

Climate-induced Threshold Responses in Rangelands

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Beyond Boxes and Arrows -

Assessing Climate Change/Variability and Ecosystem Impacts/Responses
in Southwestern Rangelands

San Carlos - January 25, 2006

How does vegetation change?

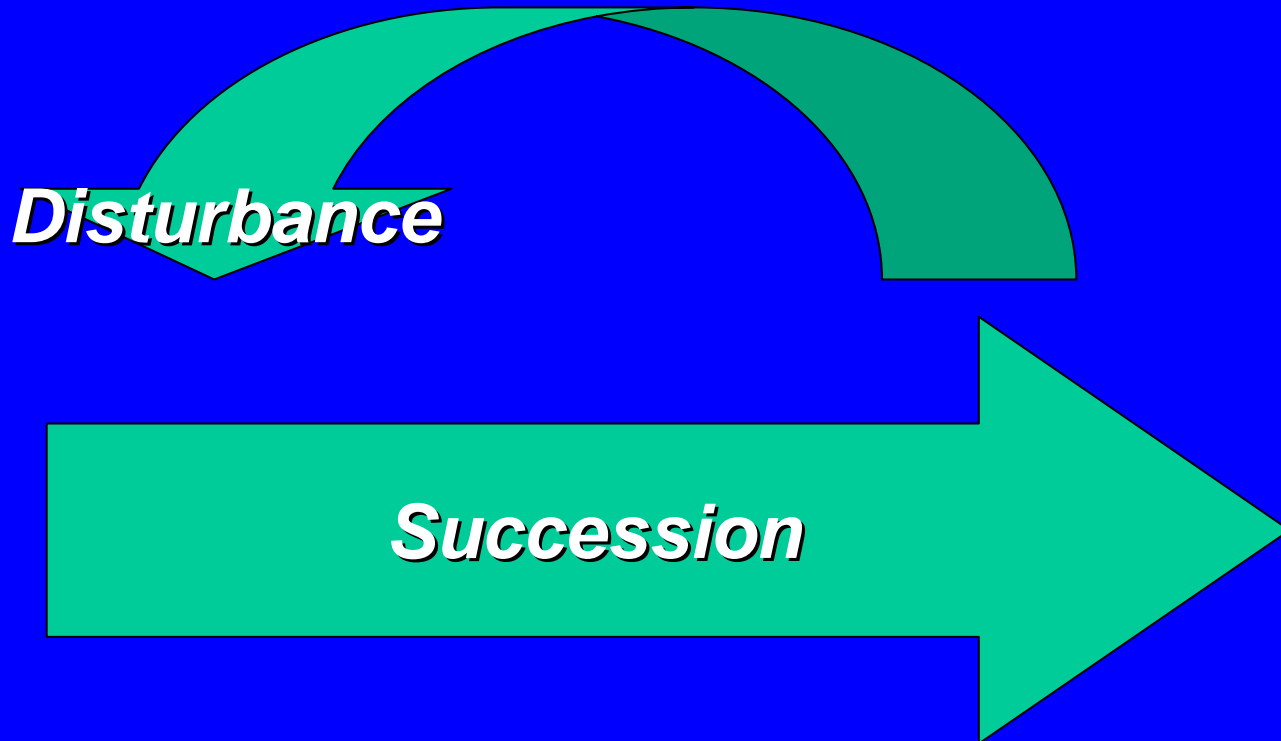
How does vegetation change?

By a simple progression



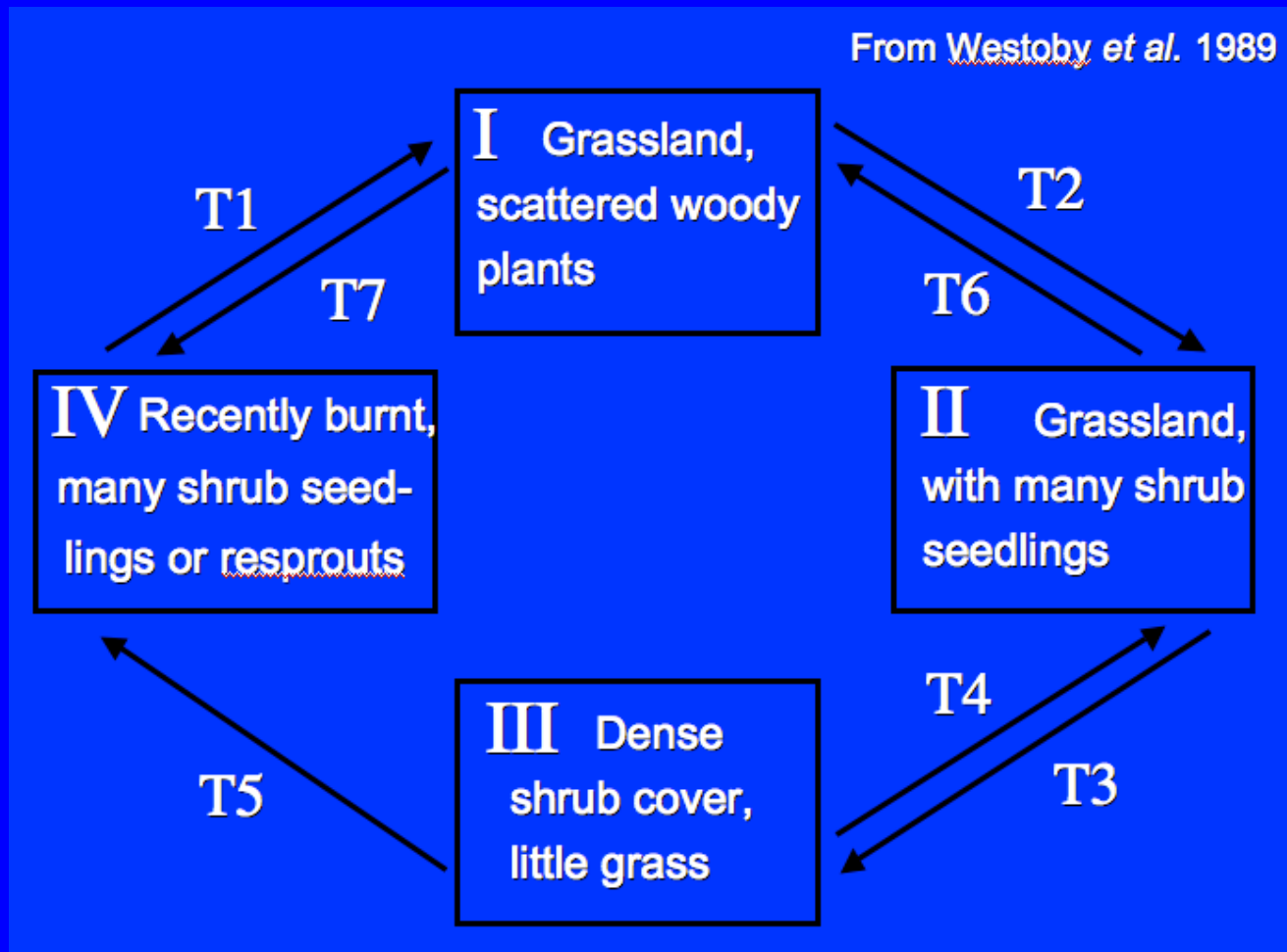
How does vegetation change?

By a simple progression



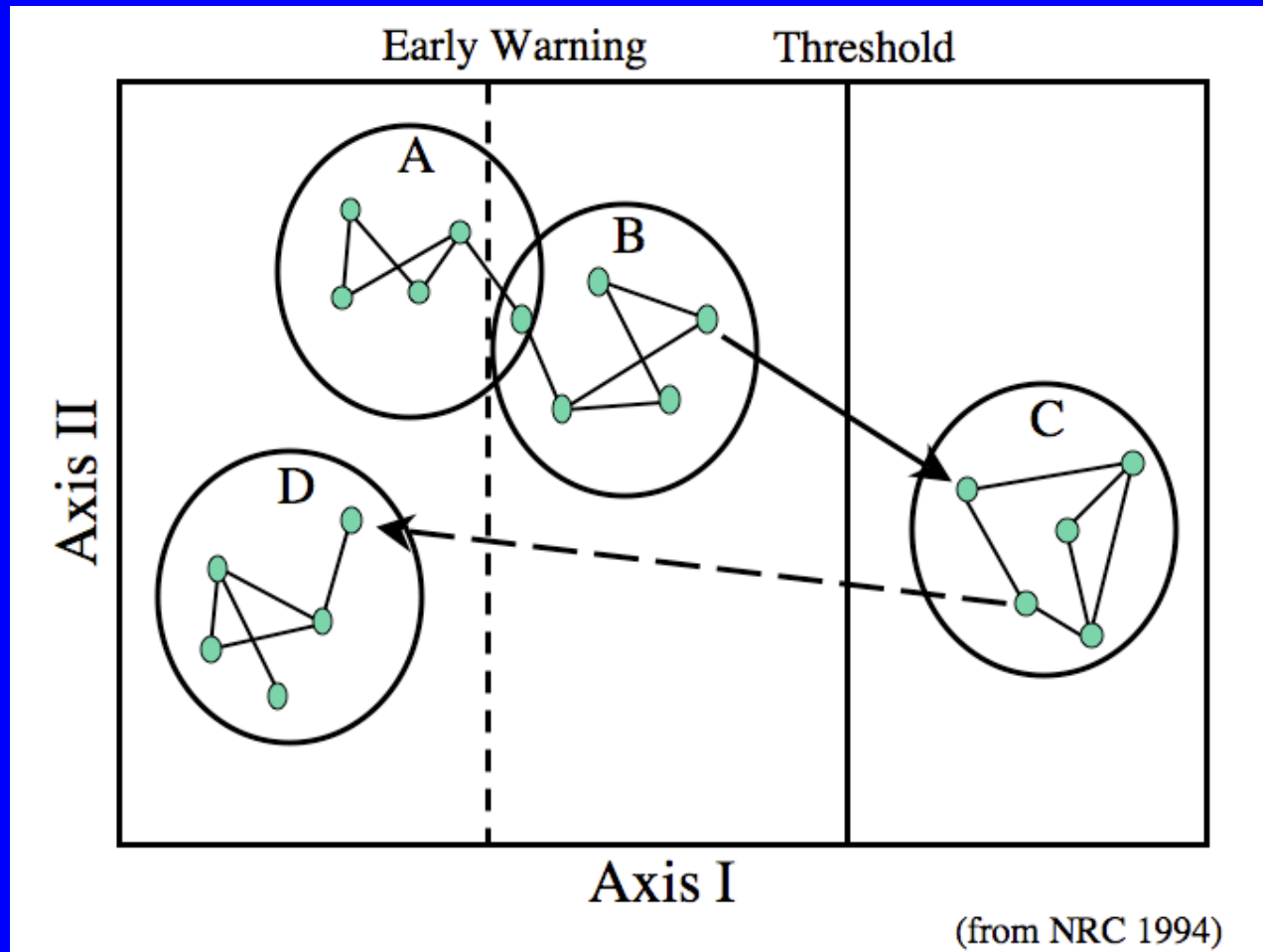
How does vegetation change?

By a shifting from state to state



How does vegetation change?

*By a shifting from state to state
- with variation within a state*



Why is this stuff so tough to predict?



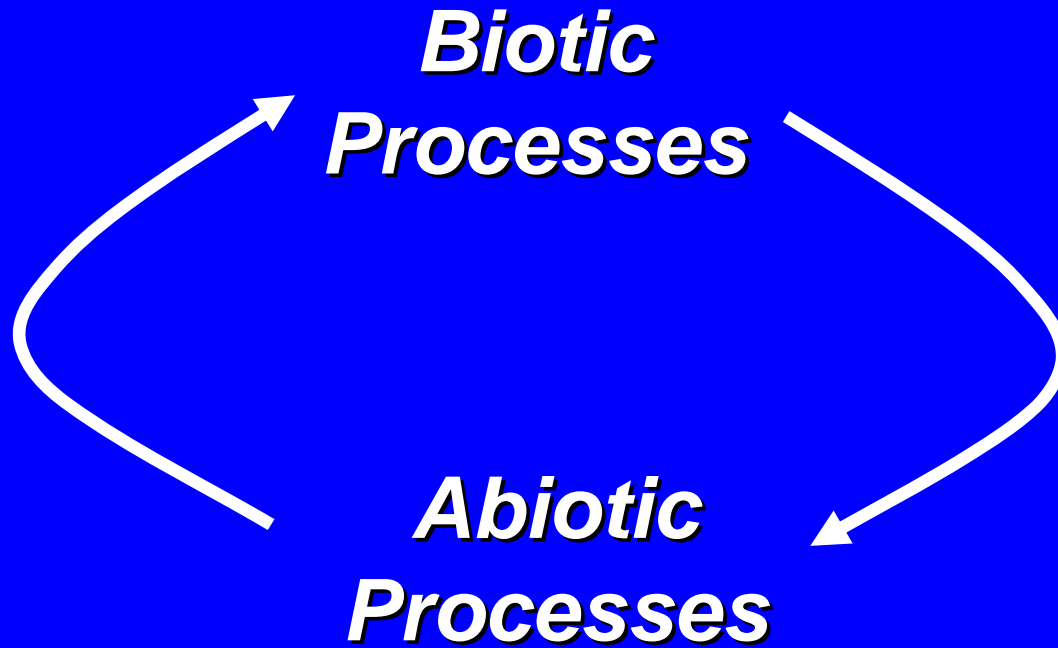
“Erasure fight!”

