Wildland Fire in SW Riparian Areas and the Tamarisk Beetle

Gail M. Drus, Ph.D.
Associate Professor of Biology and Environmental Studies
Saint Francis University

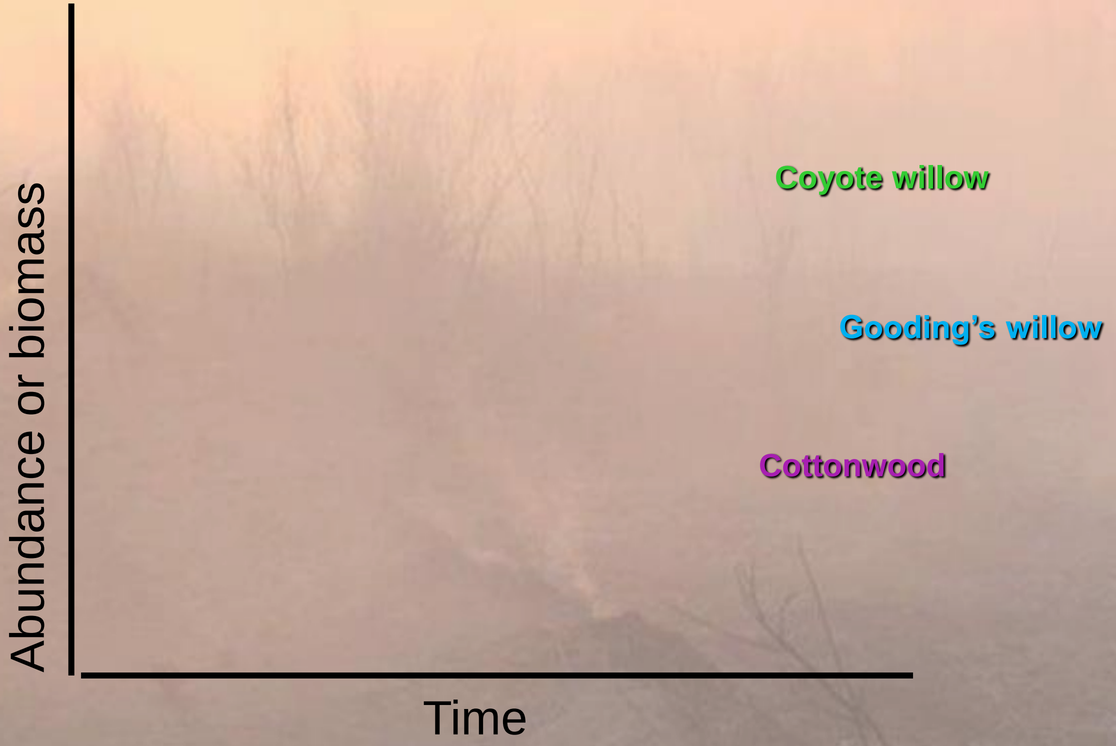
Co-authors:
Tom Dudley, Carla D'Antonio, Matt Brooks
JR Matchett, Thomas Even, James Tracy and others

Desert riparian ecosystems

- **Ecologically and economically valuable**
  - High diversity and productivity
  - Wildlife habitat
  - Water resources

Native gallery forests are adapted to cyclical flooding disturbance

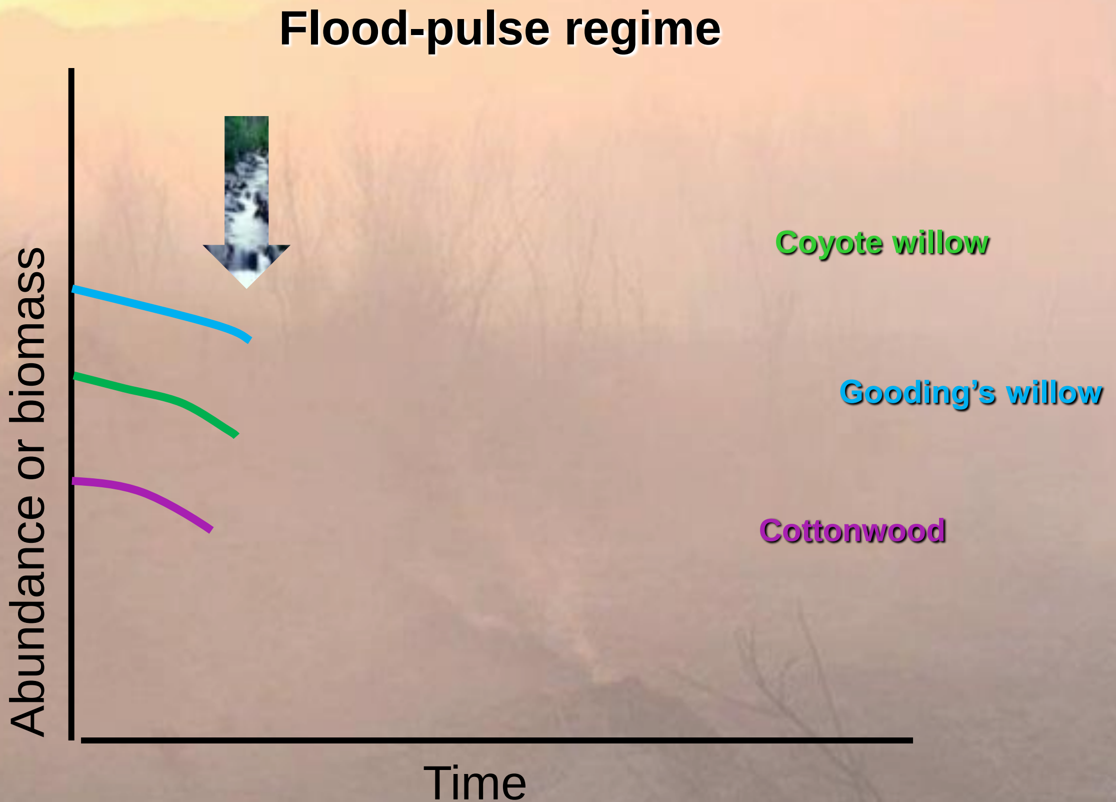
Flood-pulse regime



Rood et al. 2005

- **Flooding regime ➔ community structure**

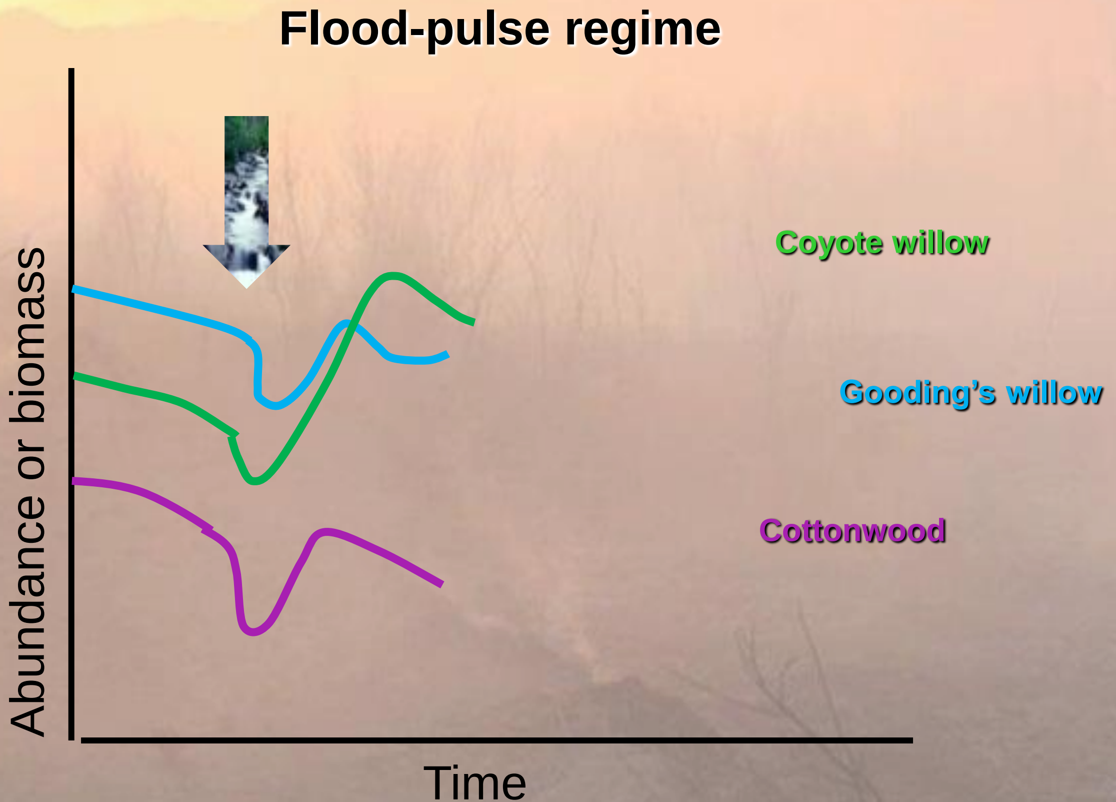
Native gallery forests are adapted to cyclical flooding disturbance



Rood et al. 2005

- Flooding regime ➔ community structure

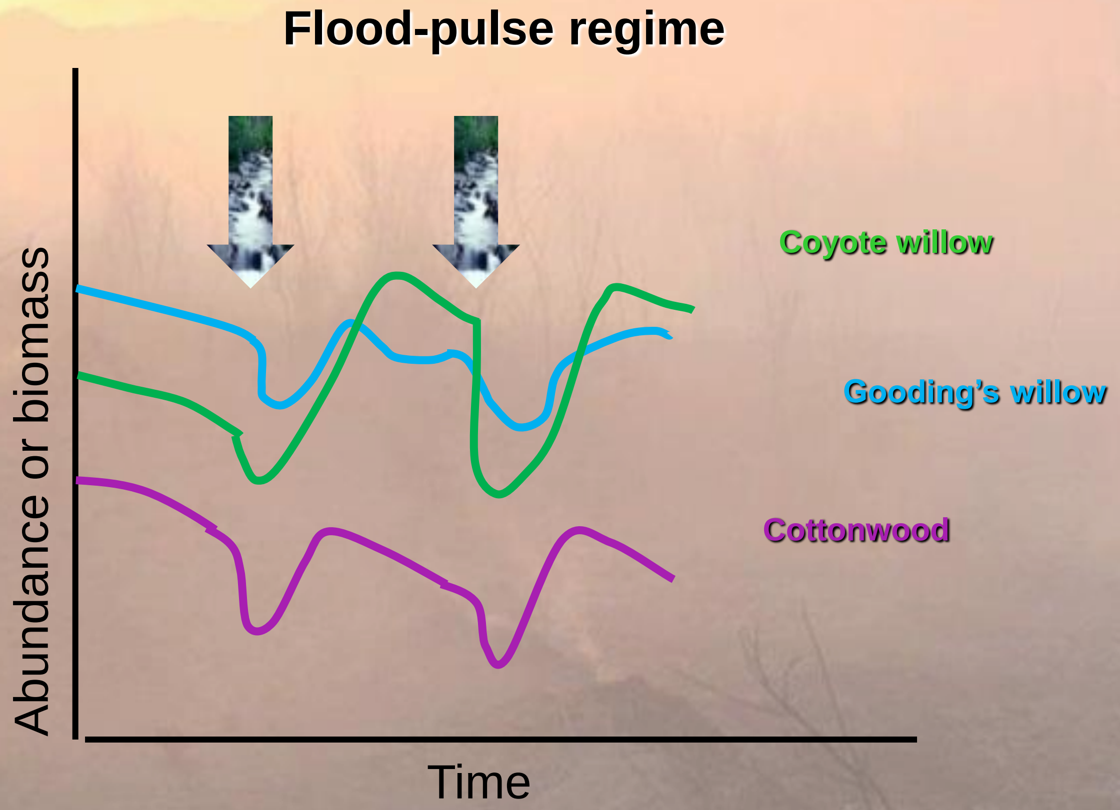
Native gallery forests are adapted to cyclical flooding disturbance



