 buffelgrass patches were measured for rate of spread using aerial photographs taken in different years
500m
A
B
C
D
E
F
G
H
I
J
K
N
Julio's house
University of Arizona
Downtown Tucson
US
Tucson
MX
500km

A
B
C

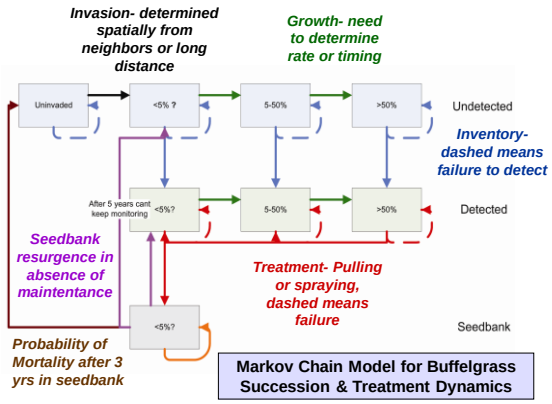

Change point analysis for means & variances of plant species richness & diversity with buffelgrass cover
Diversity (all)
Richness (all)
Diversity (secondary)
Richness (secondary)
>44% cover
Posterior probability (%)
P. ciliare cover (%)
Olsson et al. 2011. Diversity & Distributions)
Legend
Meters

Buffelgrass Spread Rates at 11 sites South slope Catalina Mts



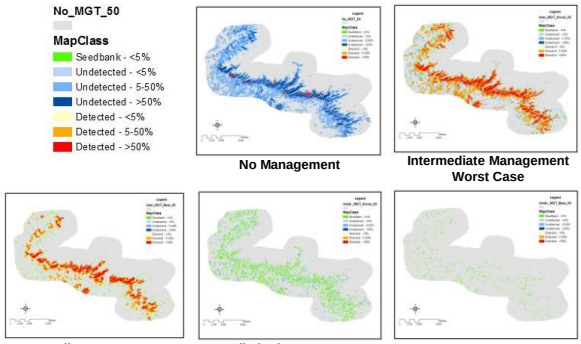


Olsson, Betancourt, Marsh & Crimmins, In Review, *Journal of Arid Environments*



Markov Chain Model for Buffelgrass Succession & Treatment Dynamics

2060 Simulation Scenarios for Buffelgrass Invasion in the Catalina Mts



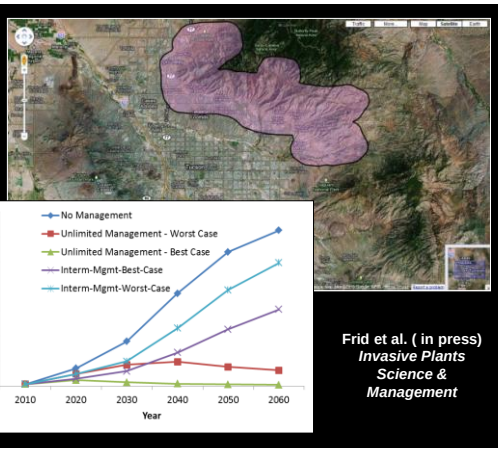
No Management

Intermediate Management Worst Case

Intermediate Management Best Case

Unlimited Management Worst Case

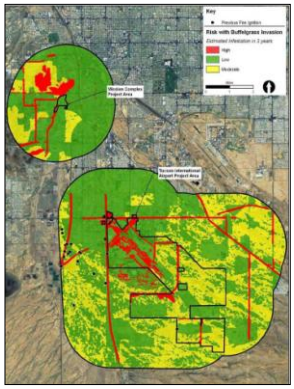
Unlimited Management Best Case



Frid et al. (in press) *Invasive Plants Science & Management*

***Losing Ground: The War On Buffelgrass In The Sonoran Desert* - April 10, 2010, Tucson**

Panel 1
Bert Frost, Associate Director
Natural Resource Stewardship & Science
National Park Service
Faye Krueger, Deputy Regional Forester
Southwestern Region
U.S. Forest Service
Dr. Ned Norris, Chairman
Tohono O'odham Nation

Panel 2
Sarah Smallhouse
The Thomas R. Brown Foundations
Chuck Huckelberry
Pima County Administrator
Dr. Richard Mack
Washington State University
Dr. John Brock
Brock & Associates

FY11 FEMA Pima County Wildfire Risk Mitigation Project ($3.4M)