Larson - The Far Side

***Biotic
Processes***

***Abiotic
Processes***

Feedbacks

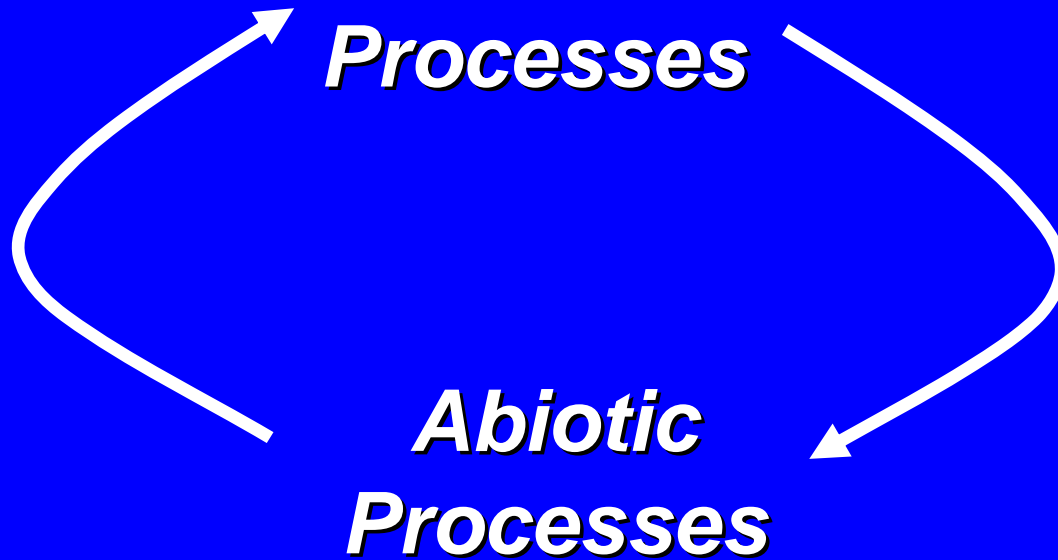


Feedbacks

***External Abiotic
Forcings***



***Biotic
Processes***



***Abiotic
Processes***

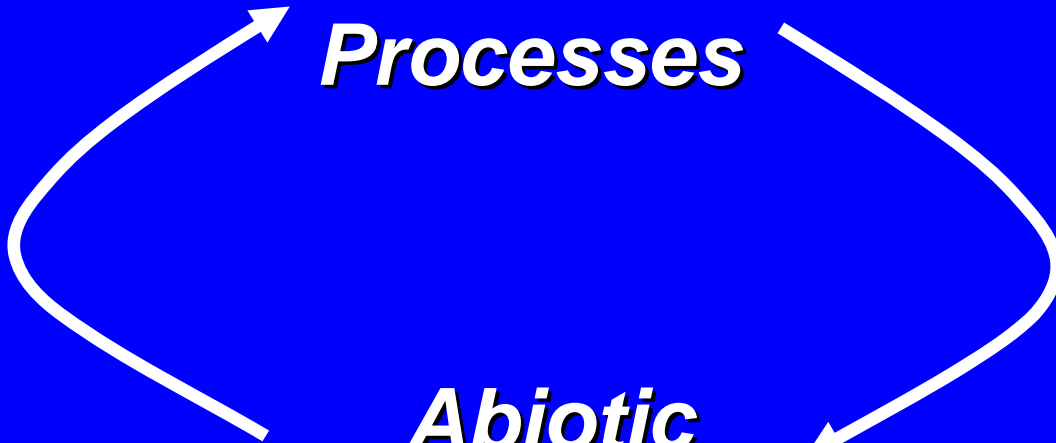
Feedbacks

External Abiotic Forcings



Biotic Processes

Abiotic Processes



Biotic Inertia

Abiotic Inertia

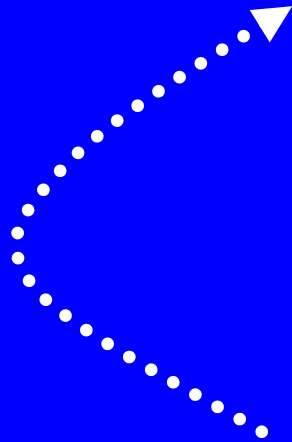
Biotic Inertia Under Disturbance

Biological Inertia

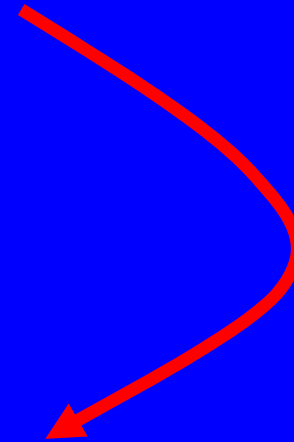
***External Abiotic
Forcings***



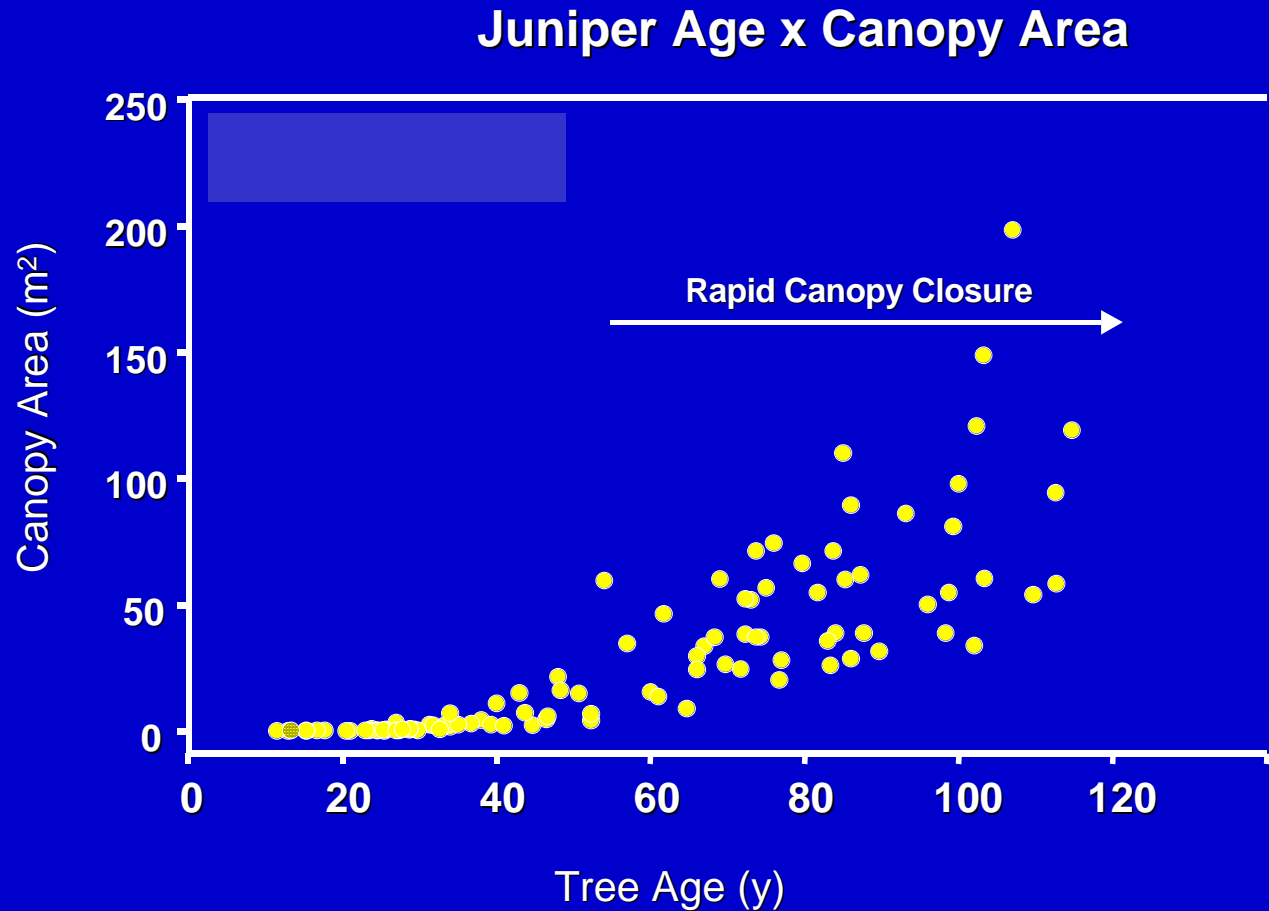
***Biotic
Processes***



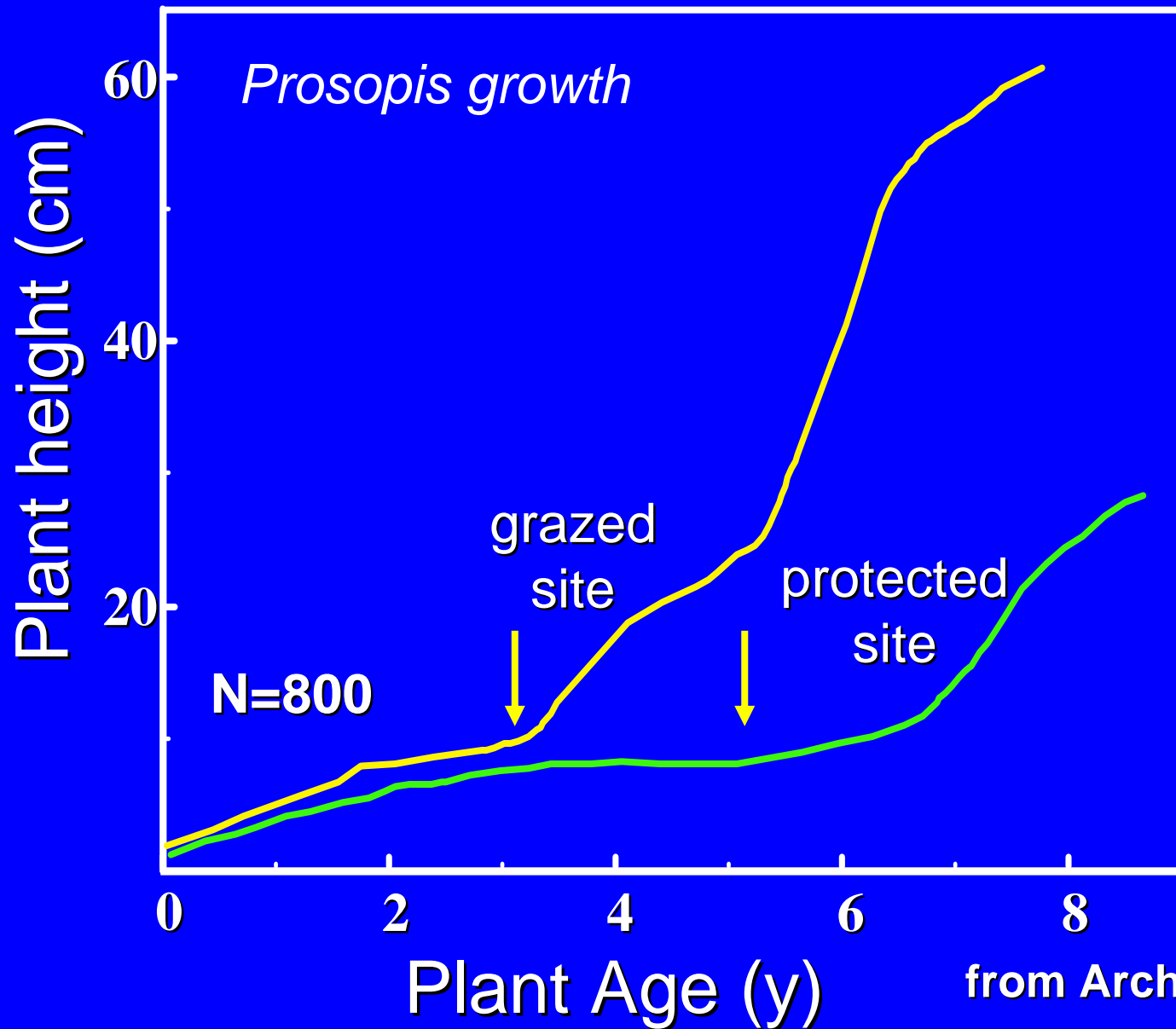
***Abiotic
Processes***



A Growth Threshold at ~40 Years



Growth threshold dependent on land management



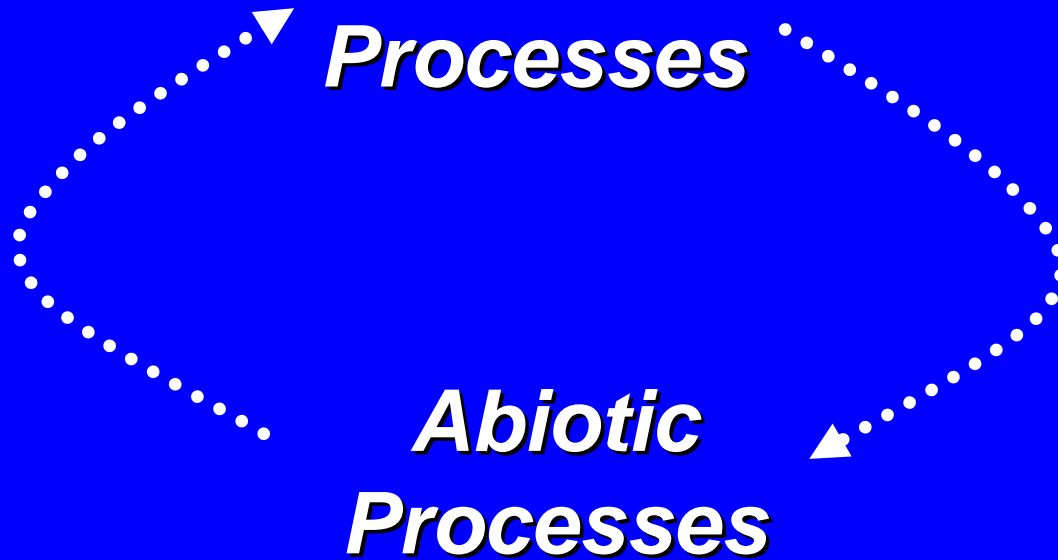
from Archer 1995

Biological Inertia

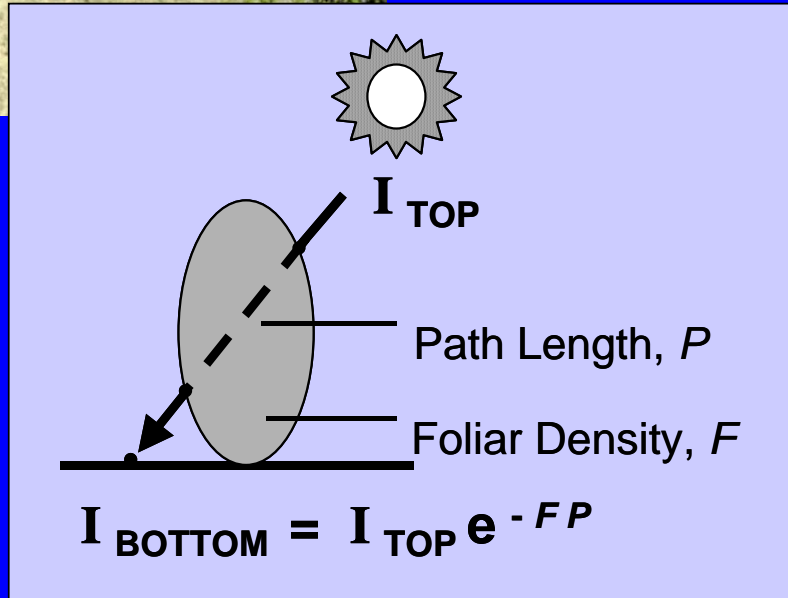
***External Abiotic
Forcings***



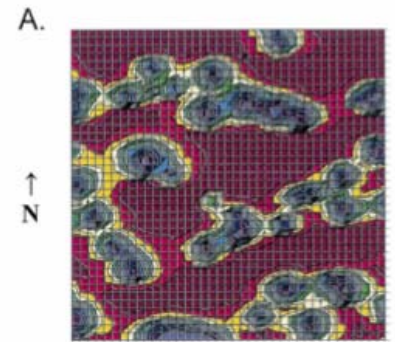