Rood et al. 2005

- **Flooding regime → community structure**

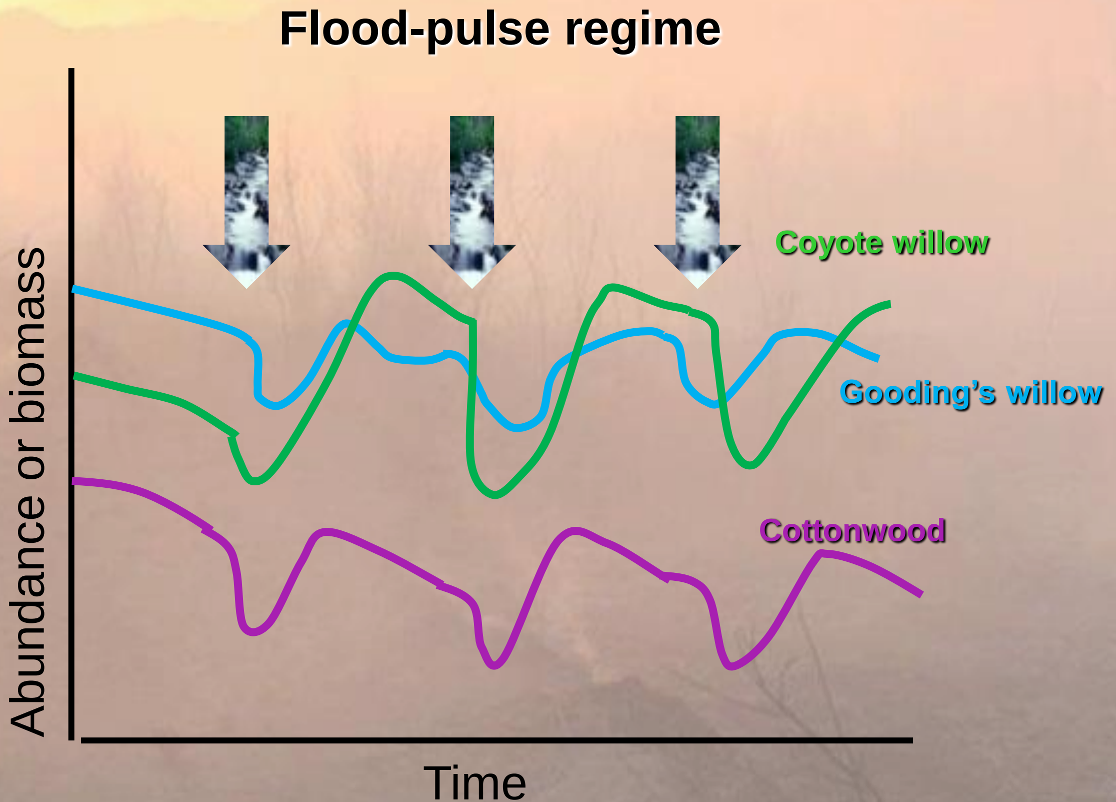
Native gallery forests are adapted to cyclical flooding disturbance



Rood et al. 2005

- **Flooding regime → community structure**

Native gallery forests are adapted to cyclical flooding disturbance



Rood et al. 2005

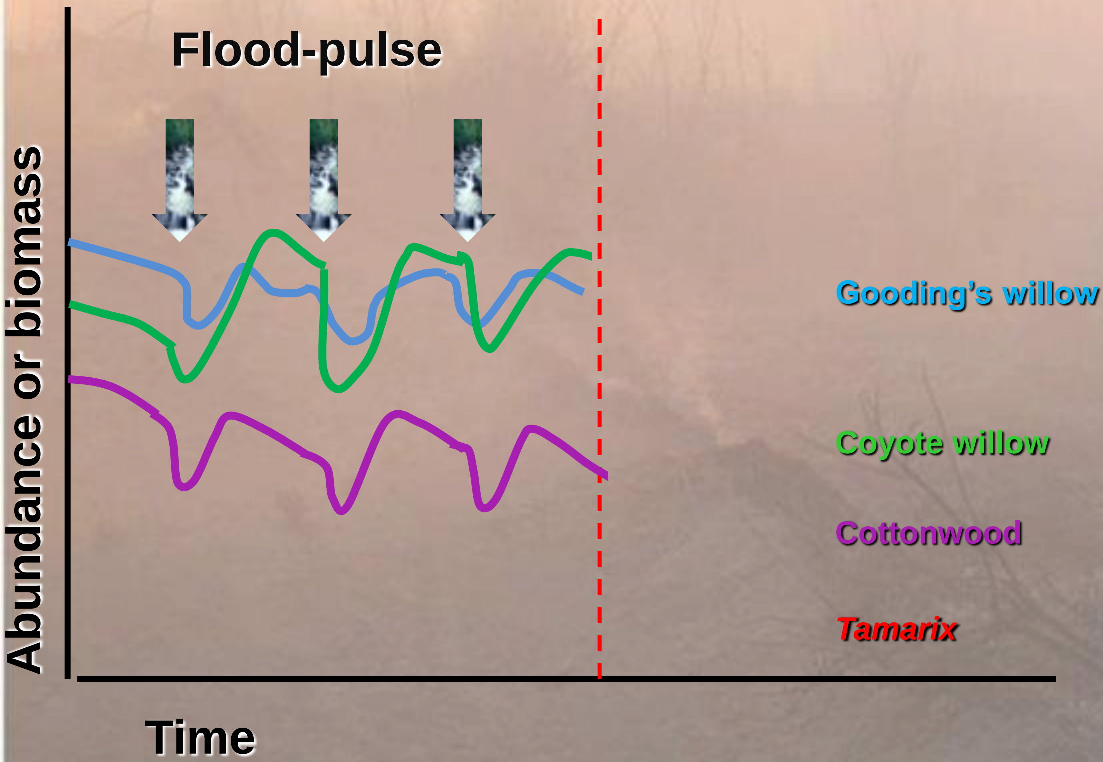
- **Flooding regime → community structure**

Human activities have modified desert riparian ecosystems

Rood et al. 2005

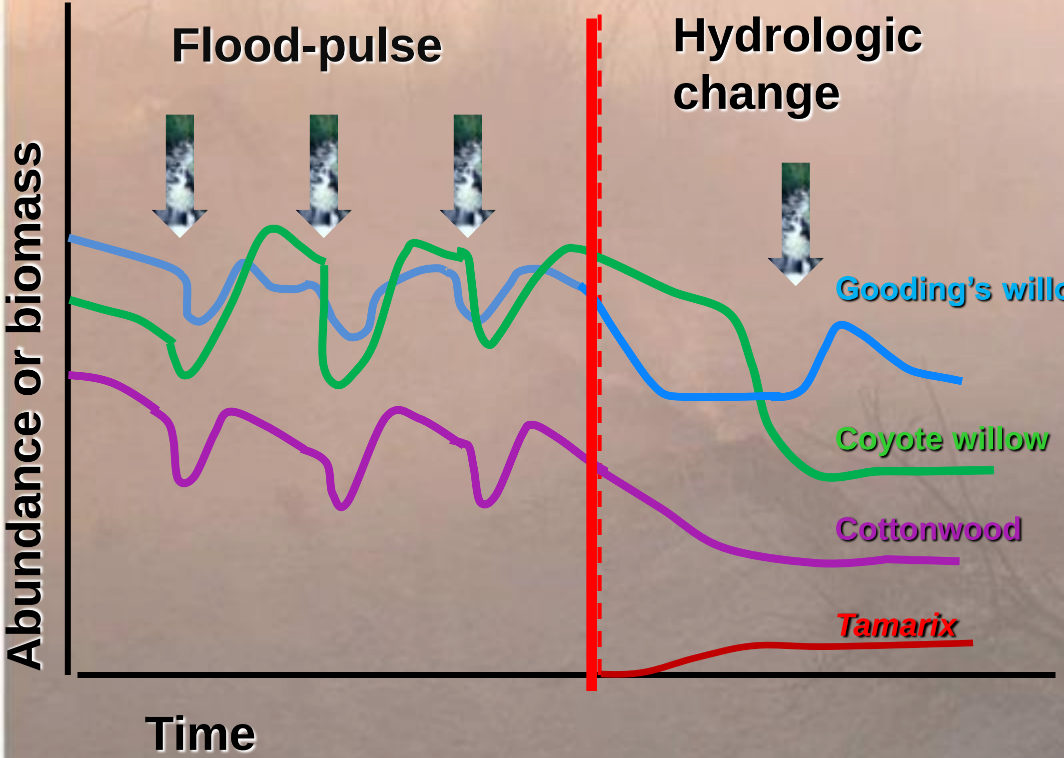
- **Human disturbance, invasion and climate change**
  ➔ changes in ecosystem structure and function

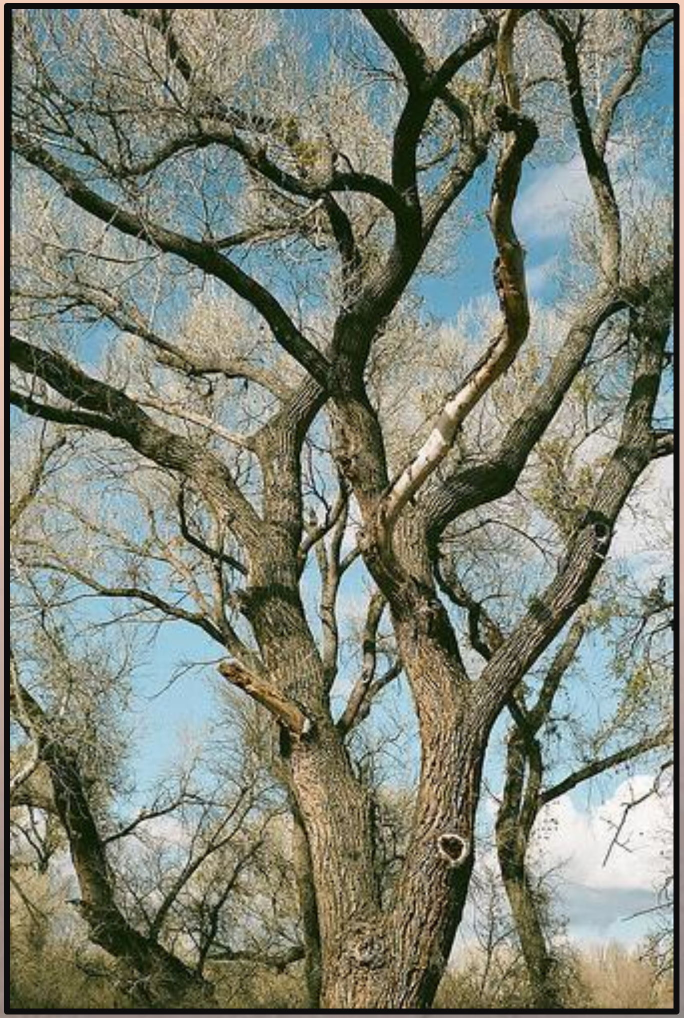
Hydrologic modifications alter flooding regimes and community composition