***Biotic
Processes***



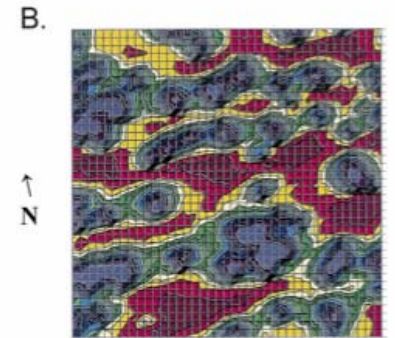
Shading Patterns



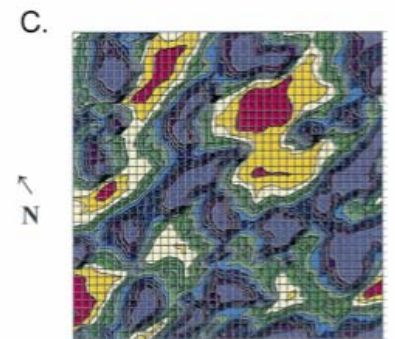
26%



34%



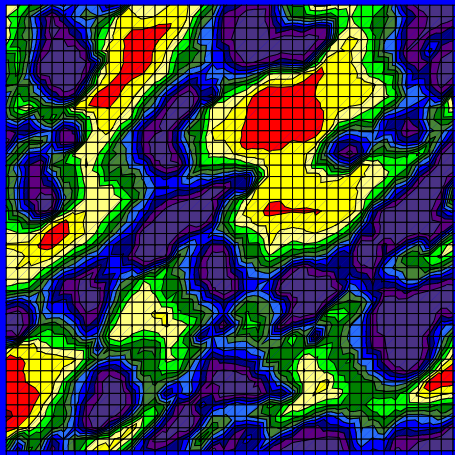
42%



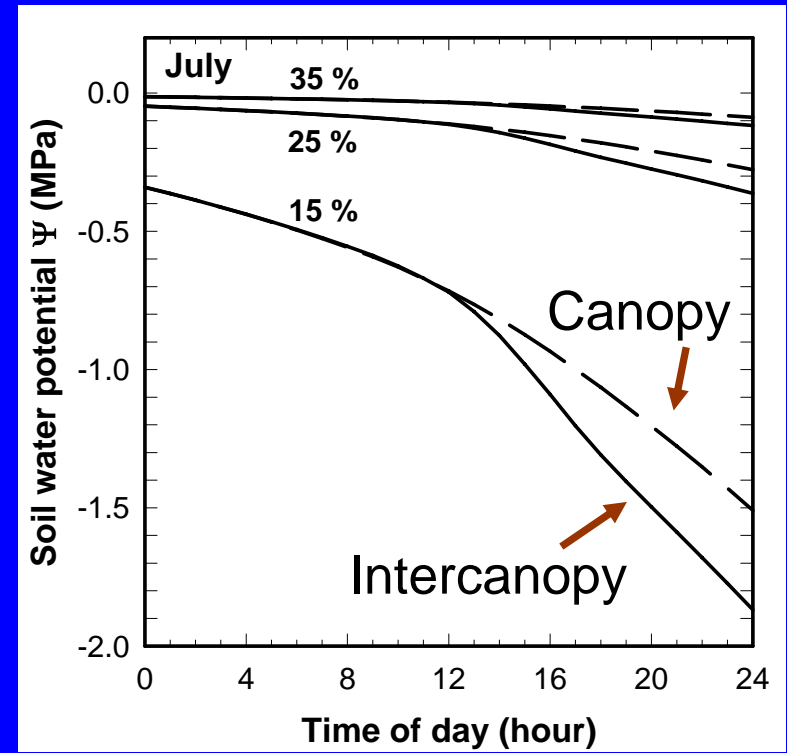
Martens et al. (2000) – *Eco. Model.*

Shading Effects on Soil Water

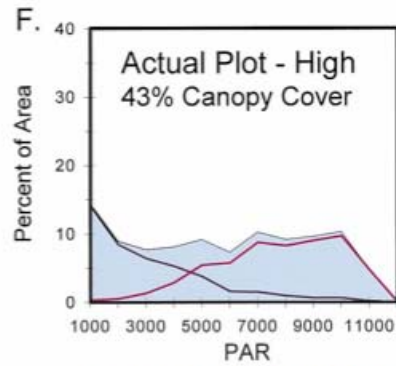
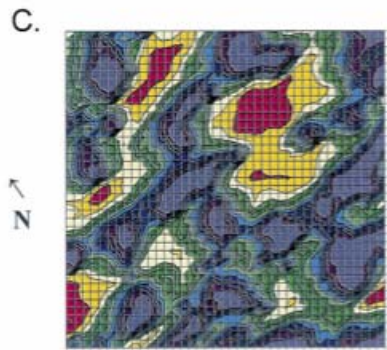
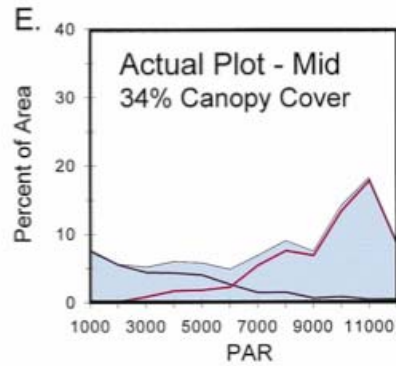
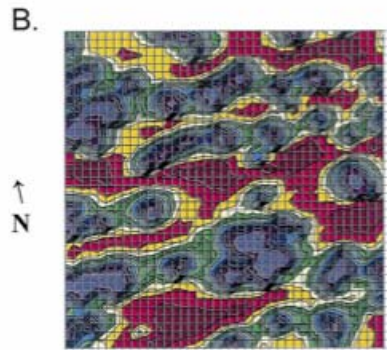
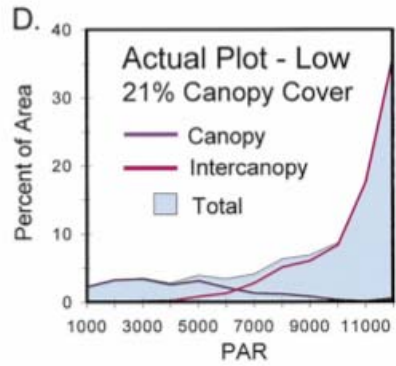
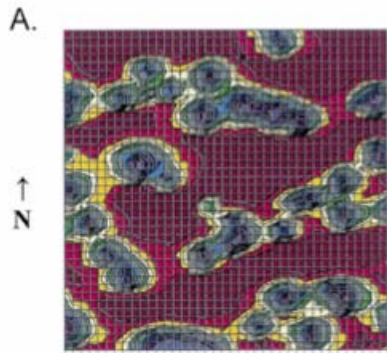
Near ground differences in incoming solar radiation
produce greater soil evaporation rates in intercanopy



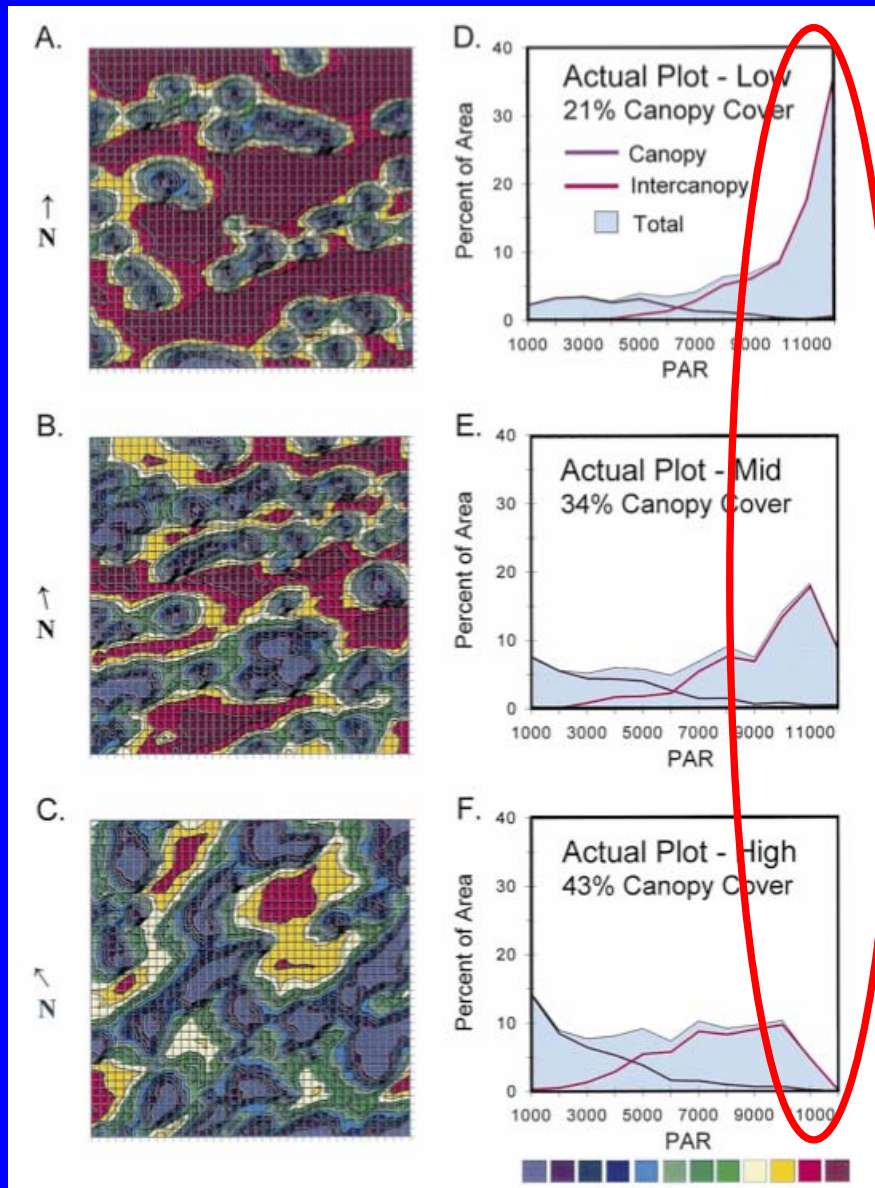
Martens et al. (2000)
Ecol. Model.



Breshears et al. (1998)
Int. J. Plant Sci.



Martens et al. (2000) - Ecol. Model.



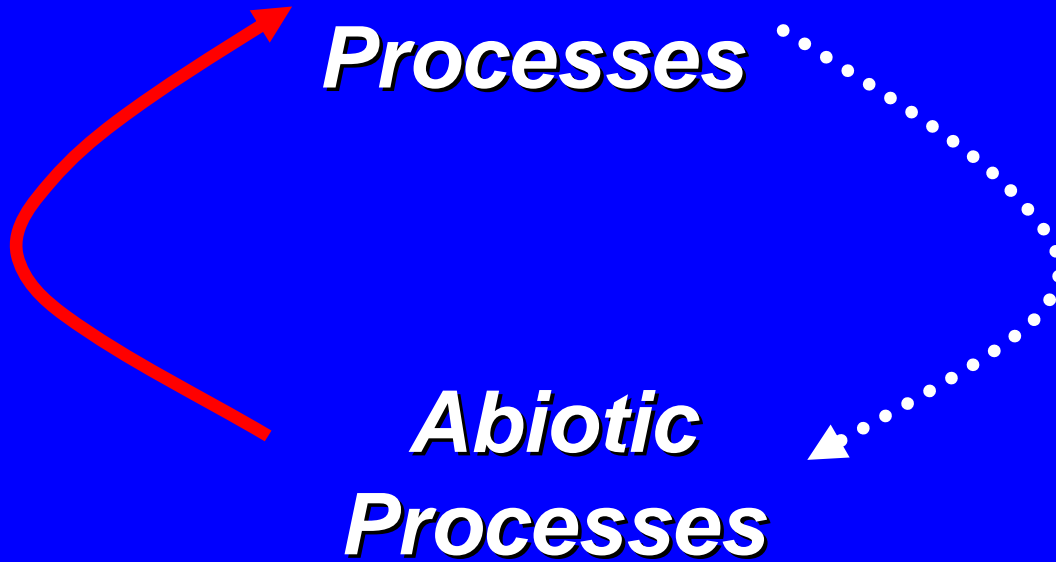
Number of HOT locations sensitive to changes in canopy cover

Abiotic Inertia

External Abiotic Forcings

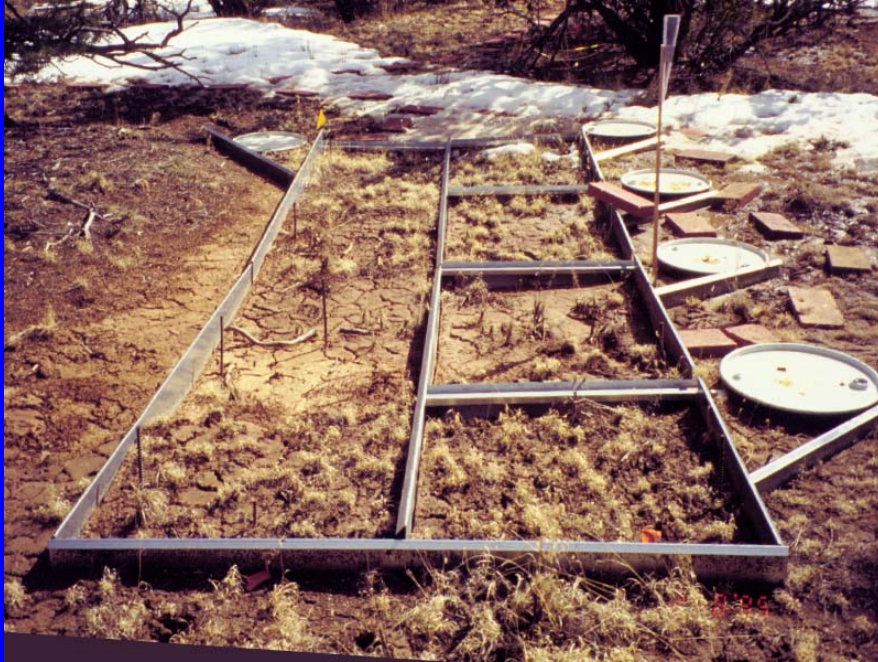


Biotic Processes



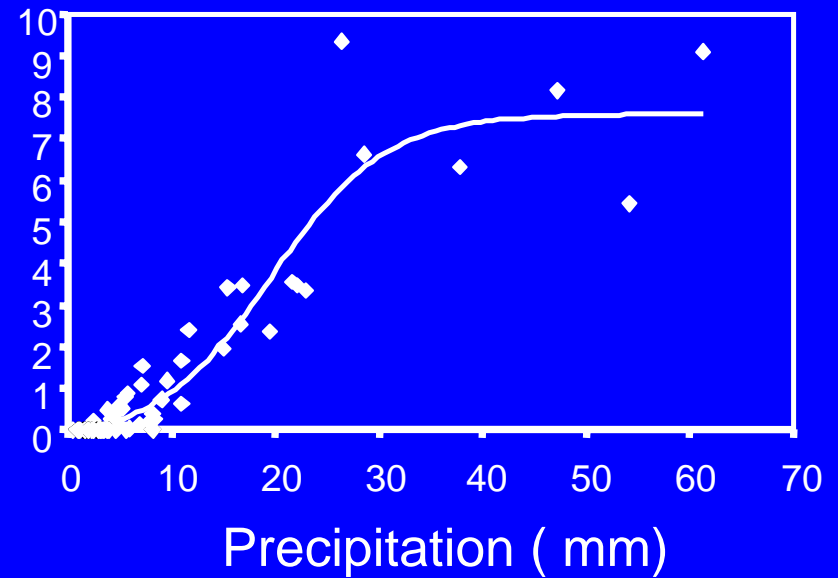
Abiotic Processes

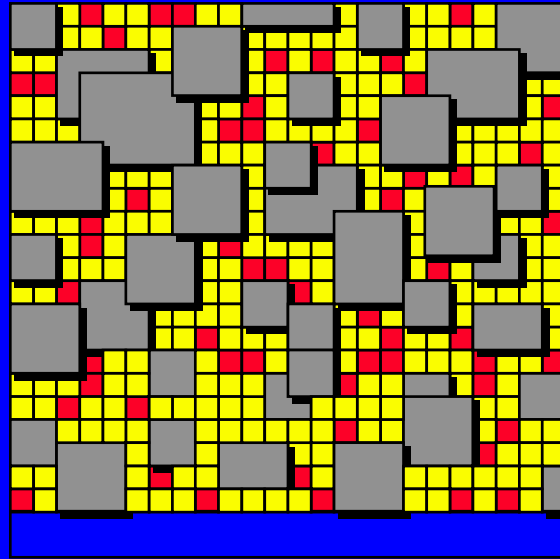
Runoff and Runon






Runon
(mm)

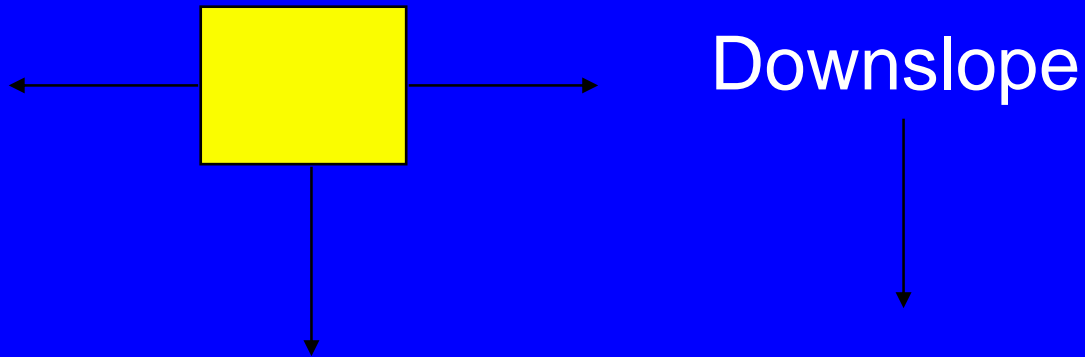
Runoff from bare patches becomes
runon to herbaceous patches





-  Canopy patch with storage.
-  Intercanopy patch with storage.
-  Intercanopy patch with no storage.

Percolation Rules



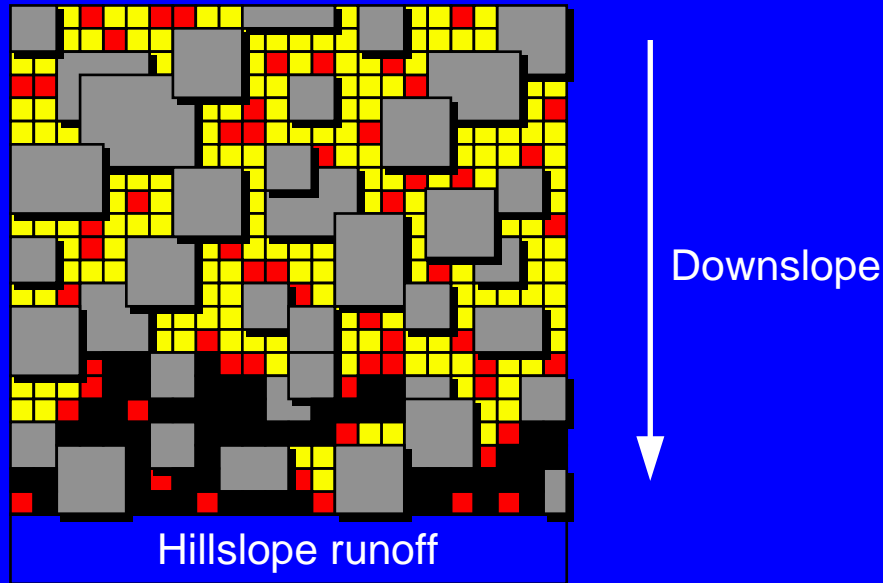
Patch-scale Runoff :

- generated on bare cells.
- redistributed to neighboring lateral or downslope cells.

Hillslope-scale Runoff:

- function of clusters connected to the bottom of slope.

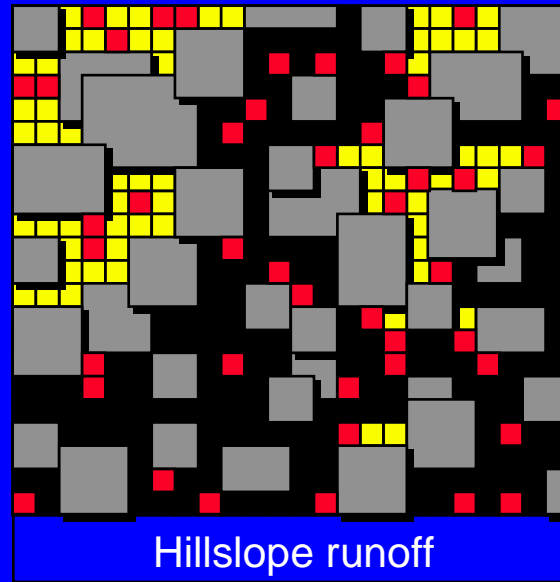
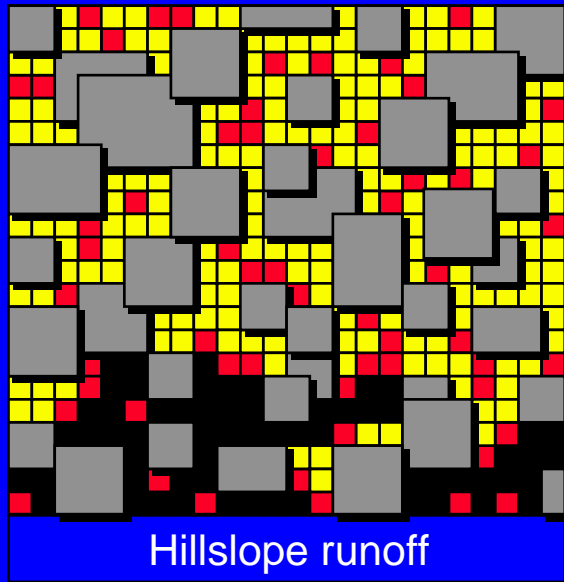
Low connectivity



- Canopy patch with storage.
- Intercanopy patch with storage.
- Intercanopy patch with no storage: no contribution to hillslope runoff.
- Intercanopy patch with no storage: contributes to hillslope runoff.

Low connectivity

High connectivity

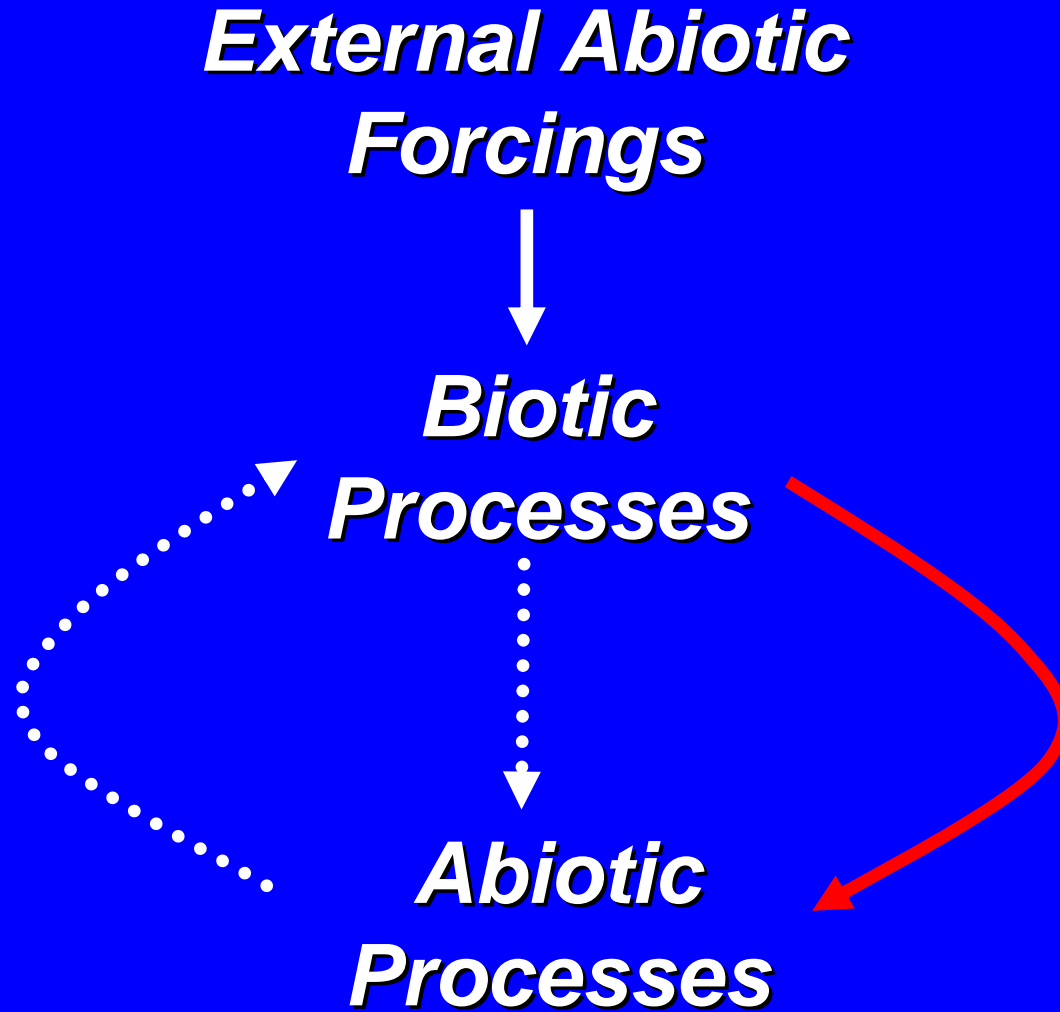


Downslope



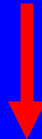
Critical threshold of
bare ground cover
exceeded

Biological Inertia Under Disturbance

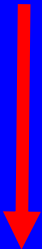


Biological Inertia Under Disturbance

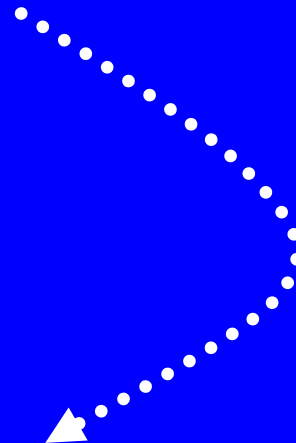
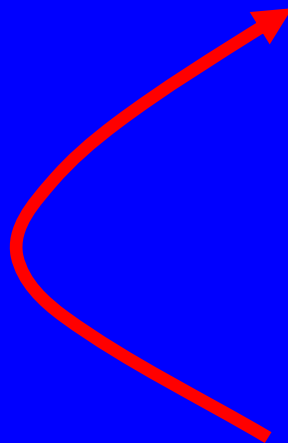
***External Abiotic
Forcings***