Populus decline

Hydrologic modifications alter flooding regimes and community composition

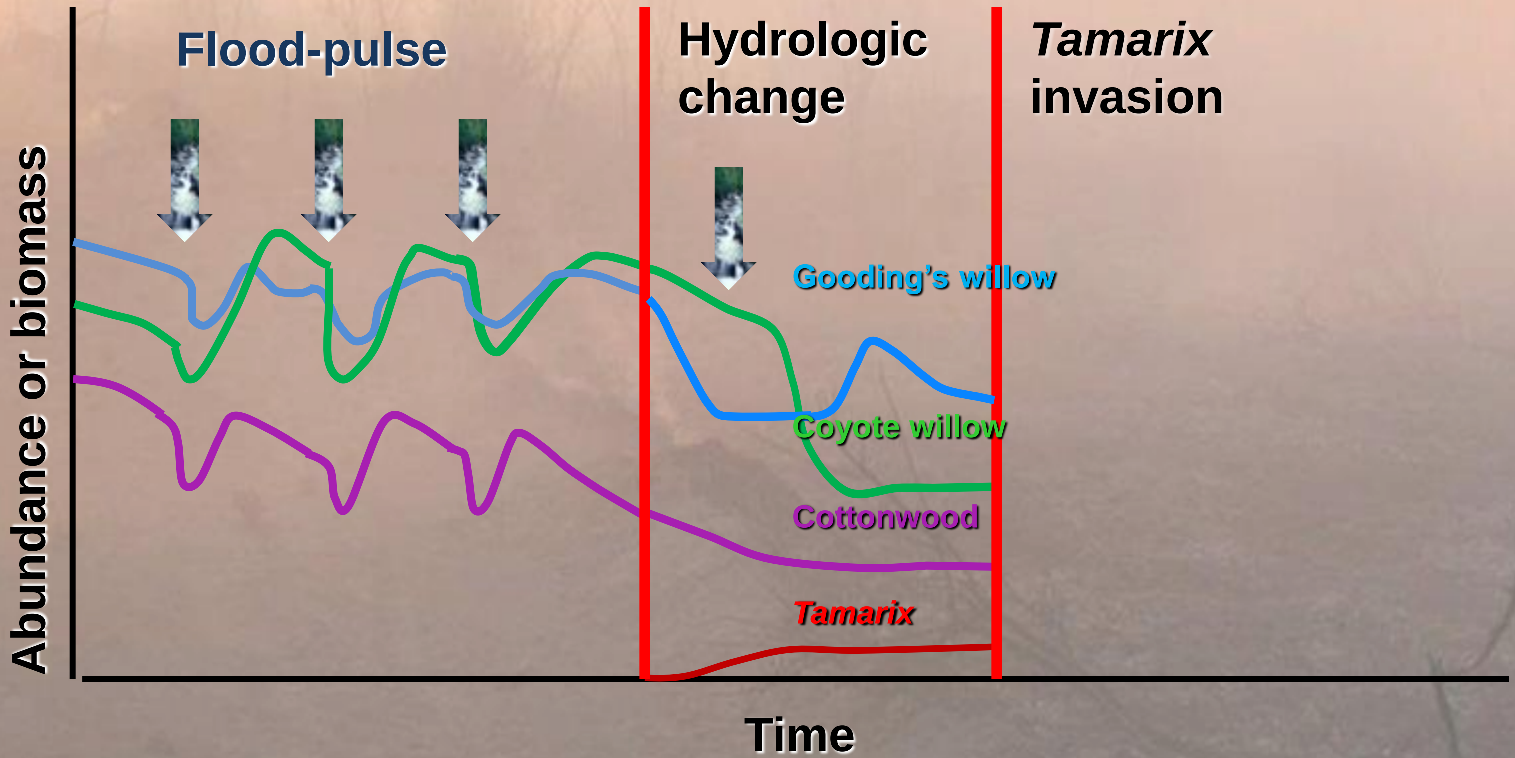




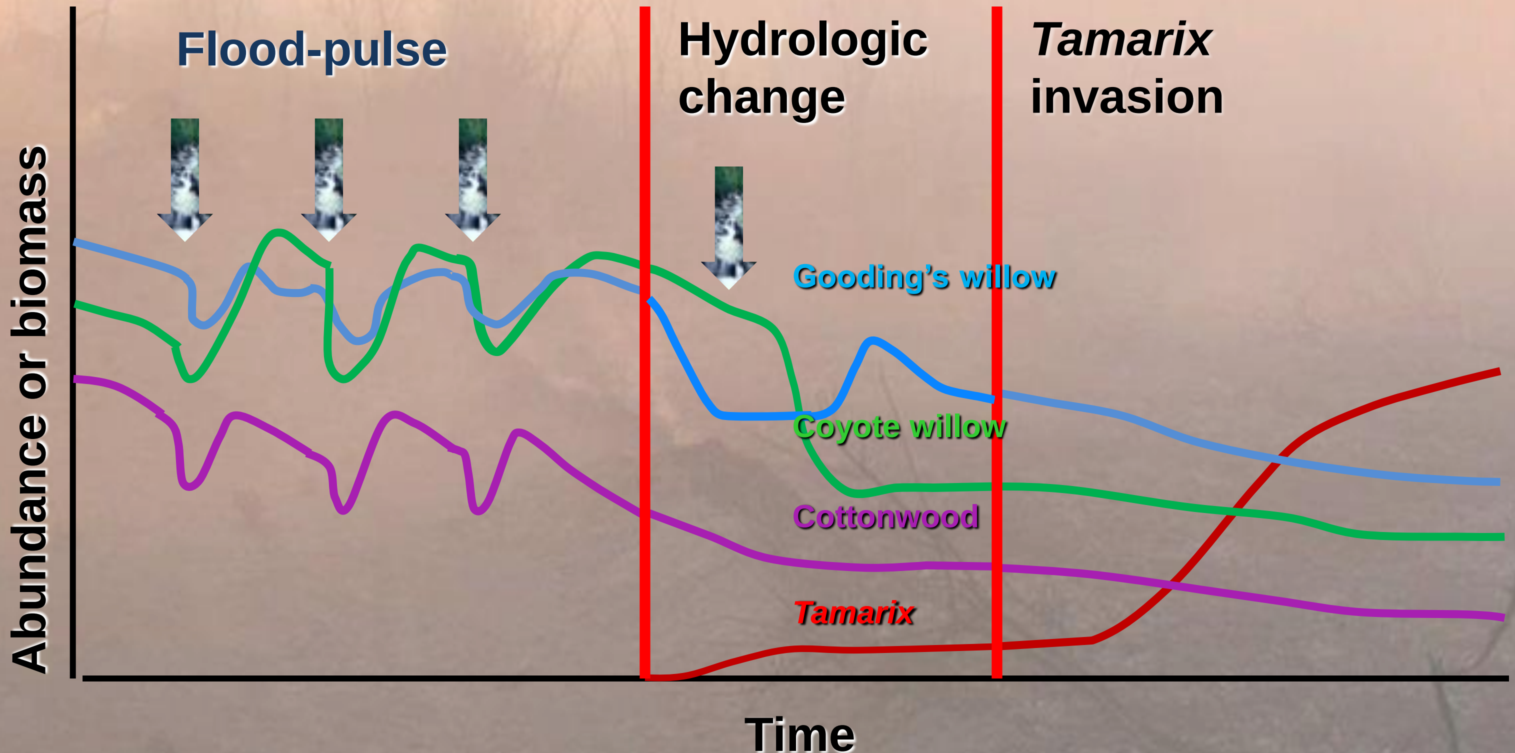
Populus decline

Tamarix invasion

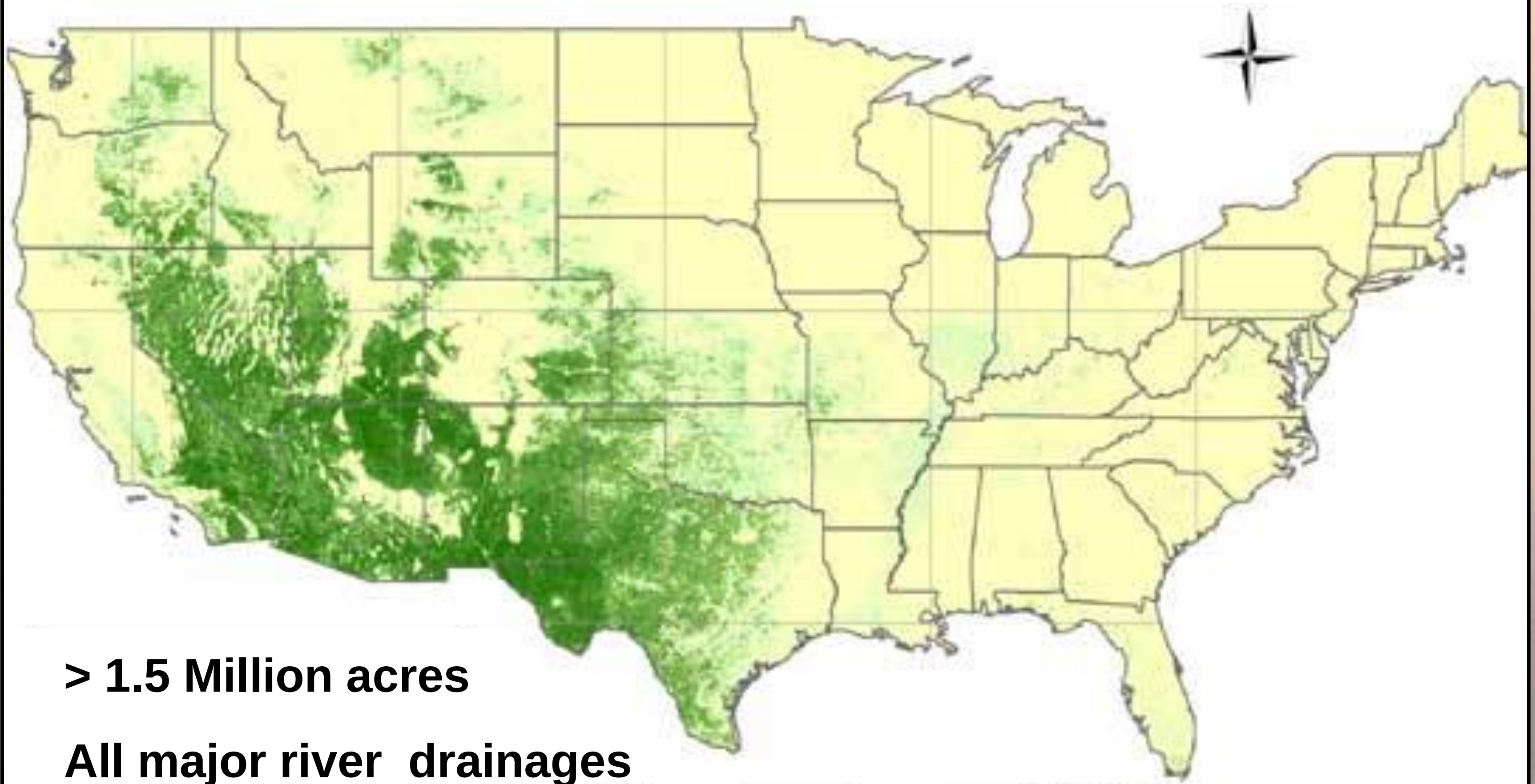
Altered flooding regimes promote *Tamarix* invasion and dominance



Altered flooding regimes promote *Tamarix* invasion and dominance



Tamarix invasion



> 1.5 Million acres

All major river drainages

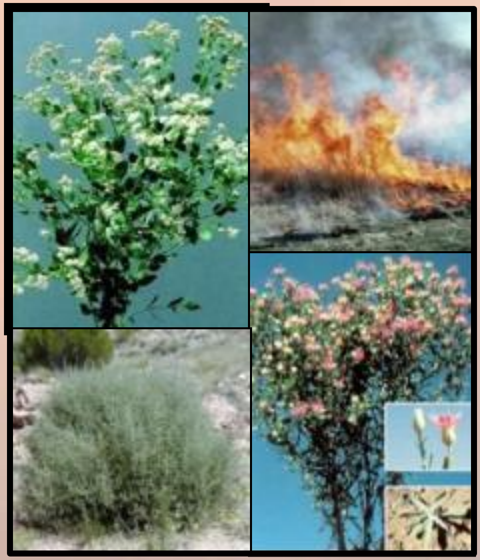
W of Mississippi

Impacts of *Tamarix* invasion are well documented



- **Habitat degradation**
- **Soil degradation and groundwater depletion**
- **Secondary invaders**

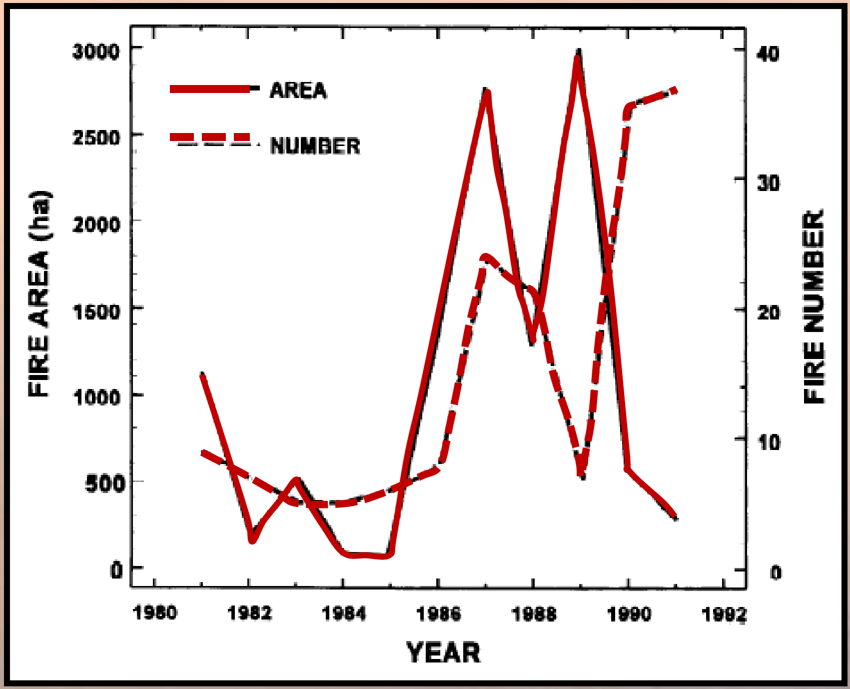
Impacts of *Tamarix* invasion are well documented



- **Habitat degradation**
- **Soil degradation and groundwater depletion**
- **Secondary invaders**
- **Increased wildfire risk**

Riparian fire has increased with *Tamarix* invasion

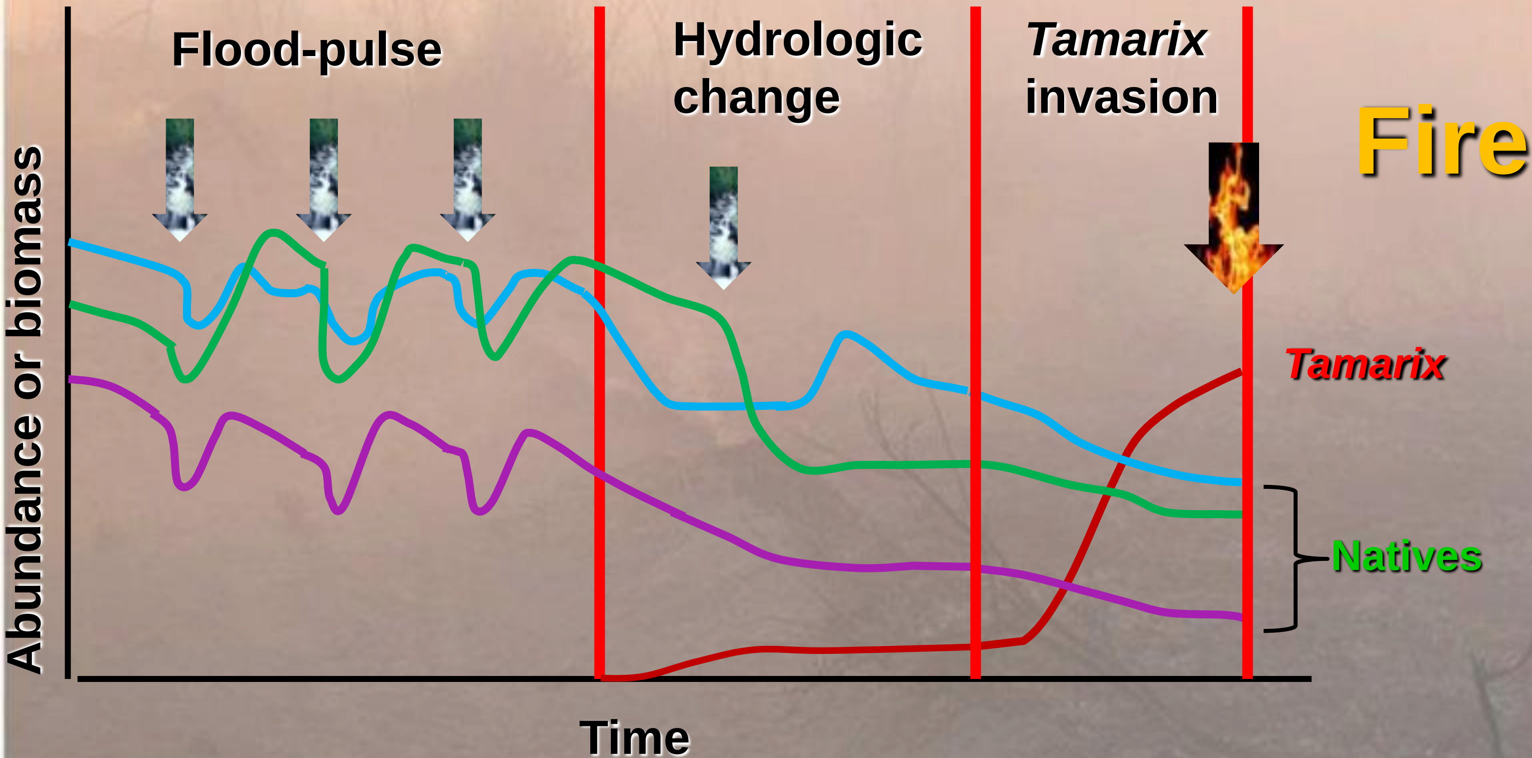
Busch 1995



- Native riparian zone ~ fire resistant
- Limited data on patterns and mechanisms

Tamarix introduces fire to desert riparian ecosystems

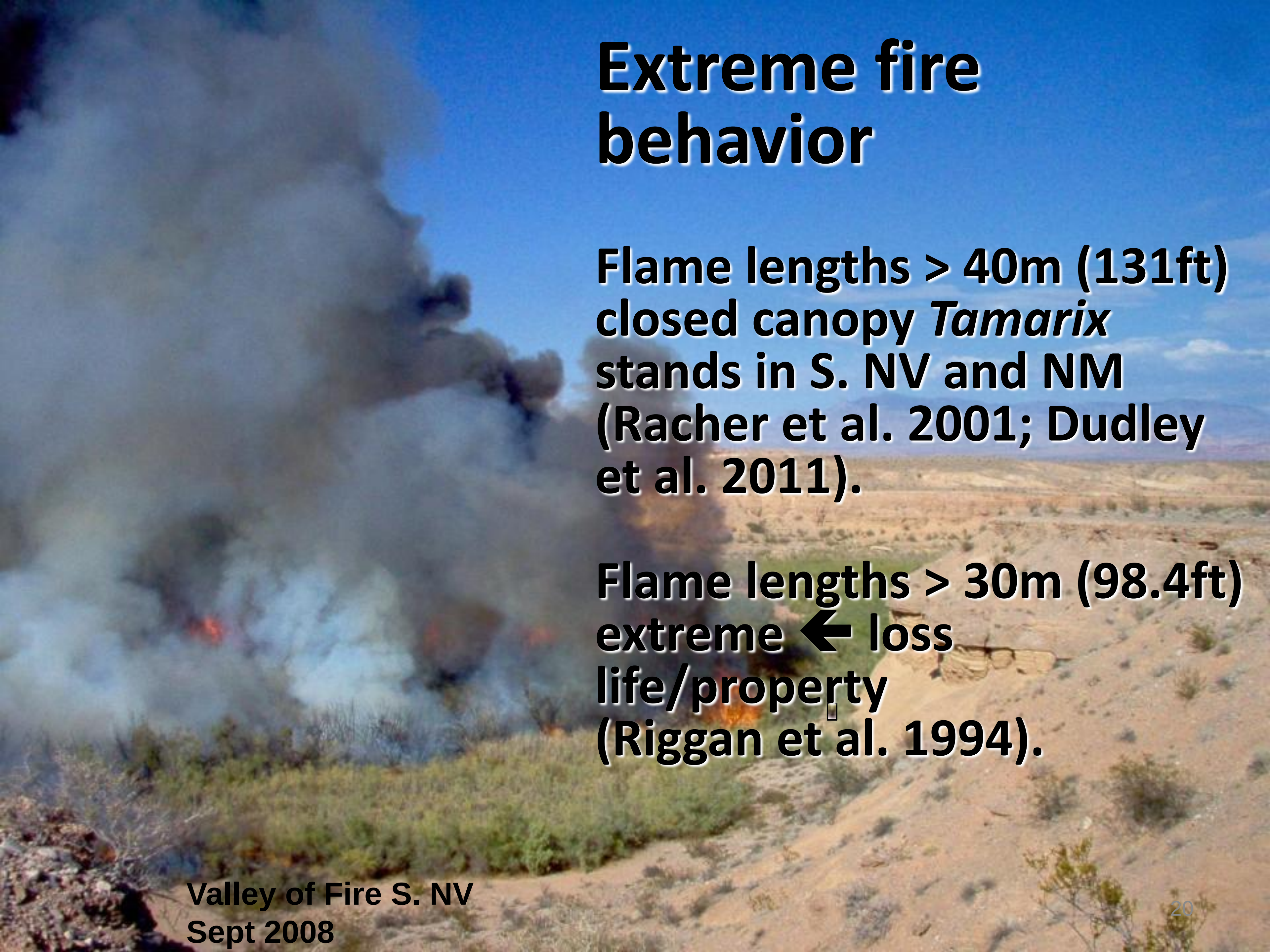


Tamarisk is highly flammable

- High fuel load
- Ladder fuel structure

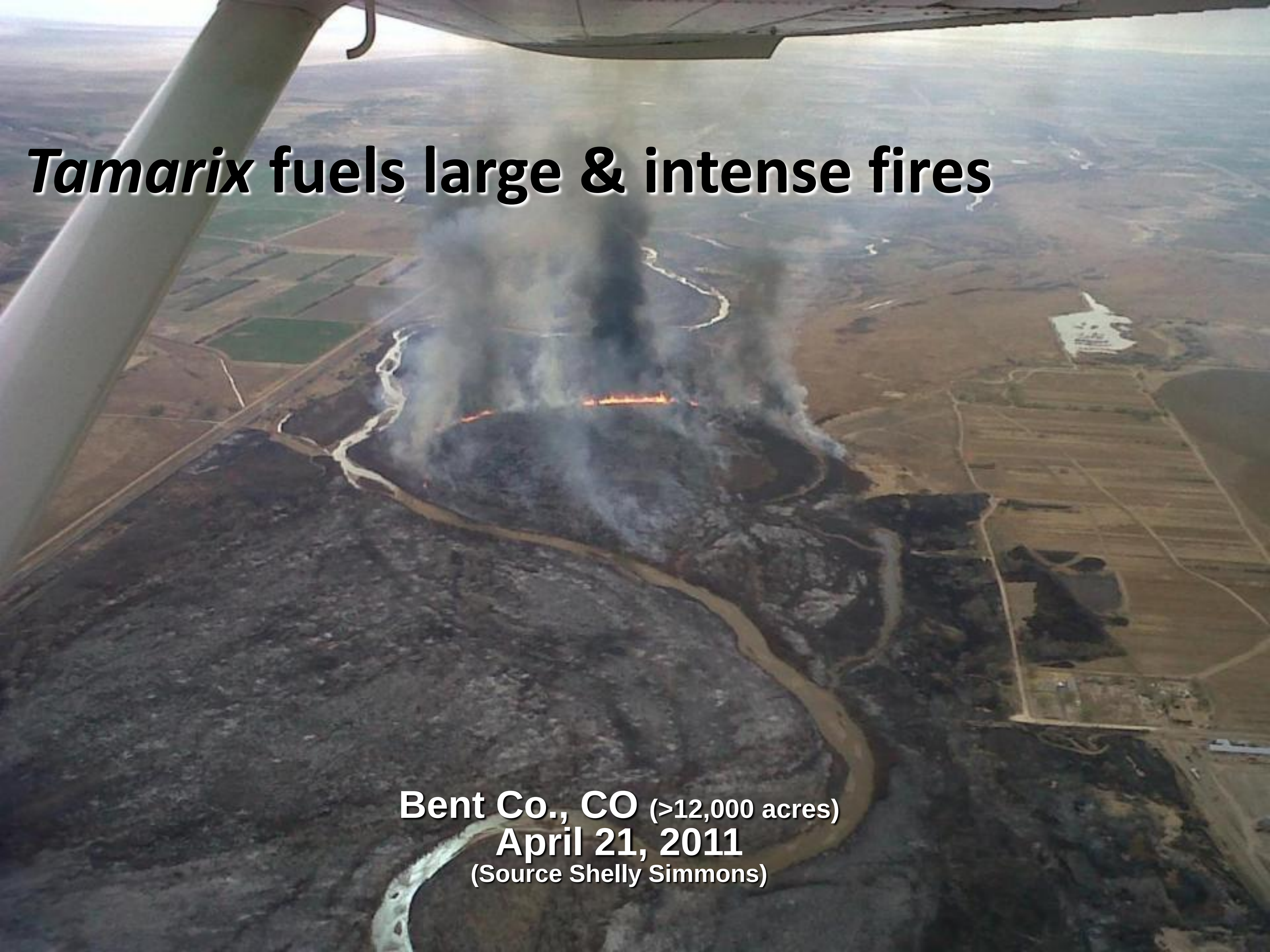
Extreme fire behavior



Valley of Fire S. NV
Sept 2008

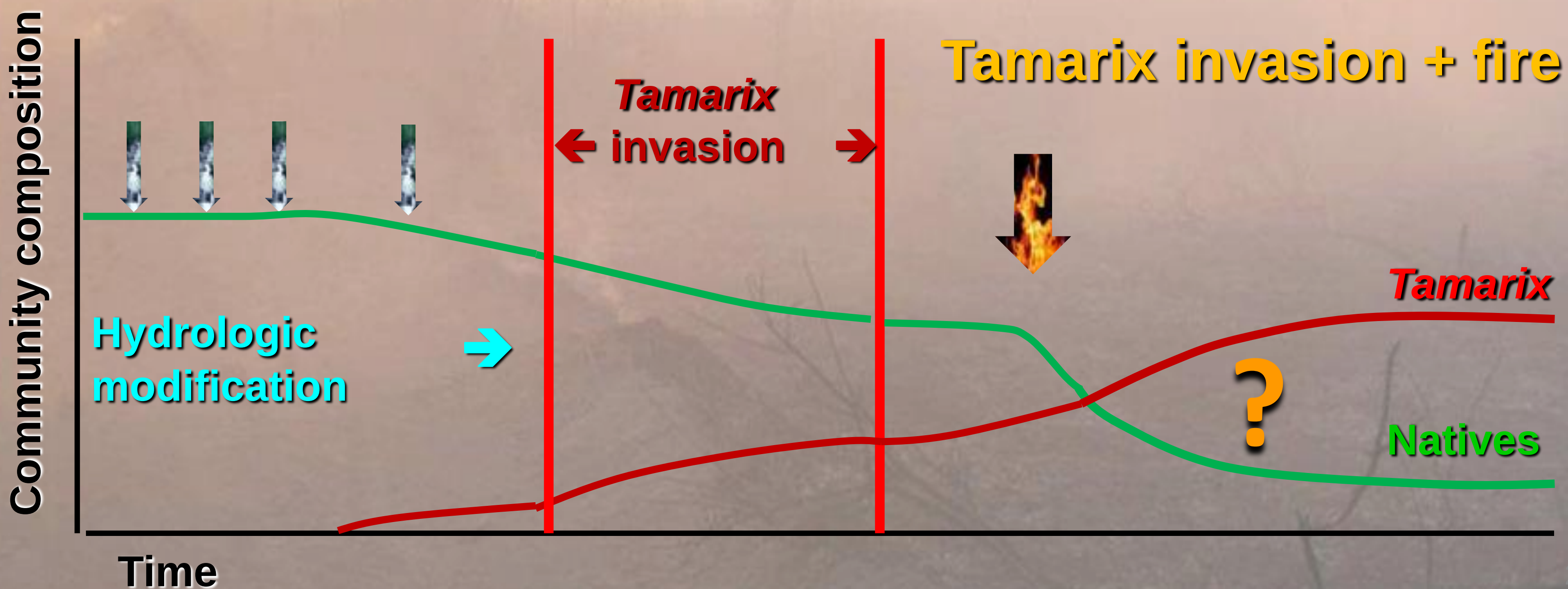
Flame lengths > 40m (131ft) closed canopy *Tamarix* stands in S. NV and NM (Racher et al. 2001; Dudley et al. 2011).

Flame lengths > 30m (98.4ft) extreme ← loss life/property (Riggan et al. 1994).


Tamarix fuels large & intense fires
Bent Co., CO (>12,000 acres)
April 21, 2011
(Source Shelly Simmons)

Tamarix fueled fires may alter riparian community composition



Is *Tamarix* invasion creating a fire cycle that further reduces native species and enhances its own success?

Is *Tamarix* invasion creating a fire cycle that further reduces native species and enhances its own success?