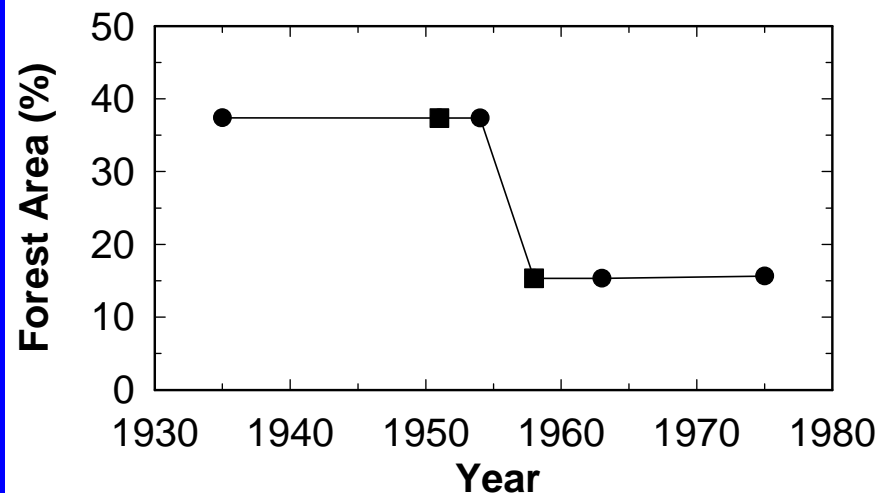
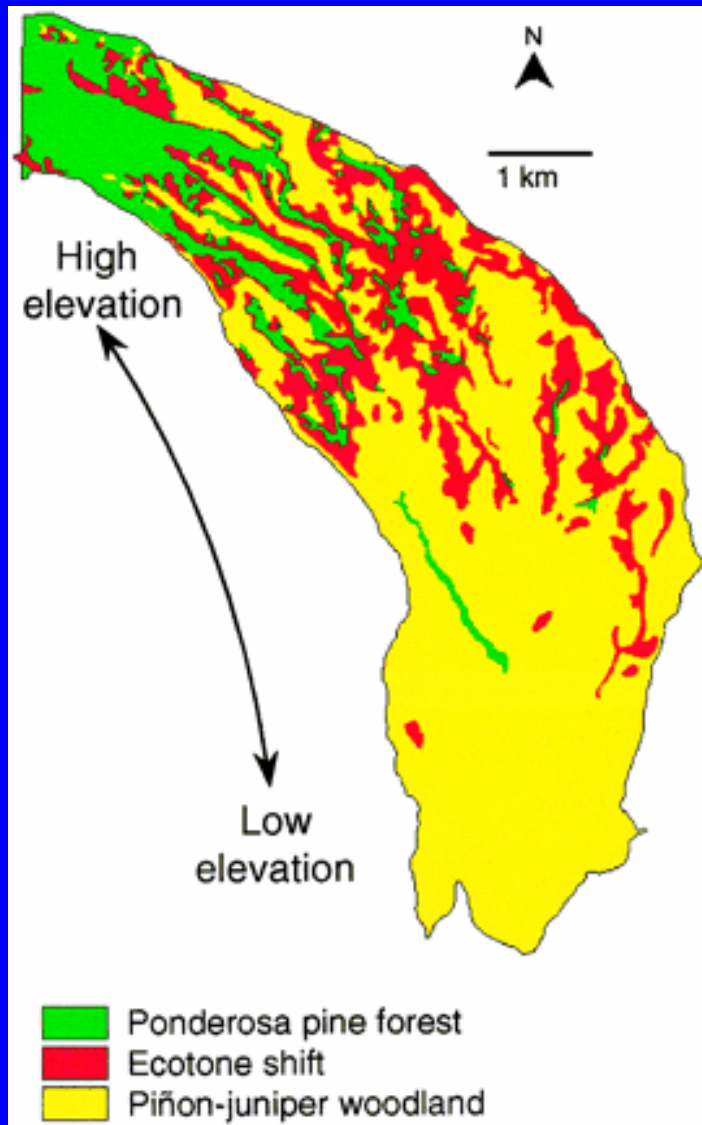
***Biotic
Processes***



***Abiotic
Processes***



Drought-induced Ecotone Shift



Drought-Induced Increases in Erosion



Drought-triggered Tree Mortality



Breshears, Myers & Barnes – in prep.

Drought-triggered Tree Mortality



Breshears, Myers & Barnes – in prep.

Drought-triggered Tree Mortality



Breshears, Myers & Barnes – in prep.