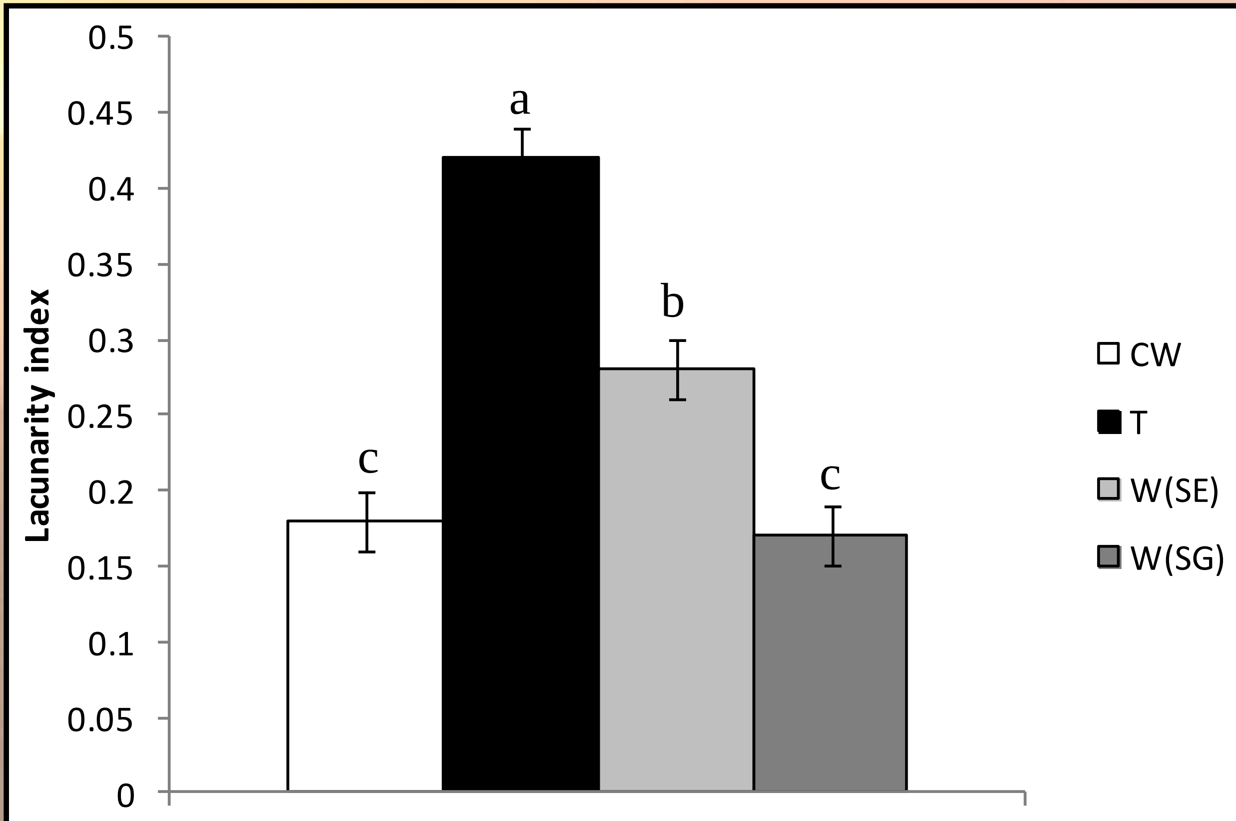
Flammability, Recovery, Fire intensity

Foliar flammability experiments




- **Muffle furnace method** (Montgomery and Cheo 1969)
  - **Relationship between foliage condition & flammability in *Tamarix* vs. native riparian species**

Tamarix foliage is more divided than foliage from native riparian species



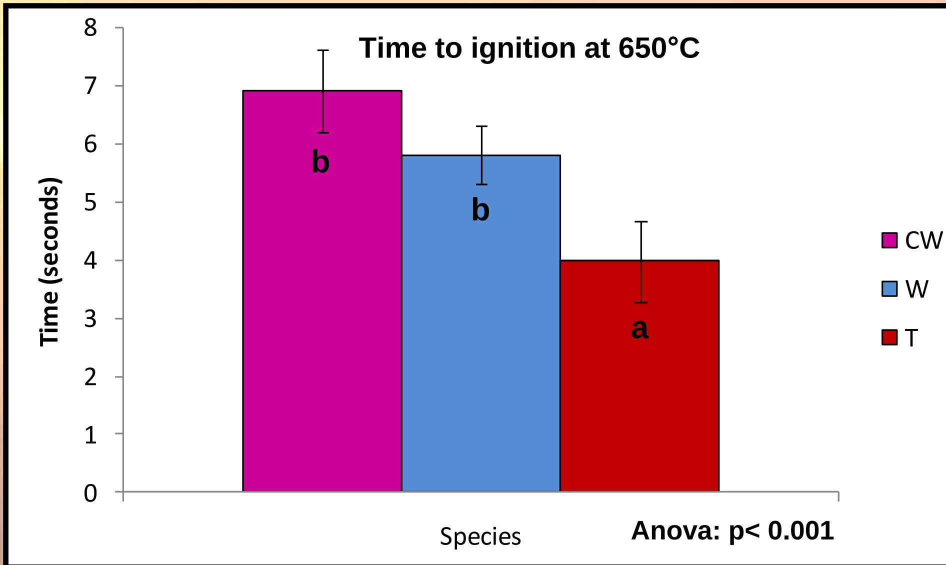
Drus and Paddock in prep, Drus 2013

Lacunarity index. CW indicates *Populus fremontii*, W(SE) *Salix exigua*, W(SG) *Salix goodingii*, and T *Tamarix* spp. (N = 23). Error bars indicate ± standard error. Letters (a, b and c) indicate significant differences among species ($p \leq 0.05$).

Gaps (lacunae) create air pockets

USDA APHIS Archives, www.forestryimages.org

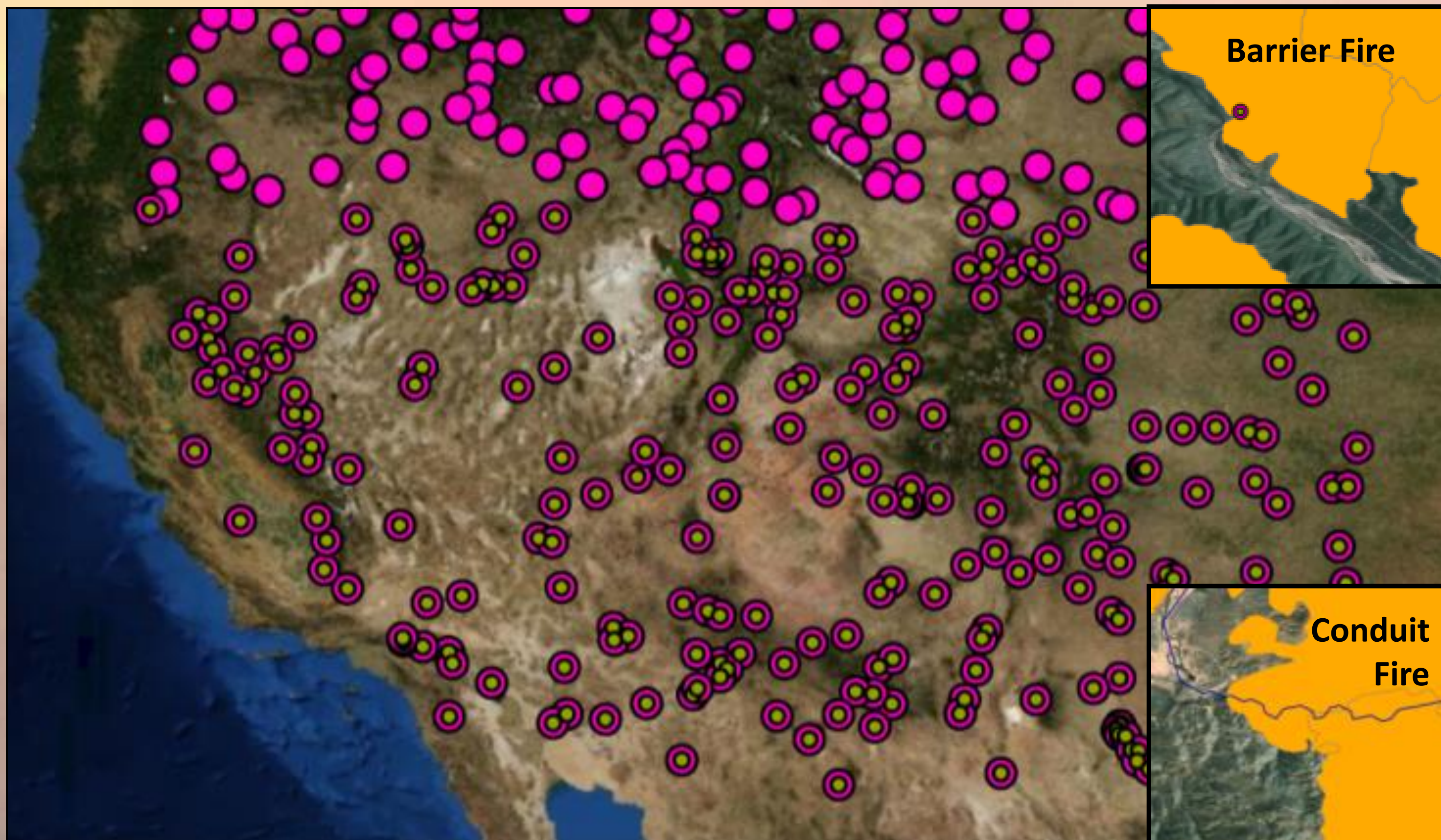
Tamarix foliage ignites more quickly than foliage from native riparian species



Cottonwood
Willow
Tamarix

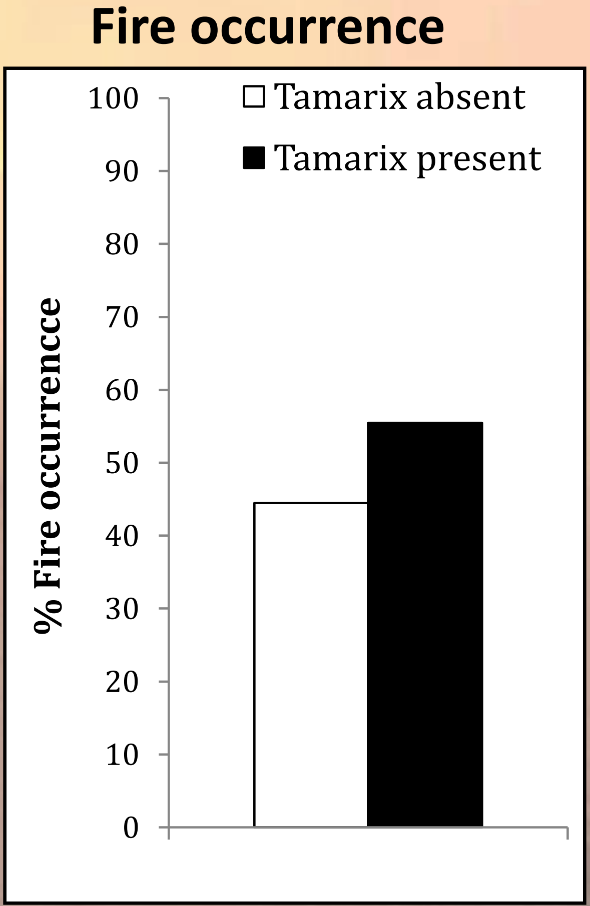
Drus and Paddock in prep, Drus 2013

Flammability at a regional scale:
Tamarix and probability and extent of riparian fire

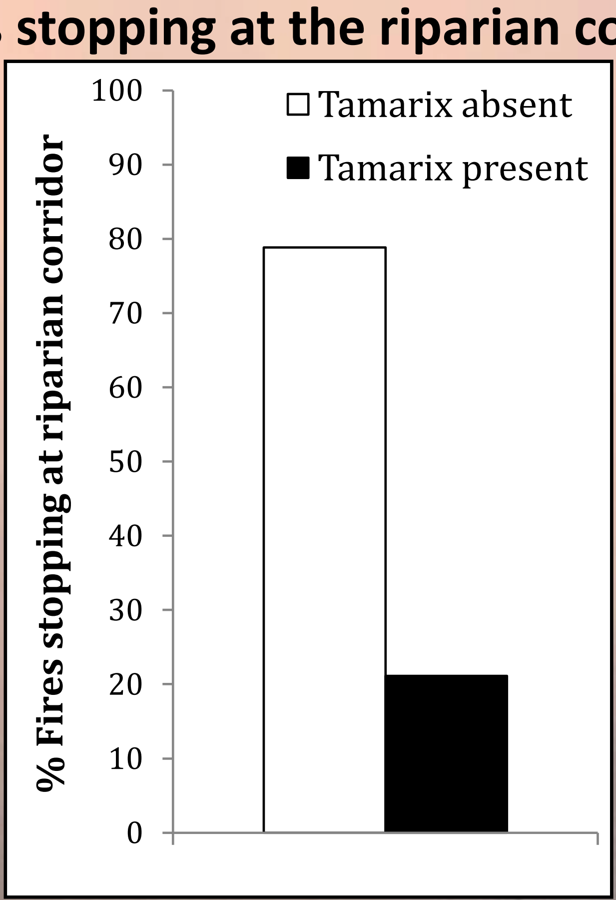


Relationship between fire and *Tamarix* at USGS gauges

Fires are more likely to occur and to spread through the riparian corridor when *Tamarix* is present (2002-2012)



(Chi-square contingency table ≤ 0.05)



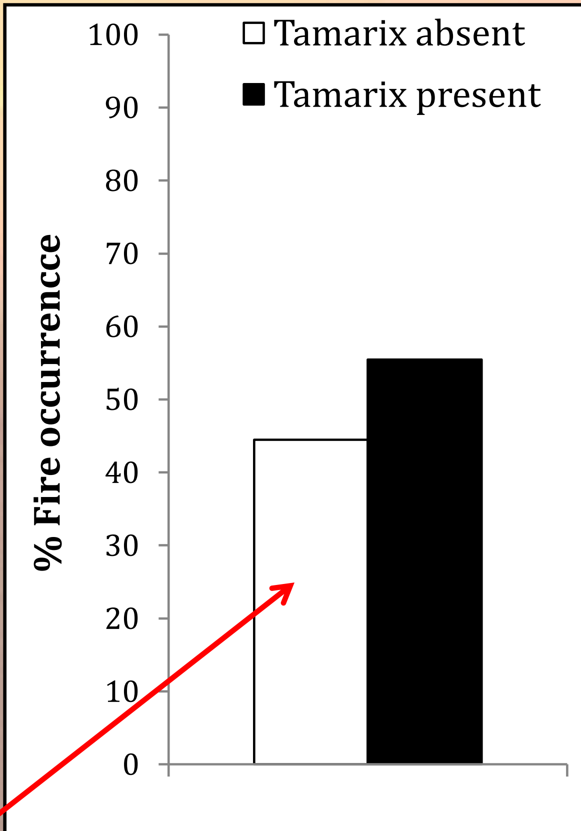
(Chi-square contingency table ≤ 0.05)

- **Why is *Tamarix* so flammable?**

Drus et al. in prep.