October 2002

Photo: C. D. Allen



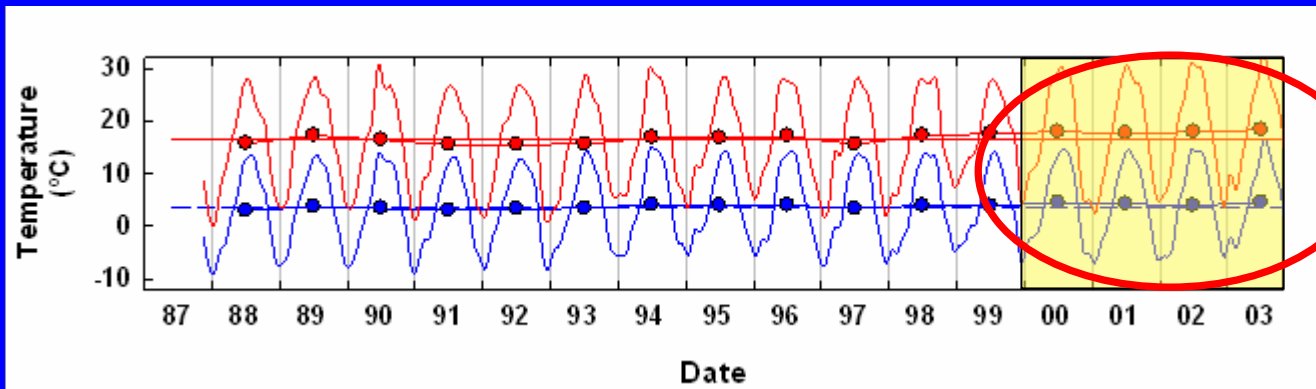
May 2004

Photo: C. D. Allen



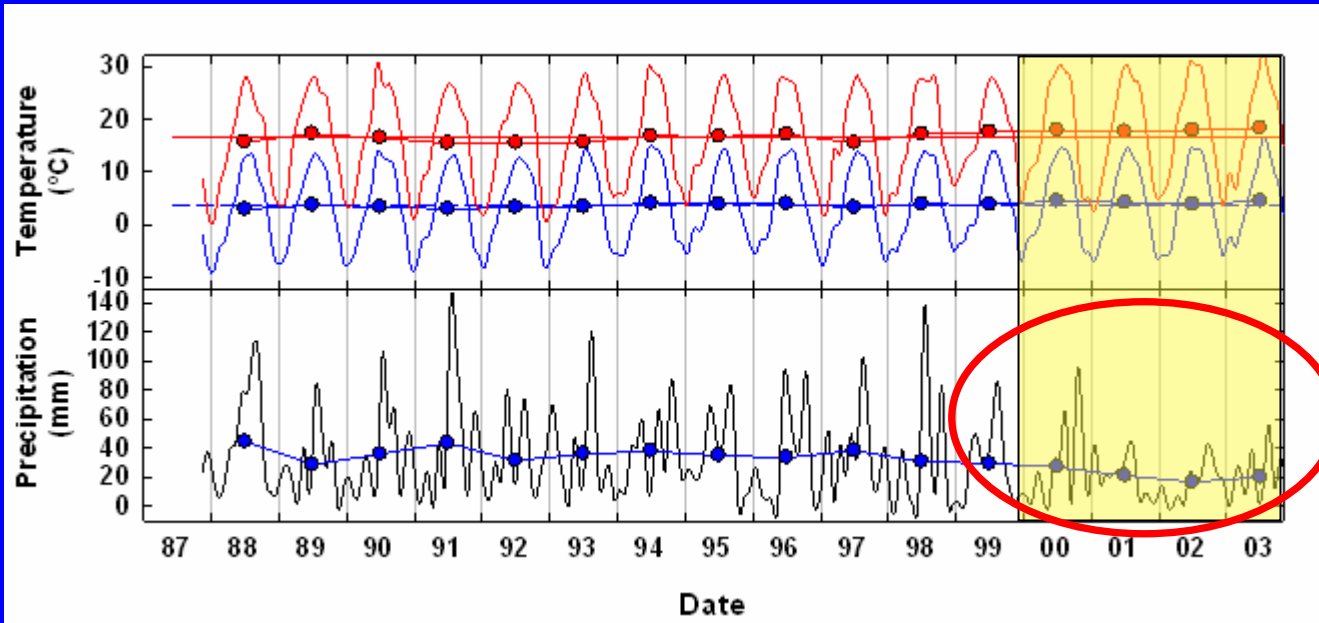
Photo: C. D. Allen

Site-specific Die-off



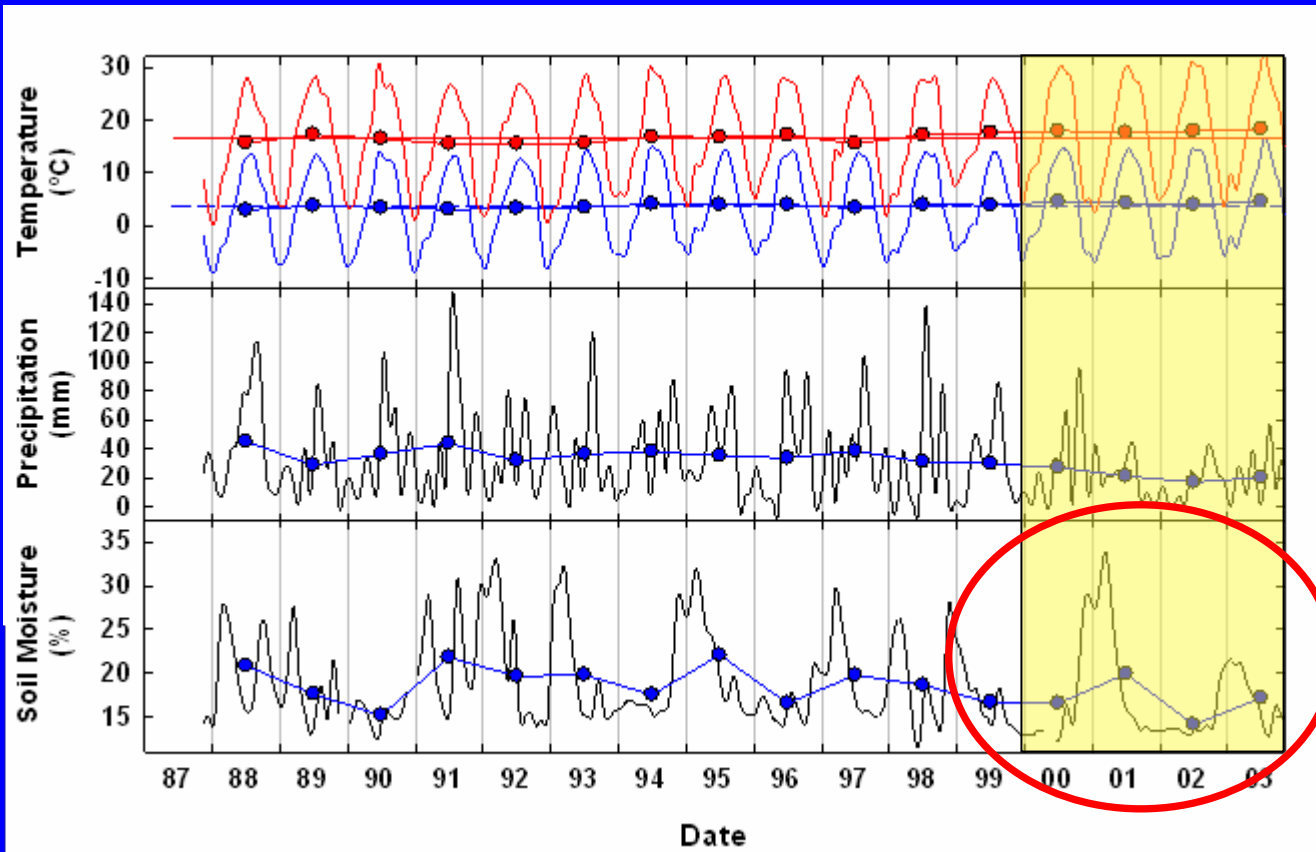
*Warmer
Temperatures*

Site-specific Die-off



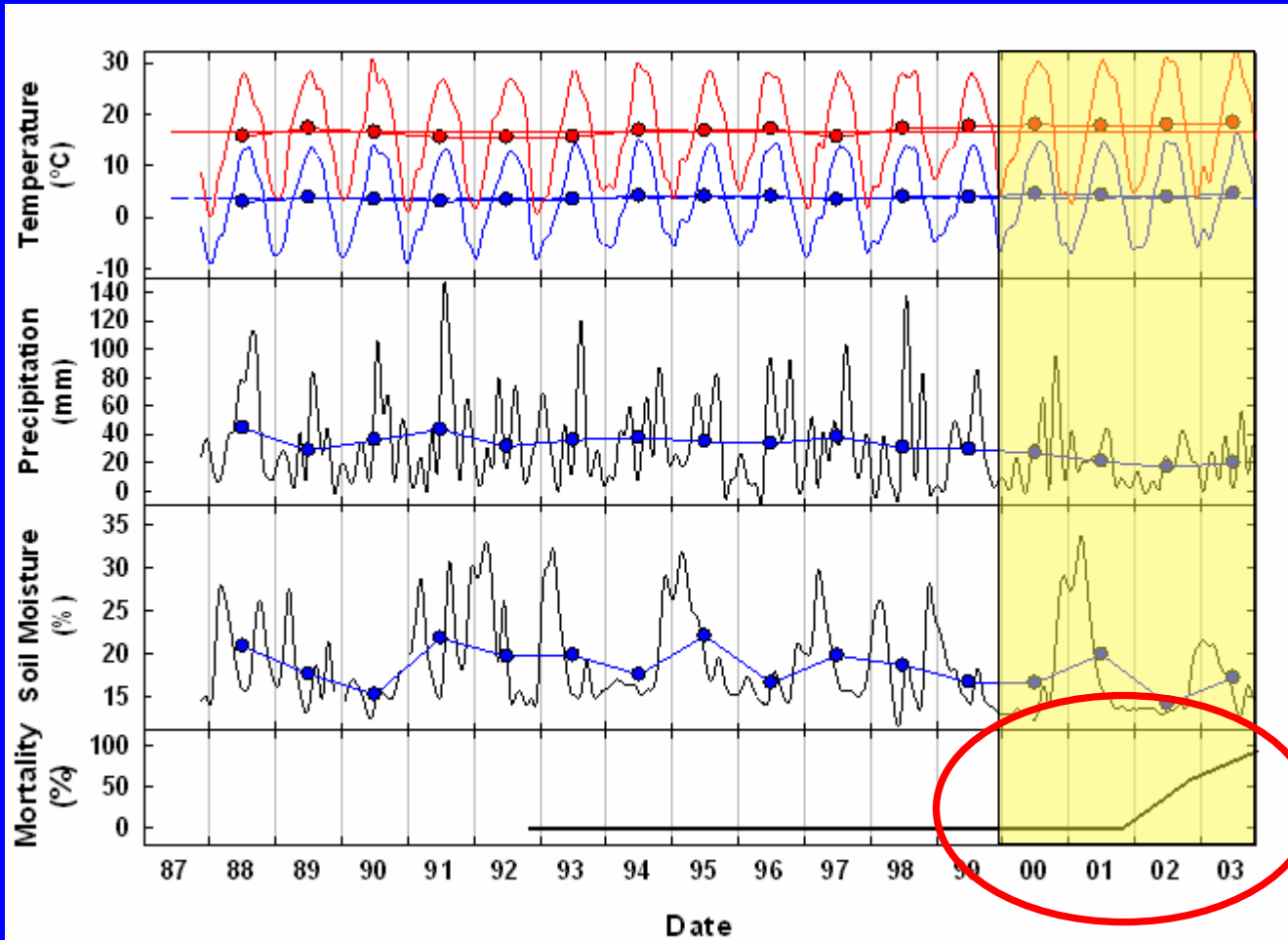
*Reduced
Precipitation*

Site-specific Die-off



*Persistent
Low
Soil Moisture*

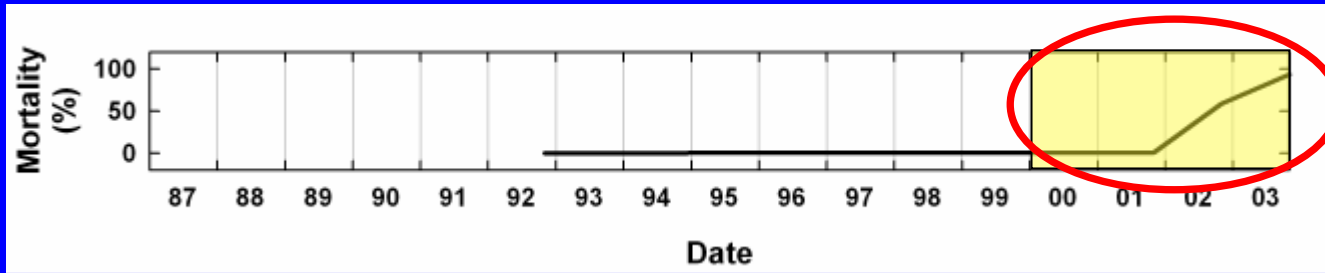
Site-specific Die-off



Bam!

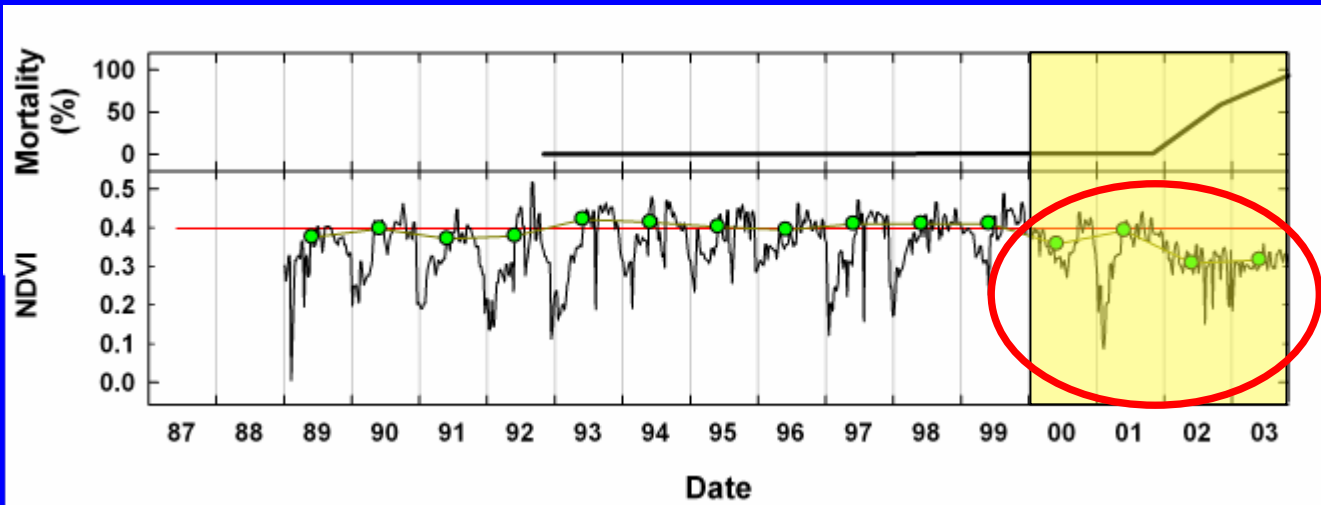
More than
90%
Tree Mortality

Die-off and NDVI



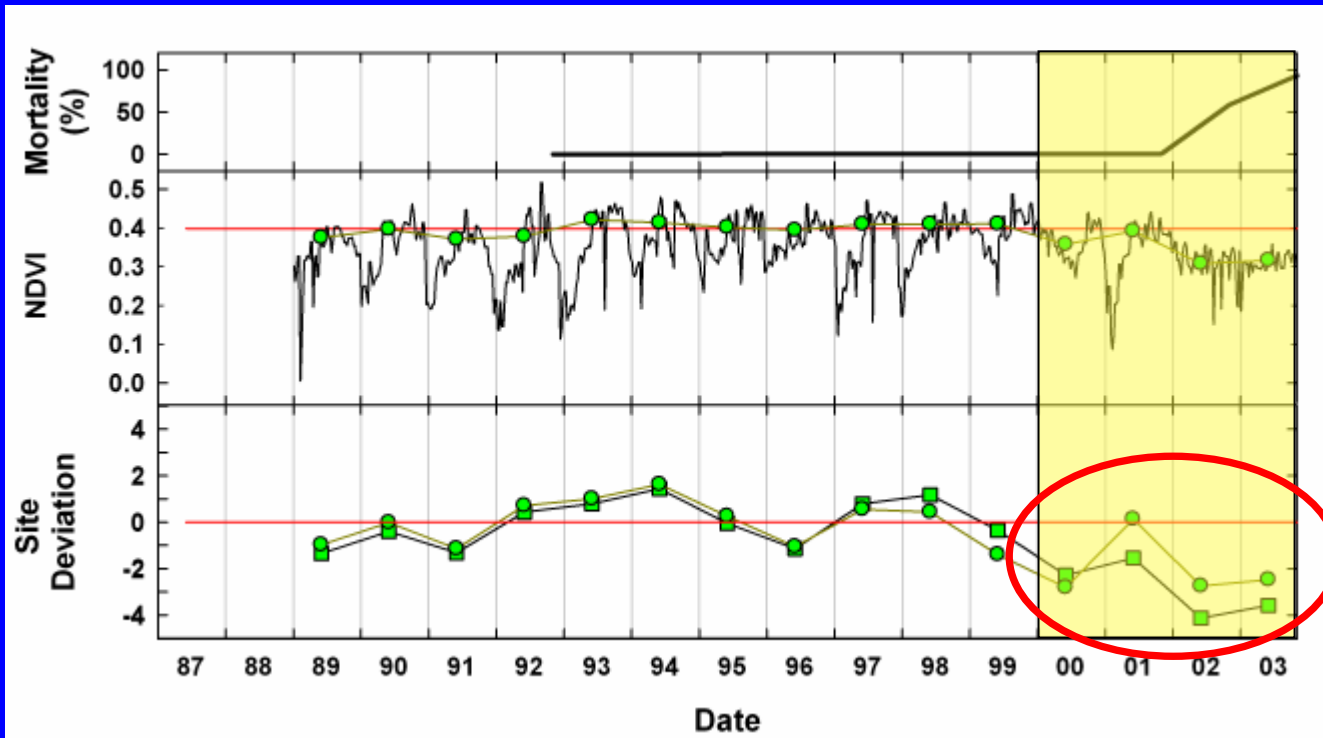
*Increase
in
Mortality*

Die-off and NDVI



*Reduced
NDVI*

Die-off and NDVI



*Reduced
Average NDVI*

Near Flagstaff



Photo: N. S. Cobb

Breshears et al. (2005) Proc. Natl. Acad. Sci.

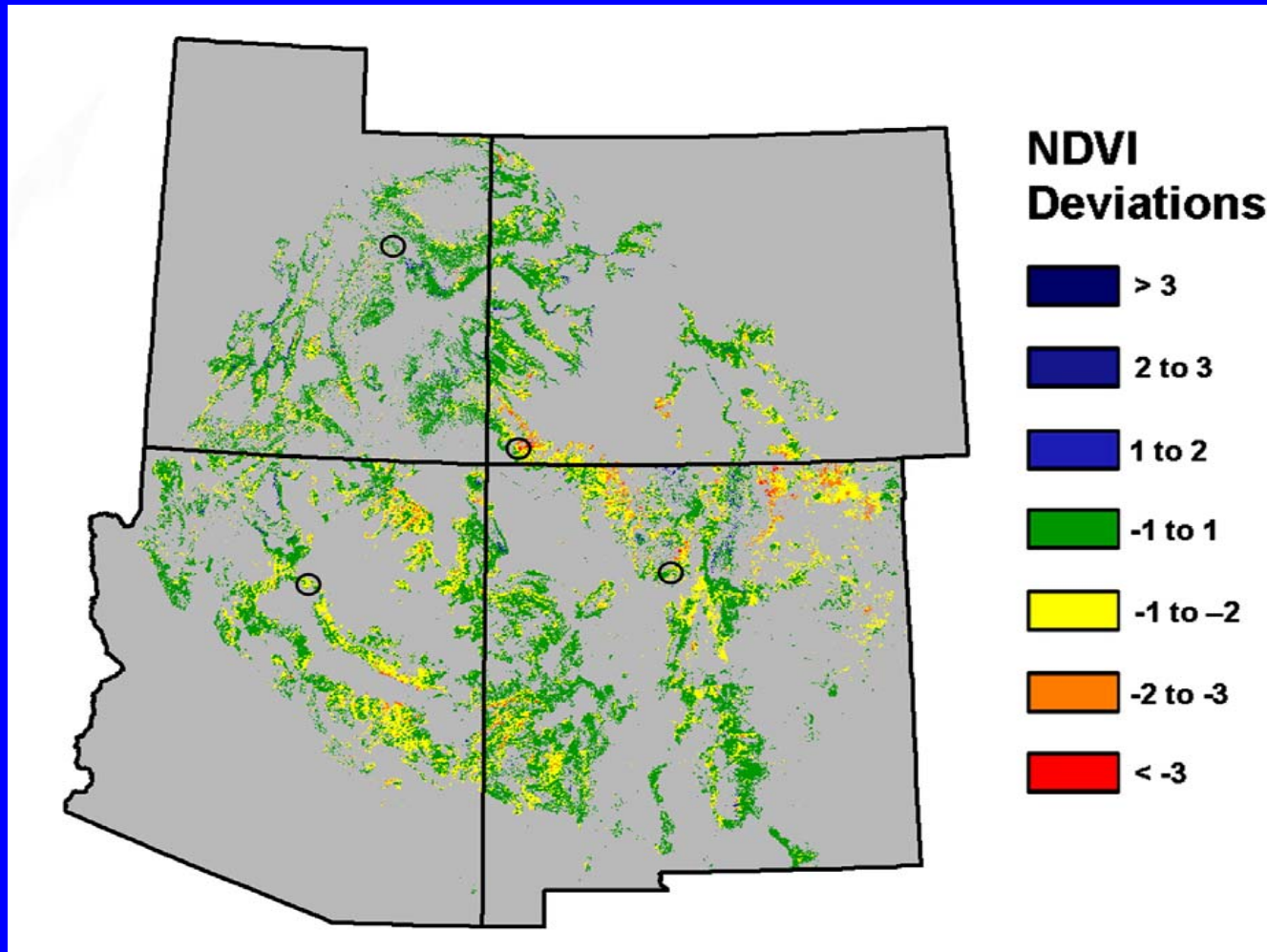
Near Flagstaff



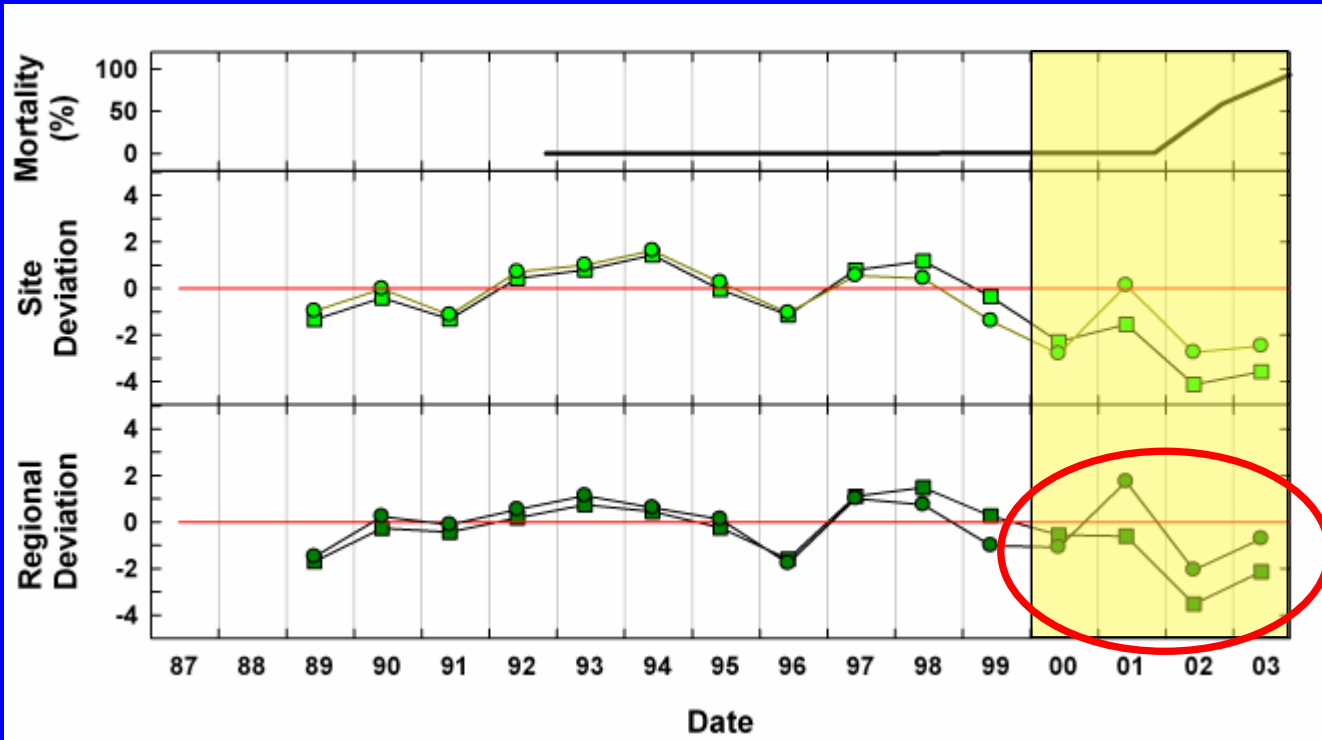
Photo: N. S. Cobb

Breshears et al. (2005) Proc. Natl. Acad. Sci.