Fires are more likely to occur and to spread through the riparian corridor when *Tamarix* is present (2002-2012)

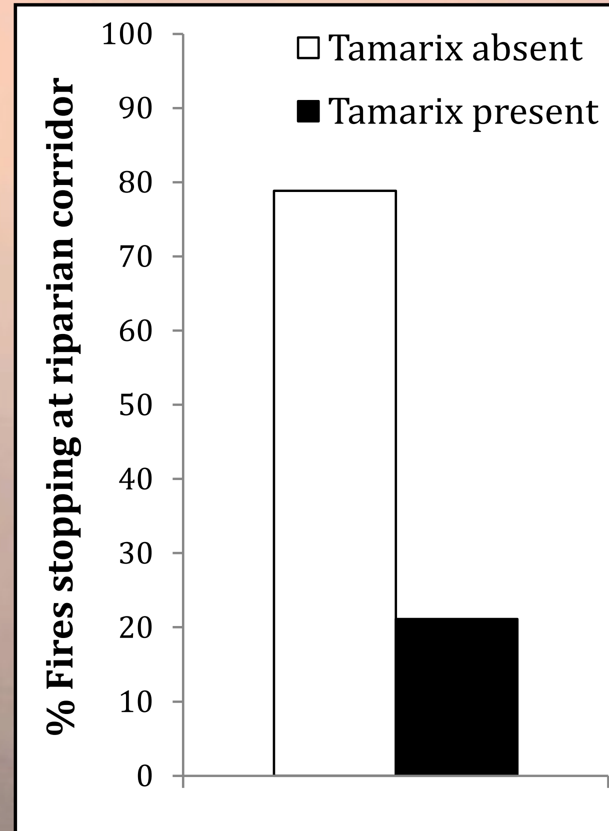
Fire occurrence



(Chi-square contingency table < 0.05)

Common too (human ignitions)

Fires stopping at the riparian corridor



(Chi-square contingency table < 0.05)

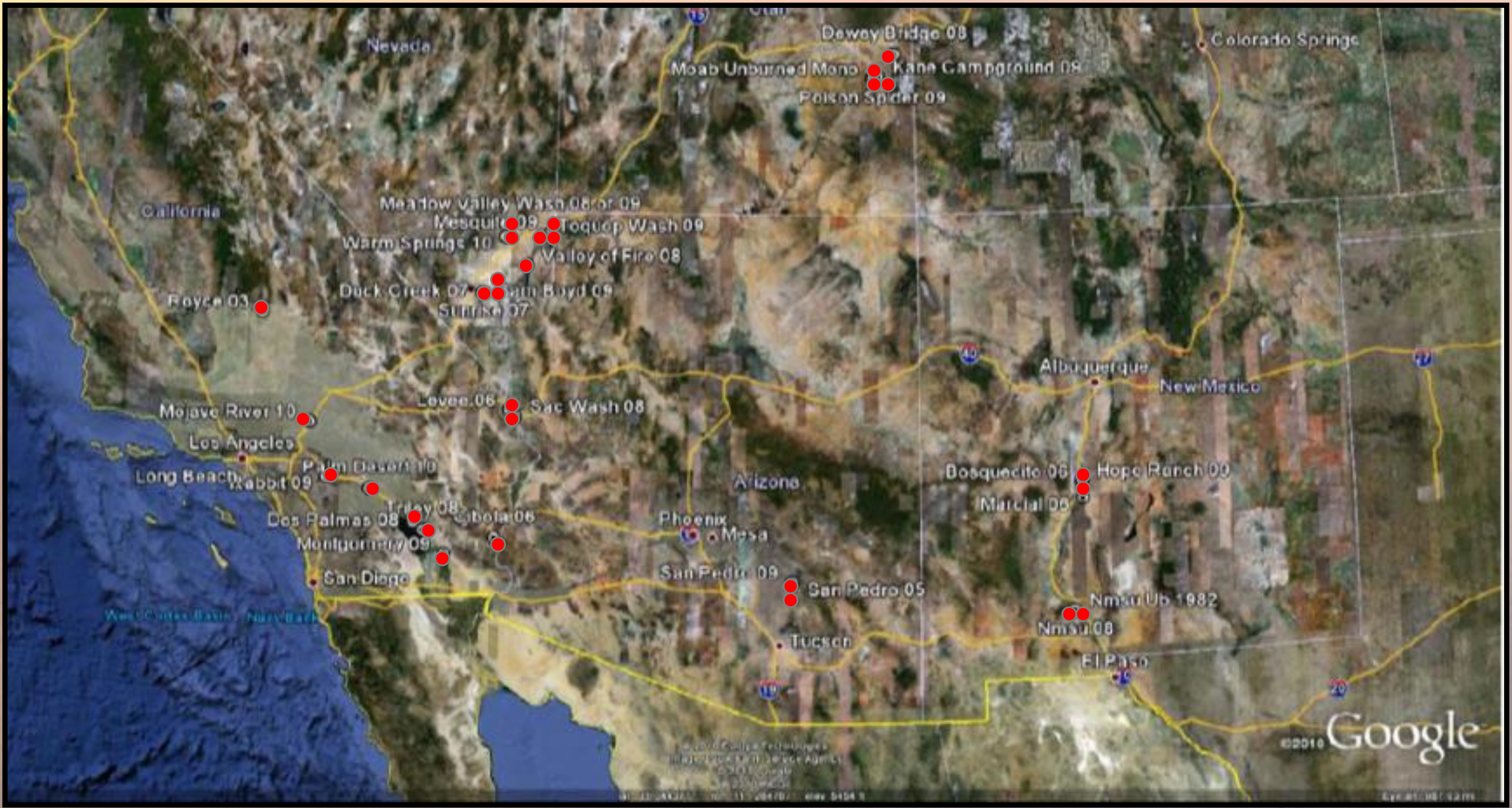
- Why is *Tamarix* so flammable?

Drus et al. in prep.

What does all of this mean to the native species?

Photo by David Brown

Recovery of *Tamarix* and native riparian species: survey



30 riparian burns: gradient of *Tamarix* ➔ native dominance

Fire survey methods

- Measurements
  - *Tamarix* vs. native density
  - Fuel structure (+/- timelag fuel classes)
  - Live vs. dead (resprout info)

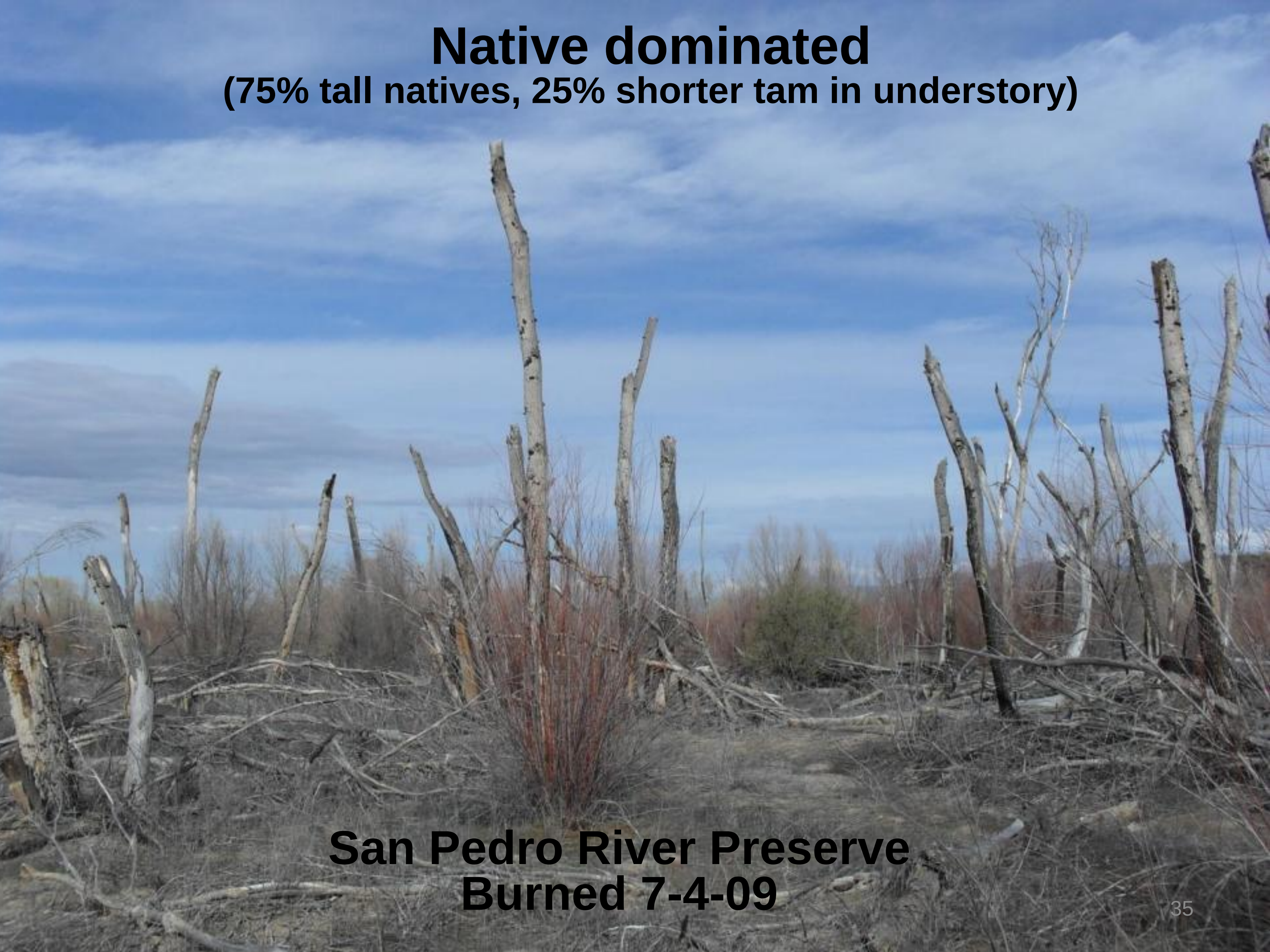
Fuel Classes

- 1hr < 0.625cm
- 10hr 0.625 – 2.5cm
- 100hr 2.5 – 7.6cm
- 1000hr > 7.6cm

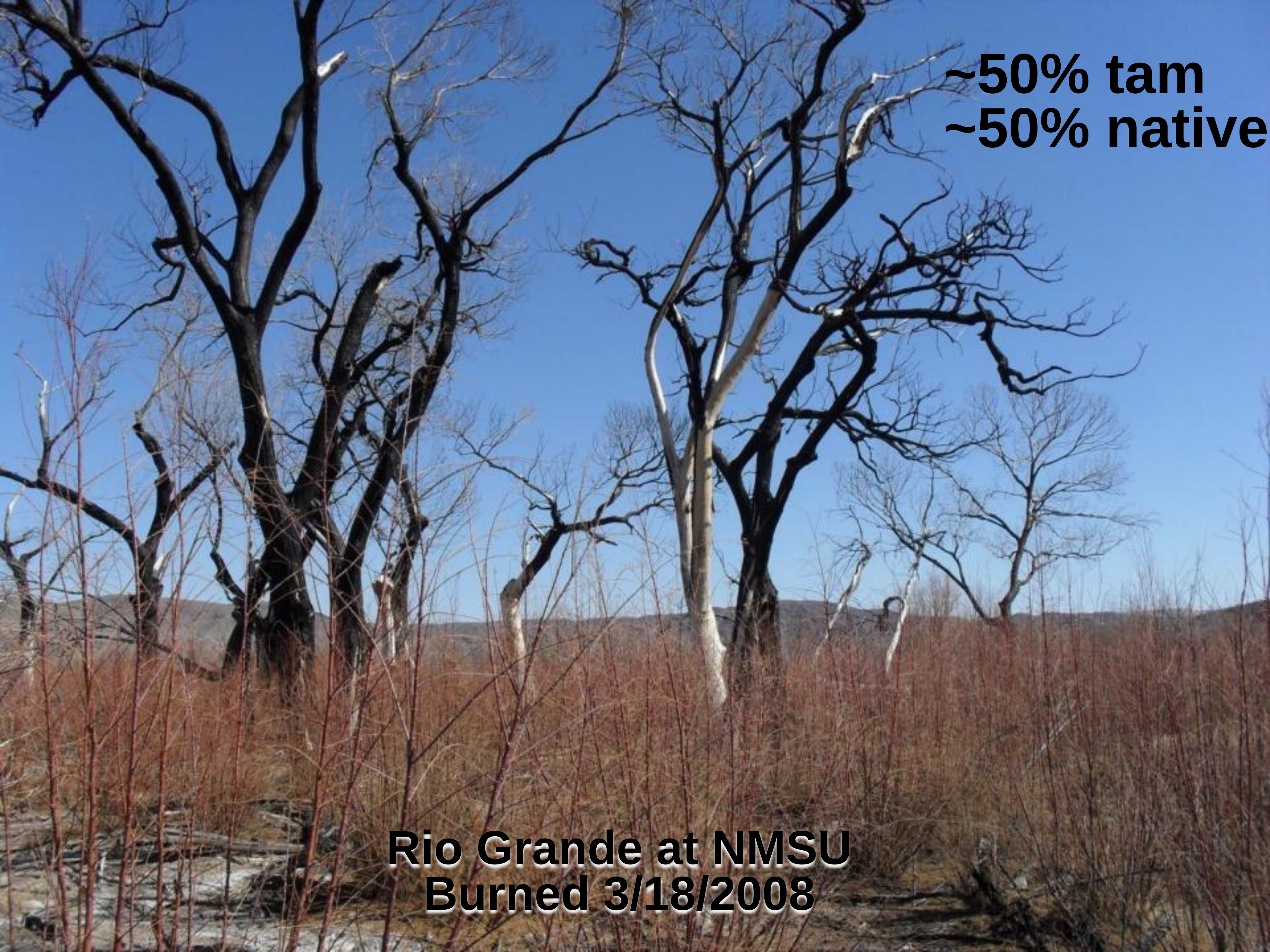
(Pyne et al. 1996)

Native dominated

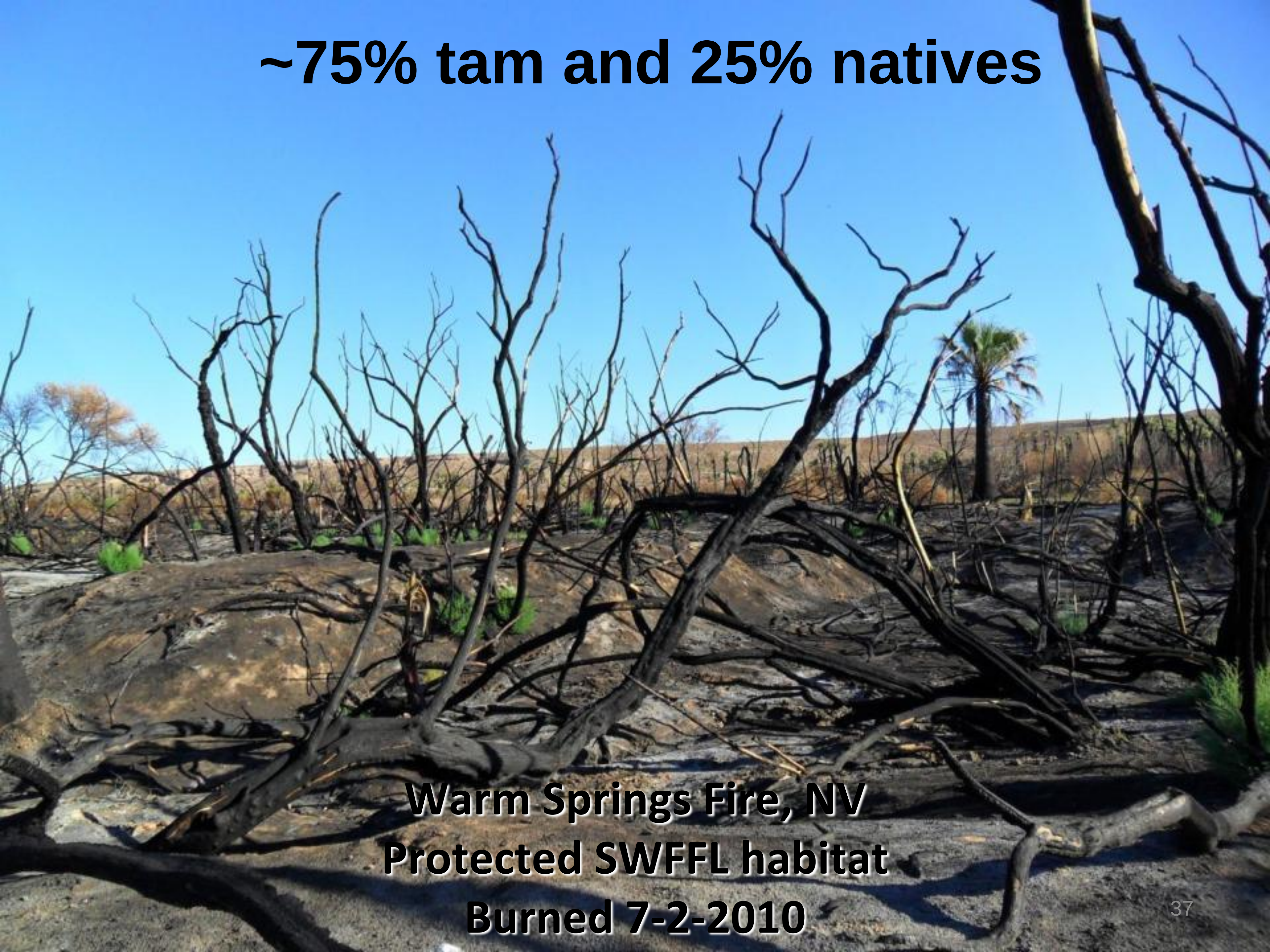
(75% tall natives, 25% shorter tam in understory)