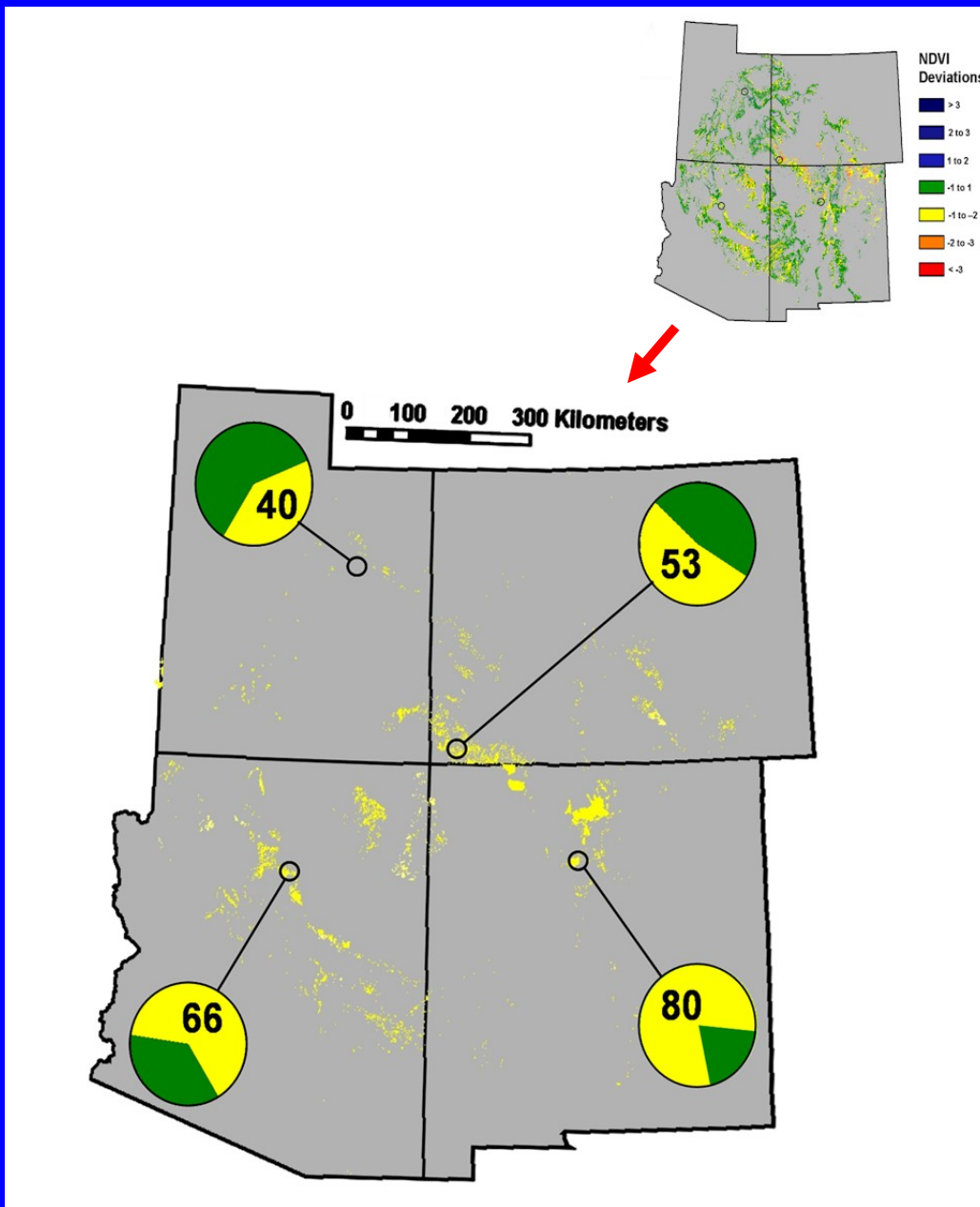
Regional NDVI Change



Die-off and NDVI



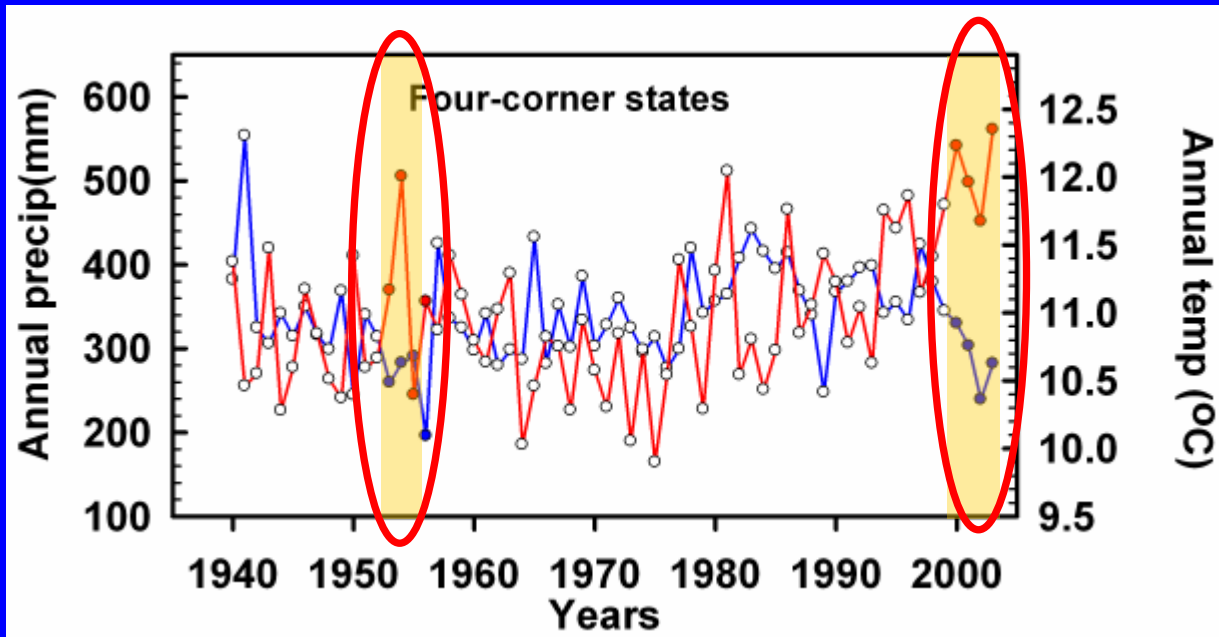
*Reduced
Regional
Average
NDVI*



Verification

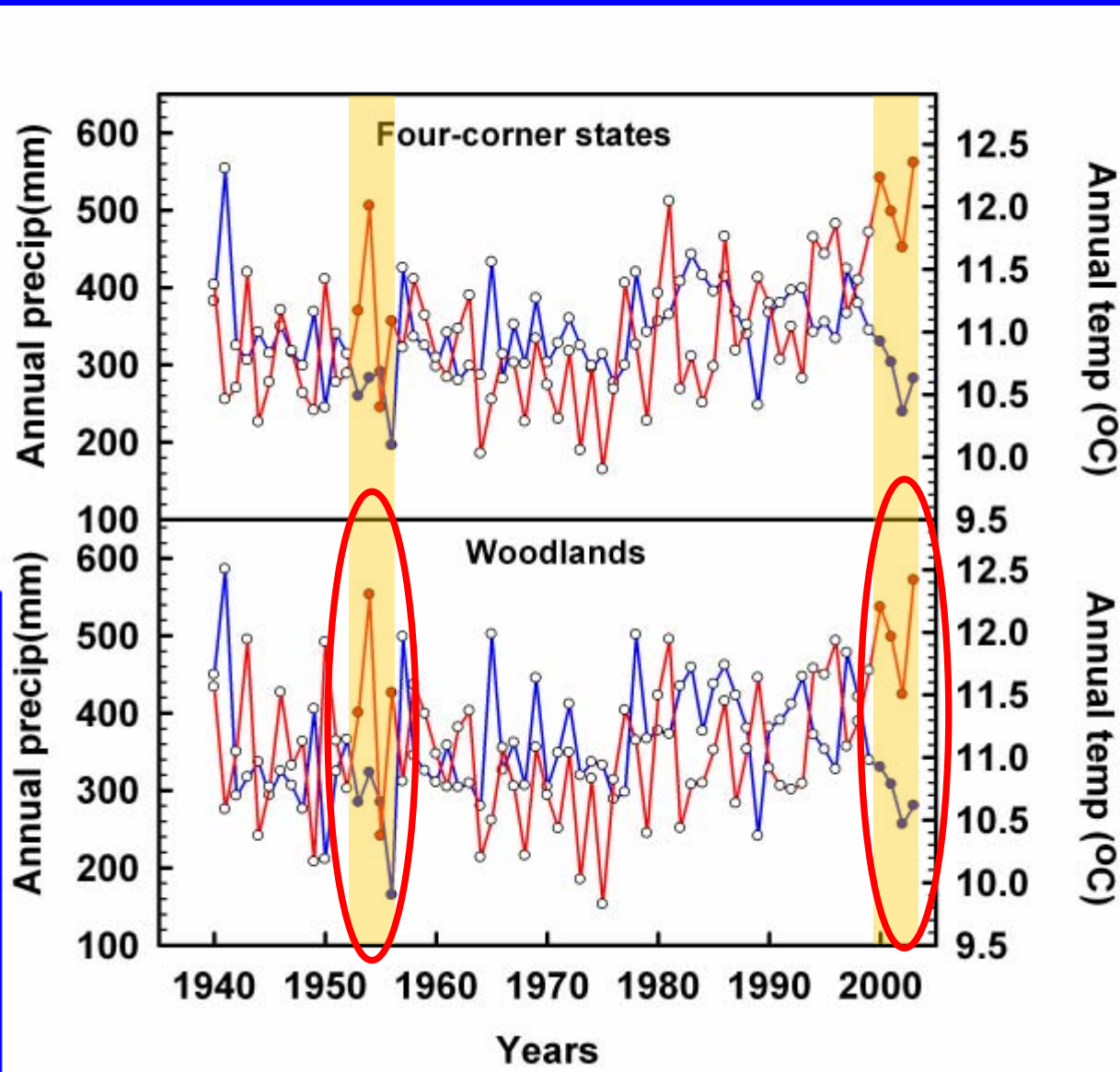
*Aerial surveys
by USGS
and
research plots*

2000s vs. 1950s Drought



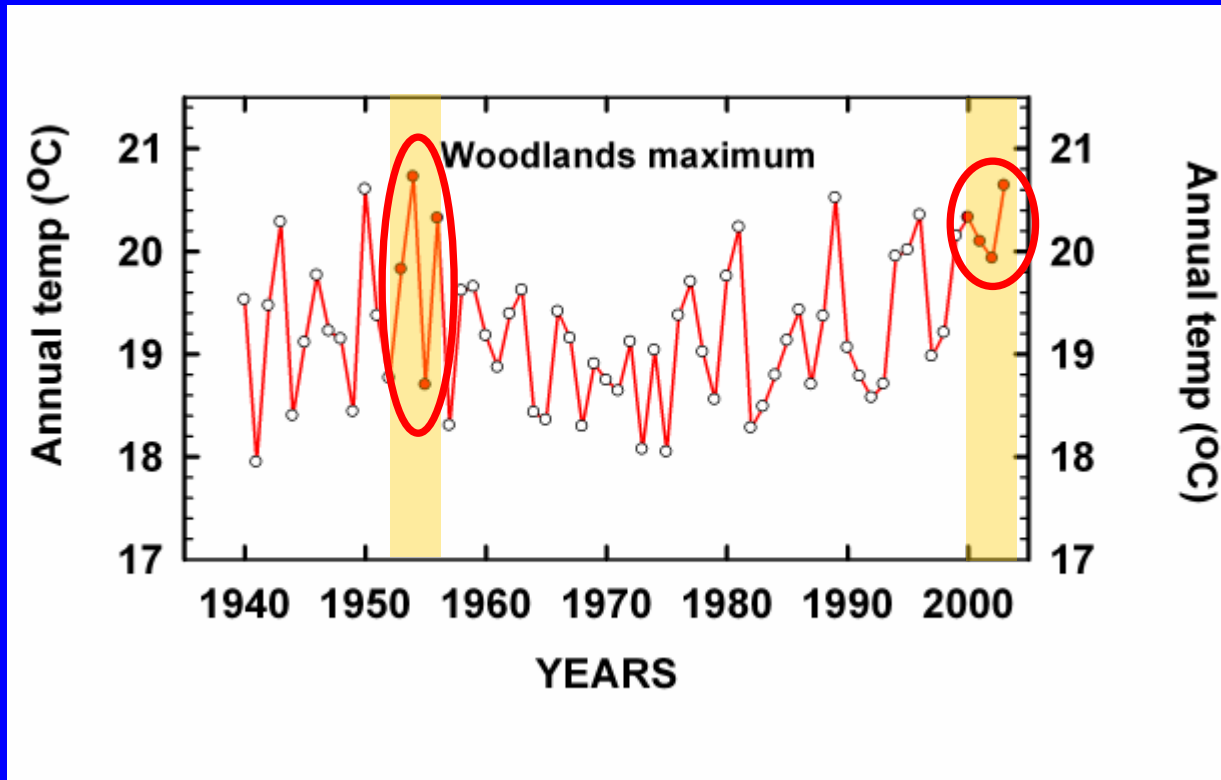
*2000s:
Not drier
but
warmer*

2000s vs. 1950s Drought



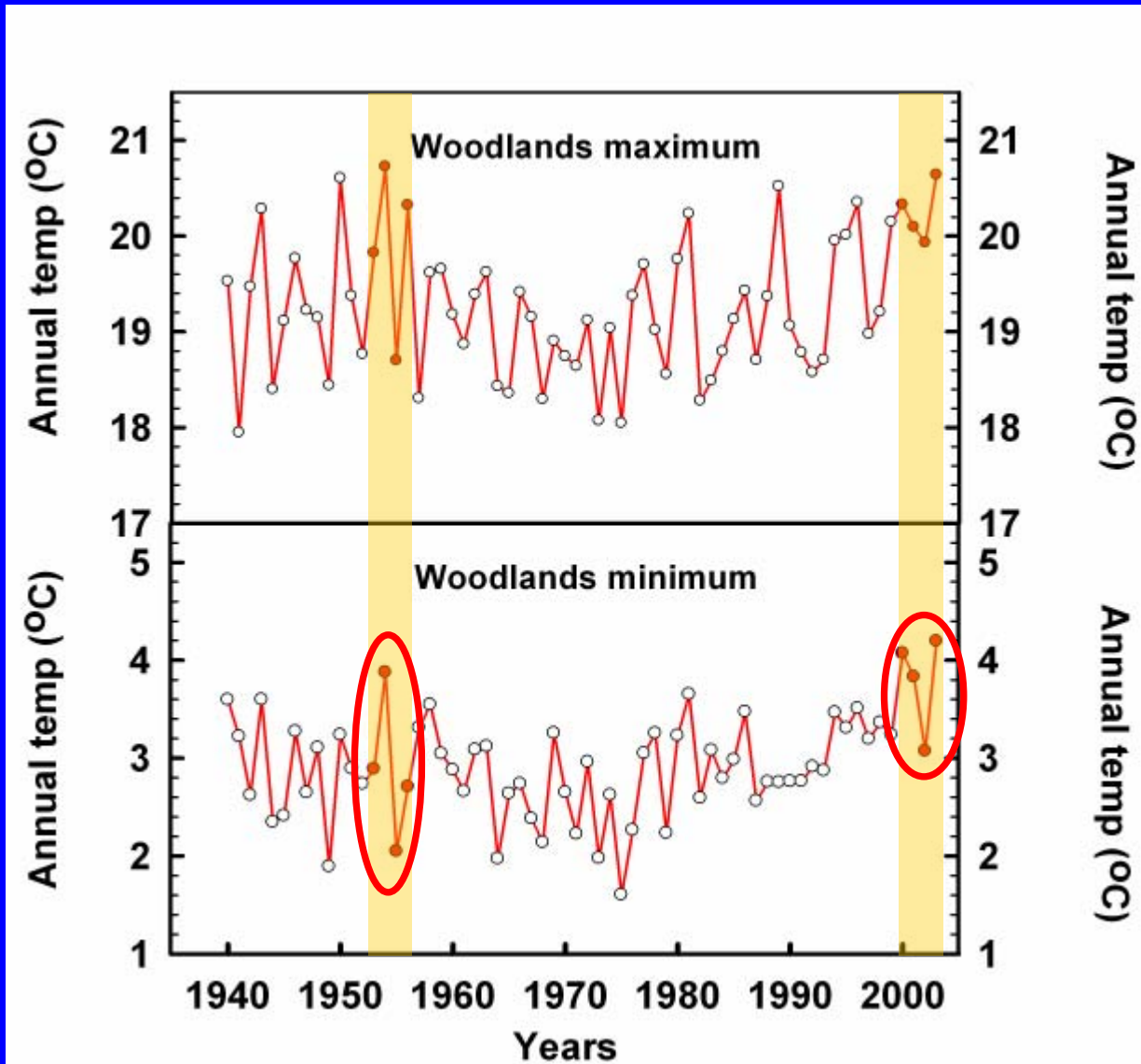
*2000s:
Not drier
but
warmer*

2000s vs. 1950s Drought



*2000s:
Warmer*

2000s vs. 1950s Drought



2000s:
Warmer

Global-change-type Drought



Drought under warmer conditions

Global-change-type Drought



Drought under warmer conditions

Mortality through wetter sites rather than just at drier ecotones

Global-change-type Drought



Drought under warmer conditions

Mortality through wetter sites rather than just at drier ecotones

Regional-scale threshold response

Ecosystem Cascades

*Ponderosa Pine
Forest*

Ecosystem Cascades

*Ponderosa Pine
Forest*



```
graph TD; A["Ponderosa Pine Forest"] --> B["Pinyon-Juniper Woodland"]
```

The diagram illustrates an ecosystem cascade. It starts with a dark green box containing the text "Ponderosa Pine Forest". A red arrow points downwards from this box to a light green box containing the text "Pinyon-Juniper Woodland".

*Pinyon-Juniper
Woodland*

Ecosystem Cascades

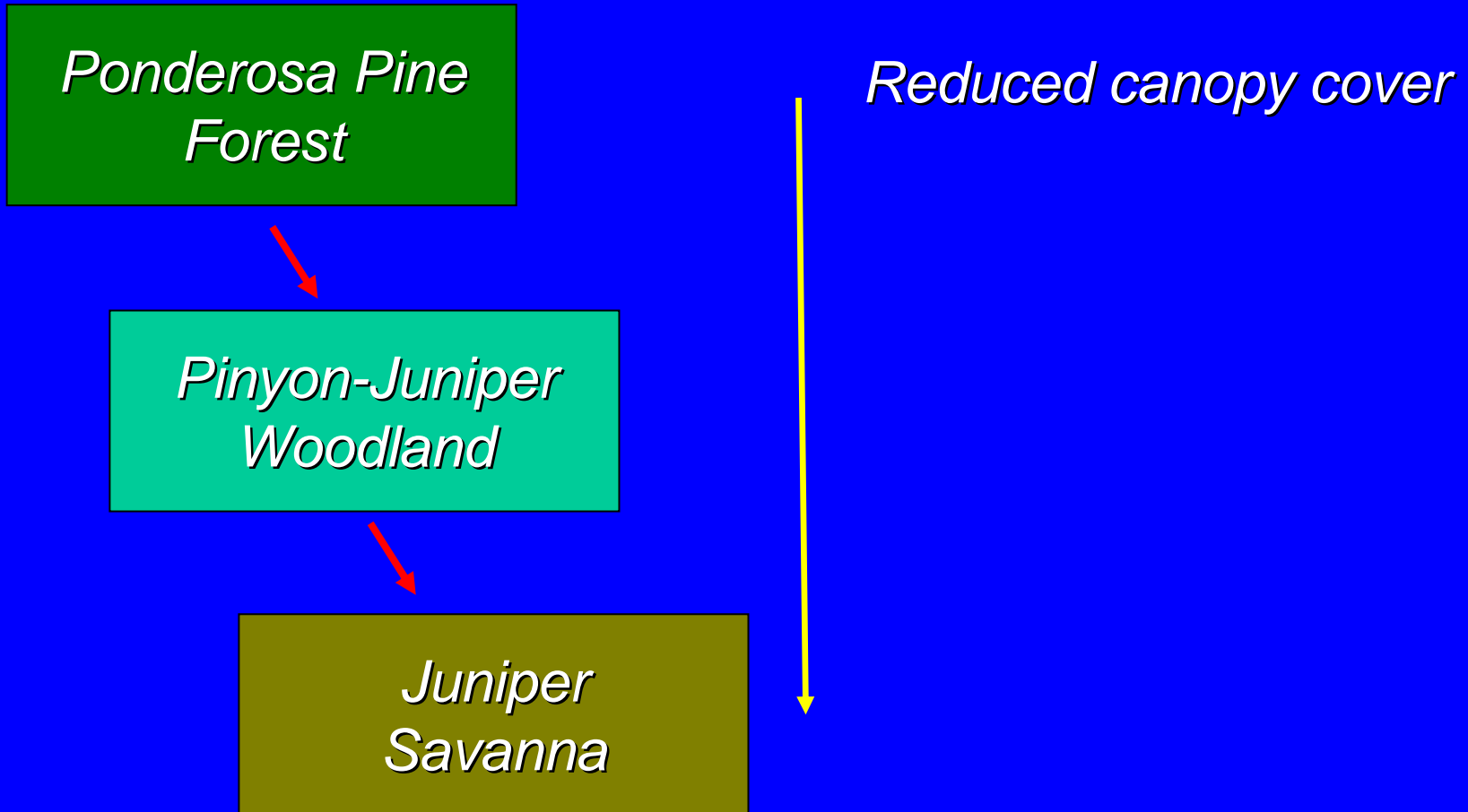
*Ponderosa Pine
Forest*

```
graph TD; A["Ponderosa Pine Forest"] --> B["Pinyon-Juniper Woodland"]; B --> C["Juniper Savanna"];
```

*Pinyon-Juniper
Woodland*

*Juniper
Savanna*

Ecosystem Cascades



Ecosystem Cascades

*Ponderosa Pine
Forest*



*Pinyon-Juniper
Woodland*



*Juniper
Savanna*

Reduced canopy cover

Reduced herbaceous cover



Ecosystem Cascades

*Ponderosa Pine
Forest*



*Pinyon-Juniper
Woodland*



*Juniper
Savanna*

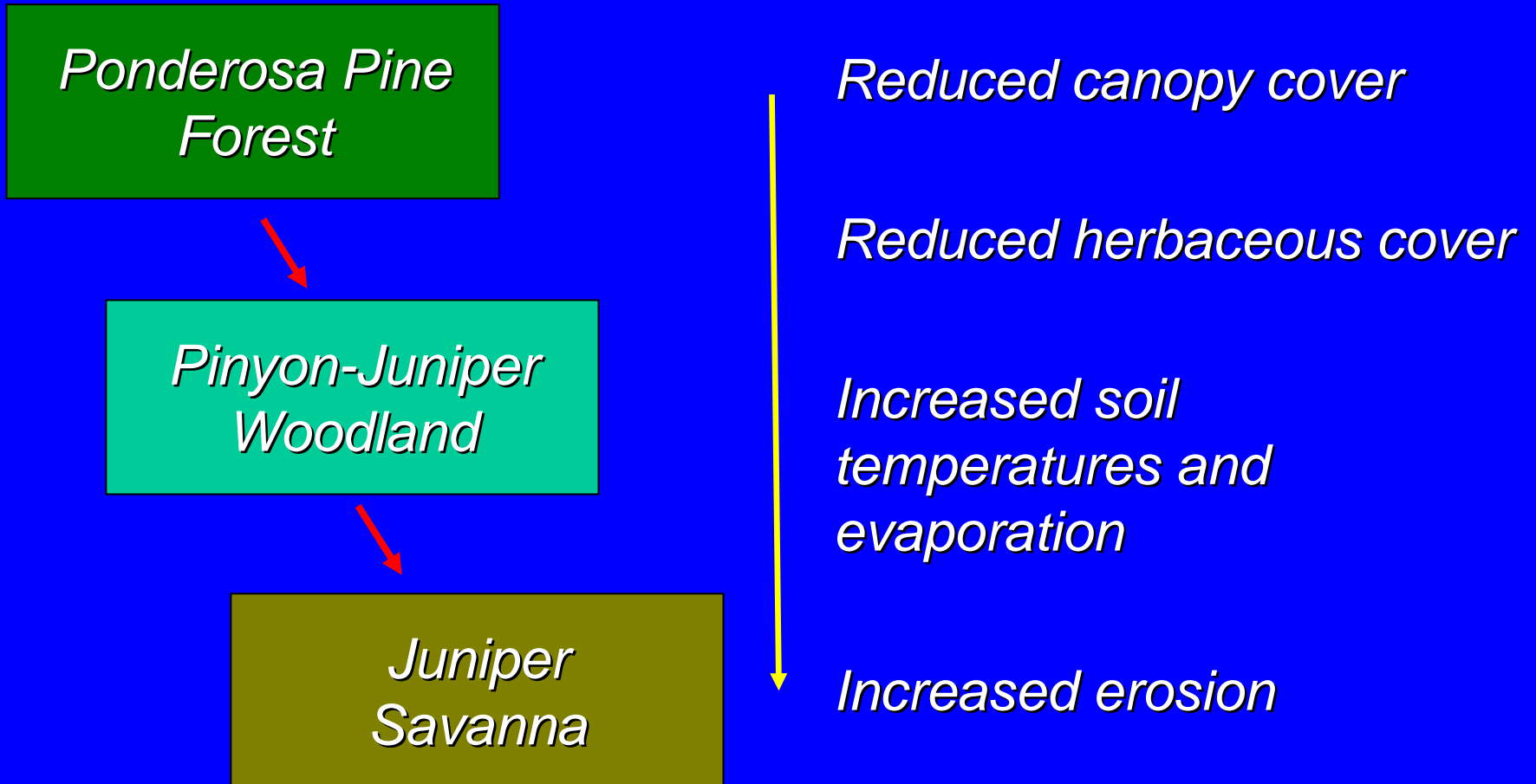
Reduced canopy cover

Reduced herbaceous cover

*Increased soil
temperatures and
evaporation*



Ecosystem Cascades



How does vegetation change?