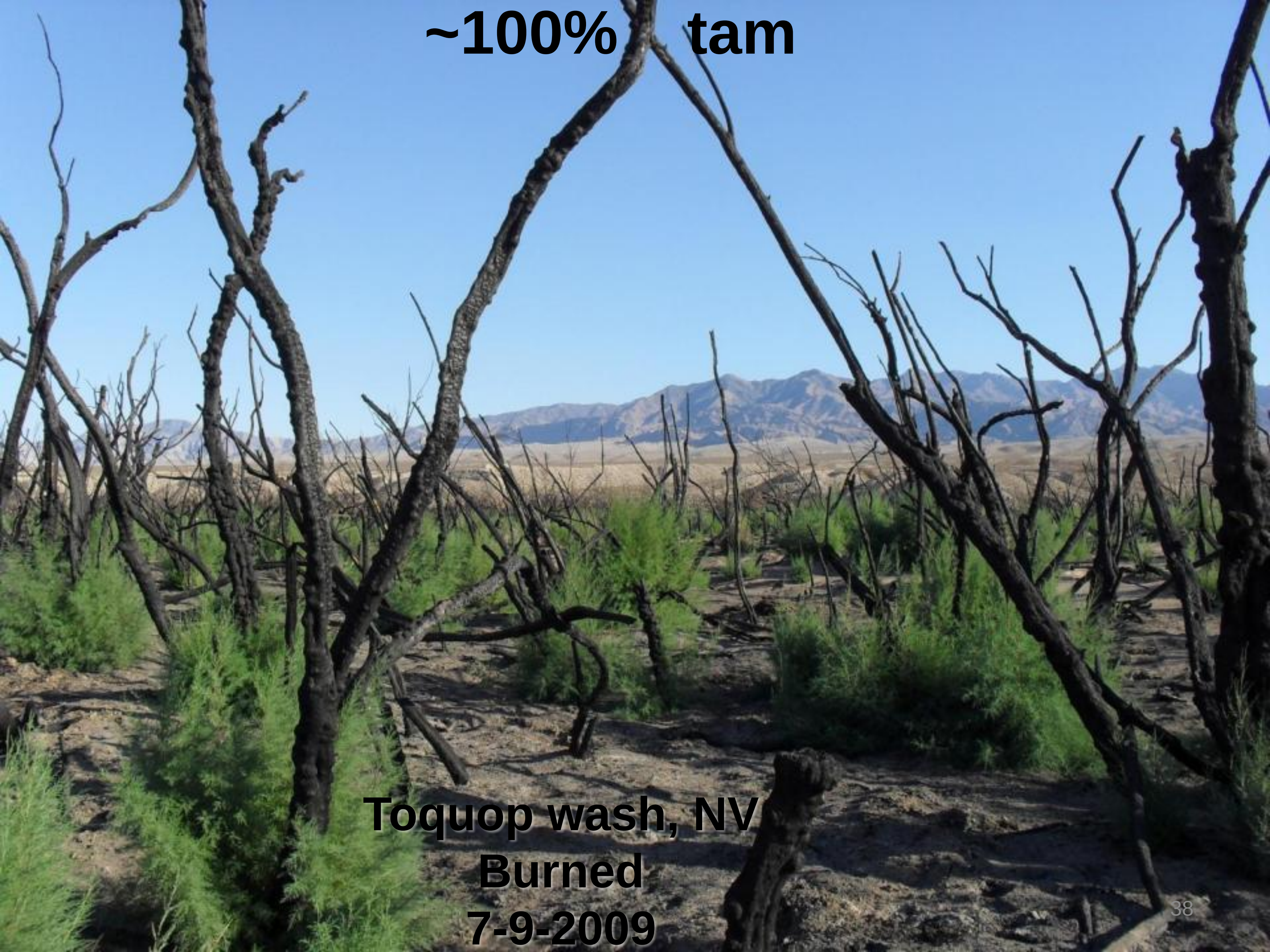
San Pedro River Preserve
Burned 7-4-09


~50% tam
~50% native
Rio Grande at NMSU
Burned 3/18/2008

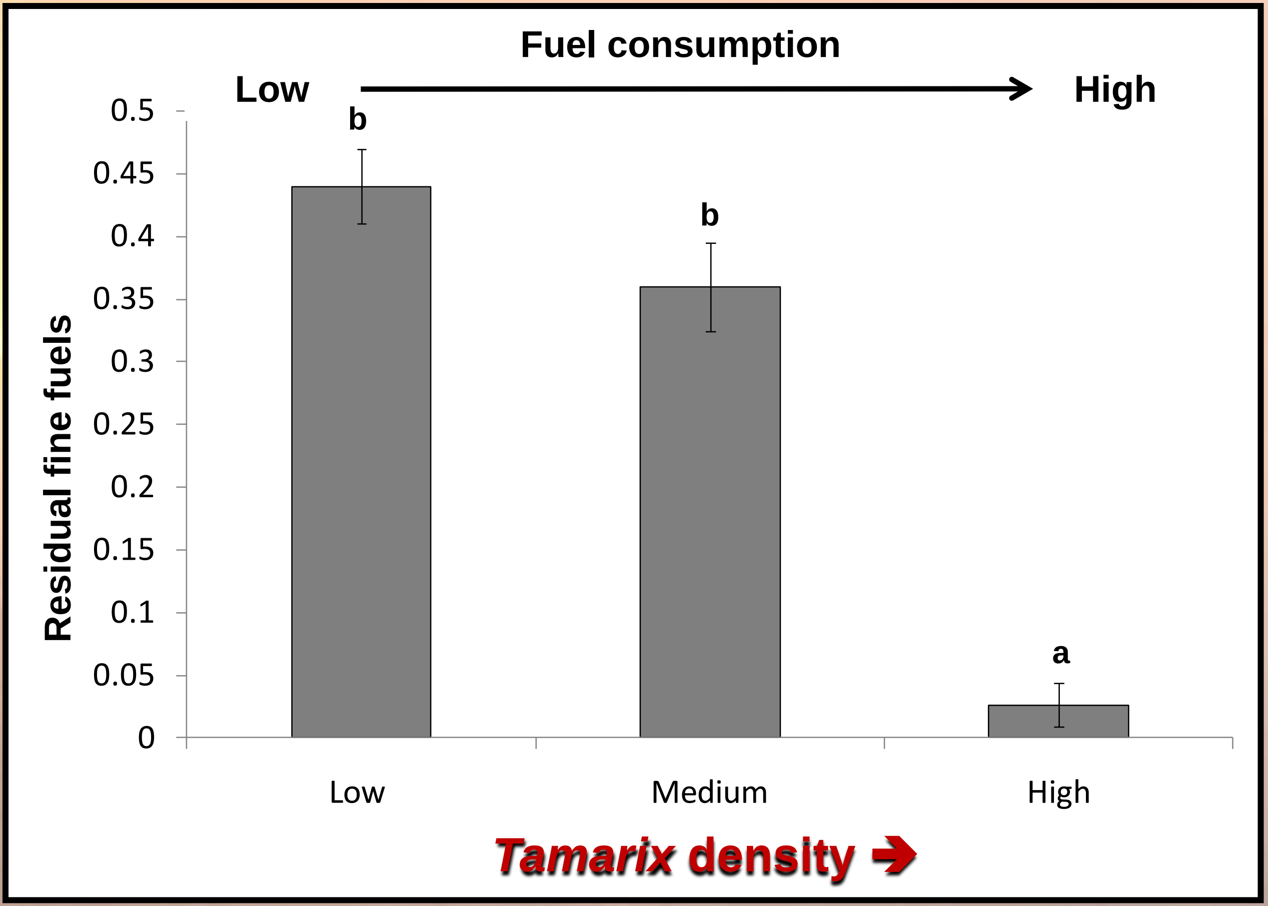
~75% tam and 25% natives



Warm Springs Fire, NV
Protected SWFFL habitat
Burned 7-2-2010


~100% tam
Toquop wash, NV
Burned
7-9-2009


Hope Ranch
2009
Transect 2
Hope Ranch, NM
Burned
2009



Tamarisk Density Classes

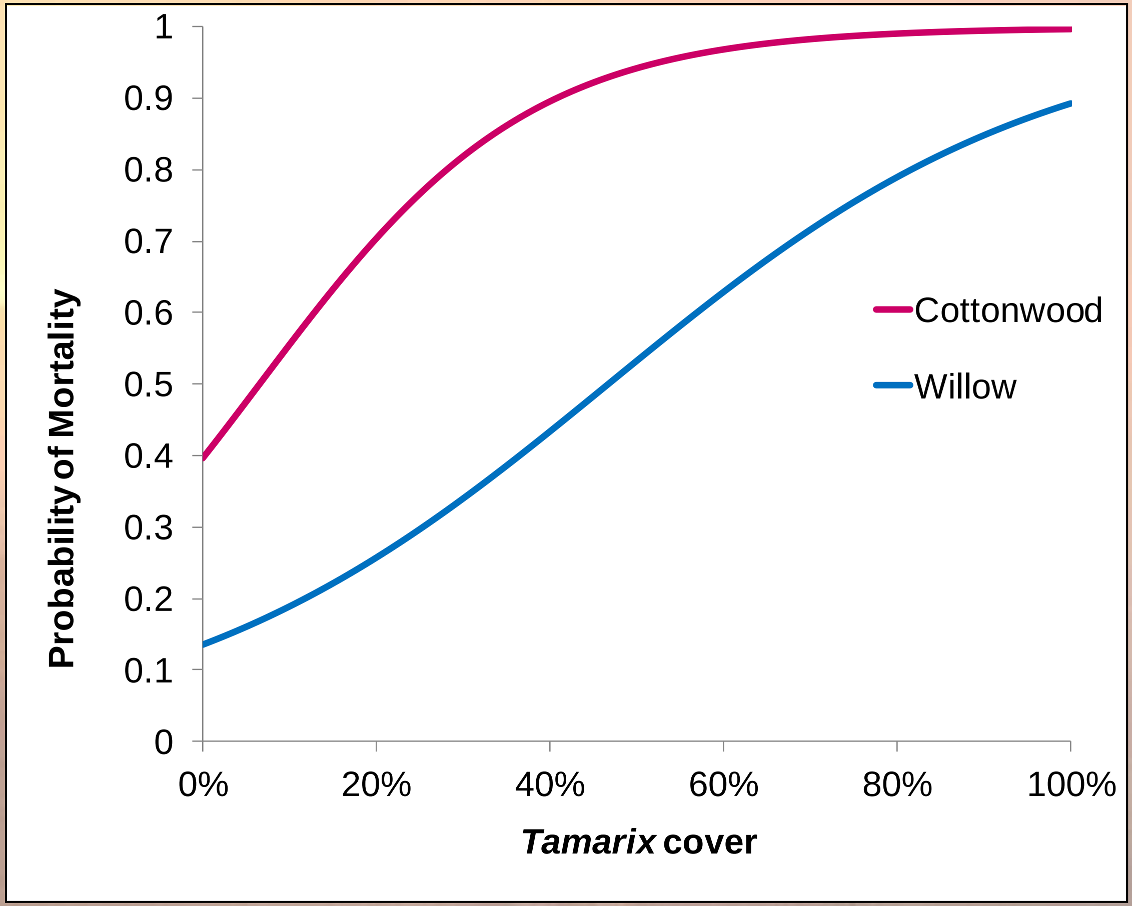
Low <10%

Medium 20-50%

High > 50%

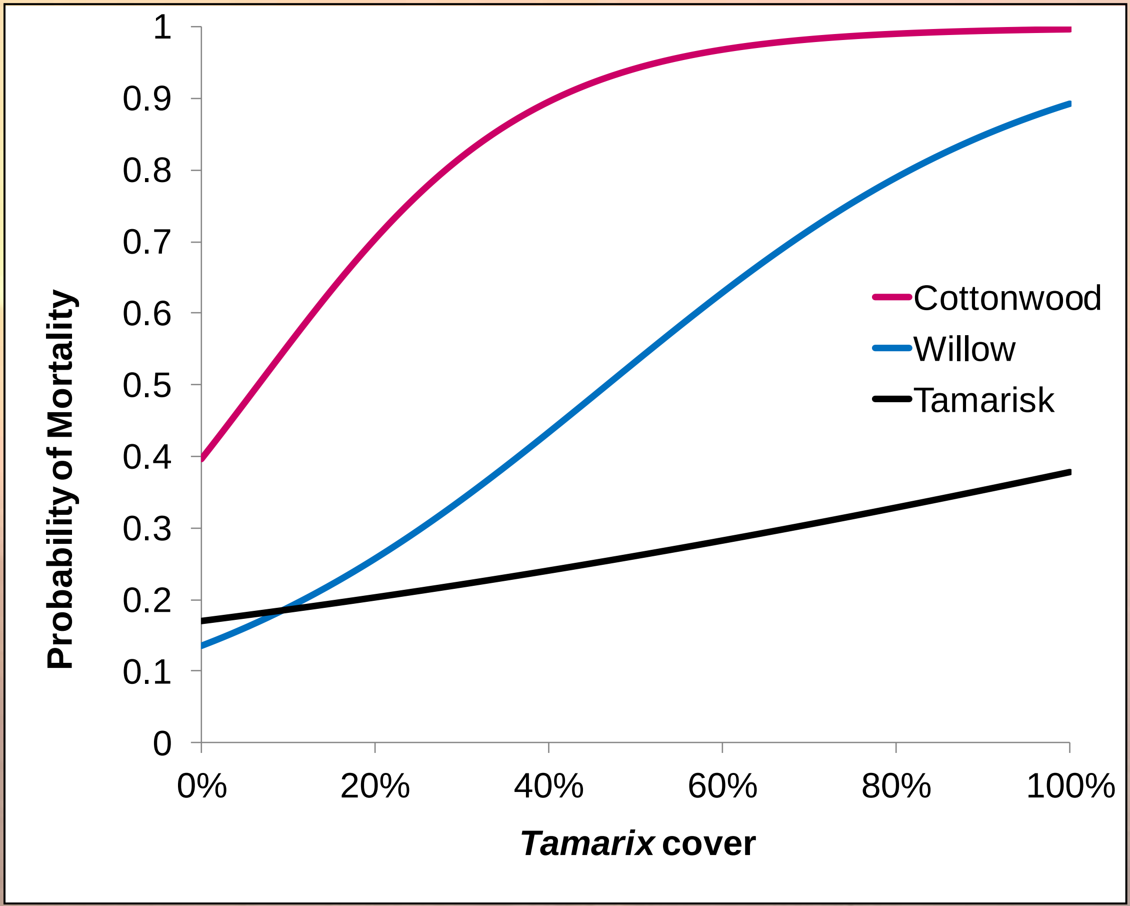
(ANOVA ≤ 0.05)

Native fuel consumption increases with *Tamarix* density



(Logistic Regression: Cottonwood; p <0.001, Willow; p<0.001, Tamarisk; p<0.001)

Native mortality increases with *Tamarix* density

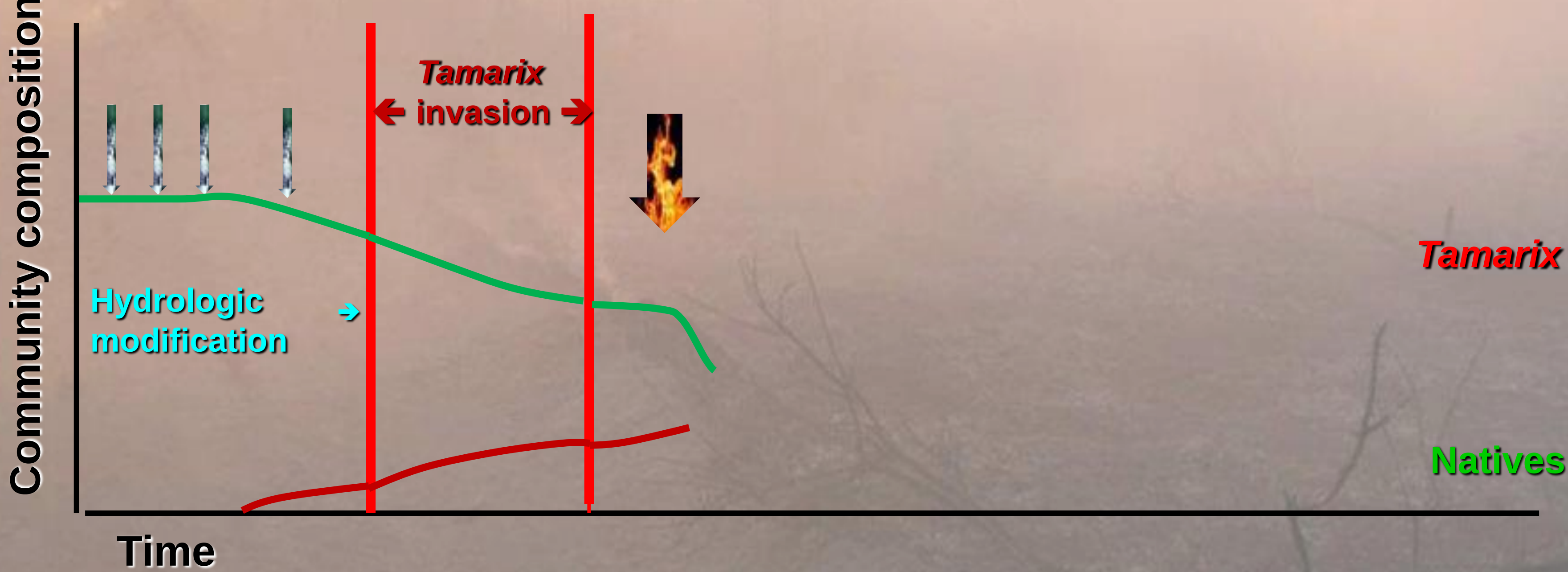


(Logistic Regression: Cottonwood; p <0.001, Willow; p<0.001, Tamarisk; p<0.001)

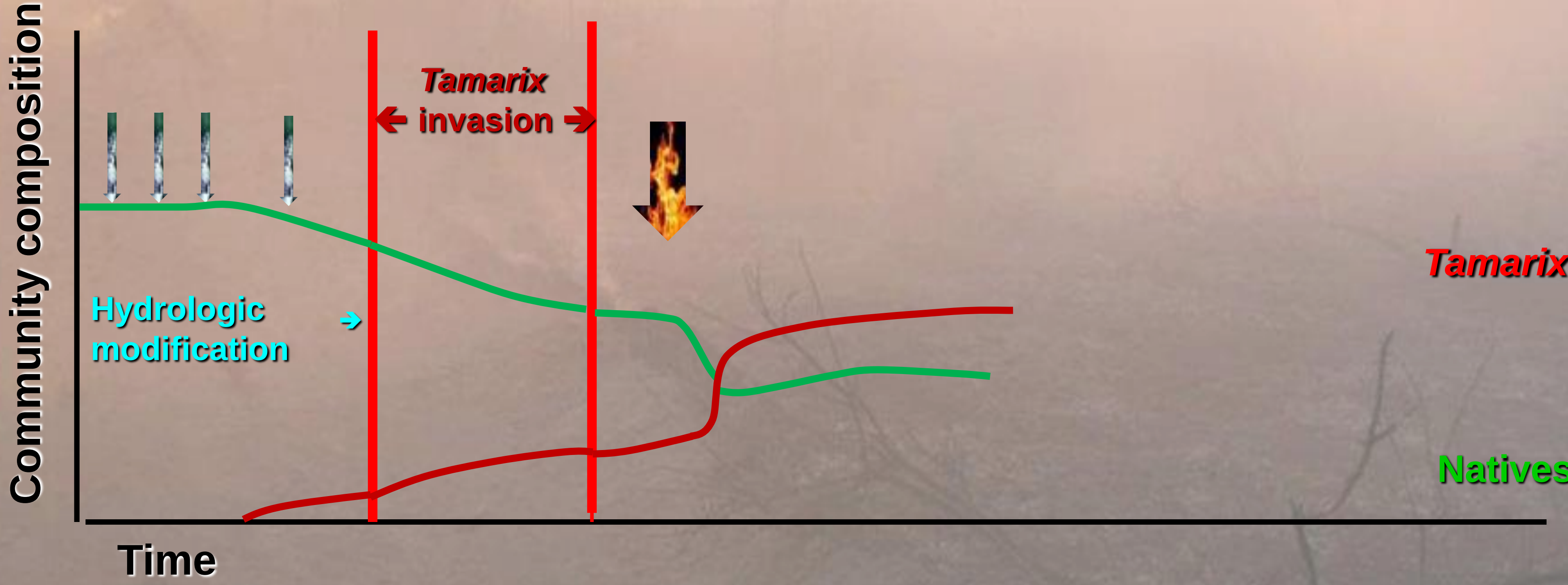
Tamarix mortality is less density dependent.

Highly fire tolerant

The *Tamarix* fire cycle

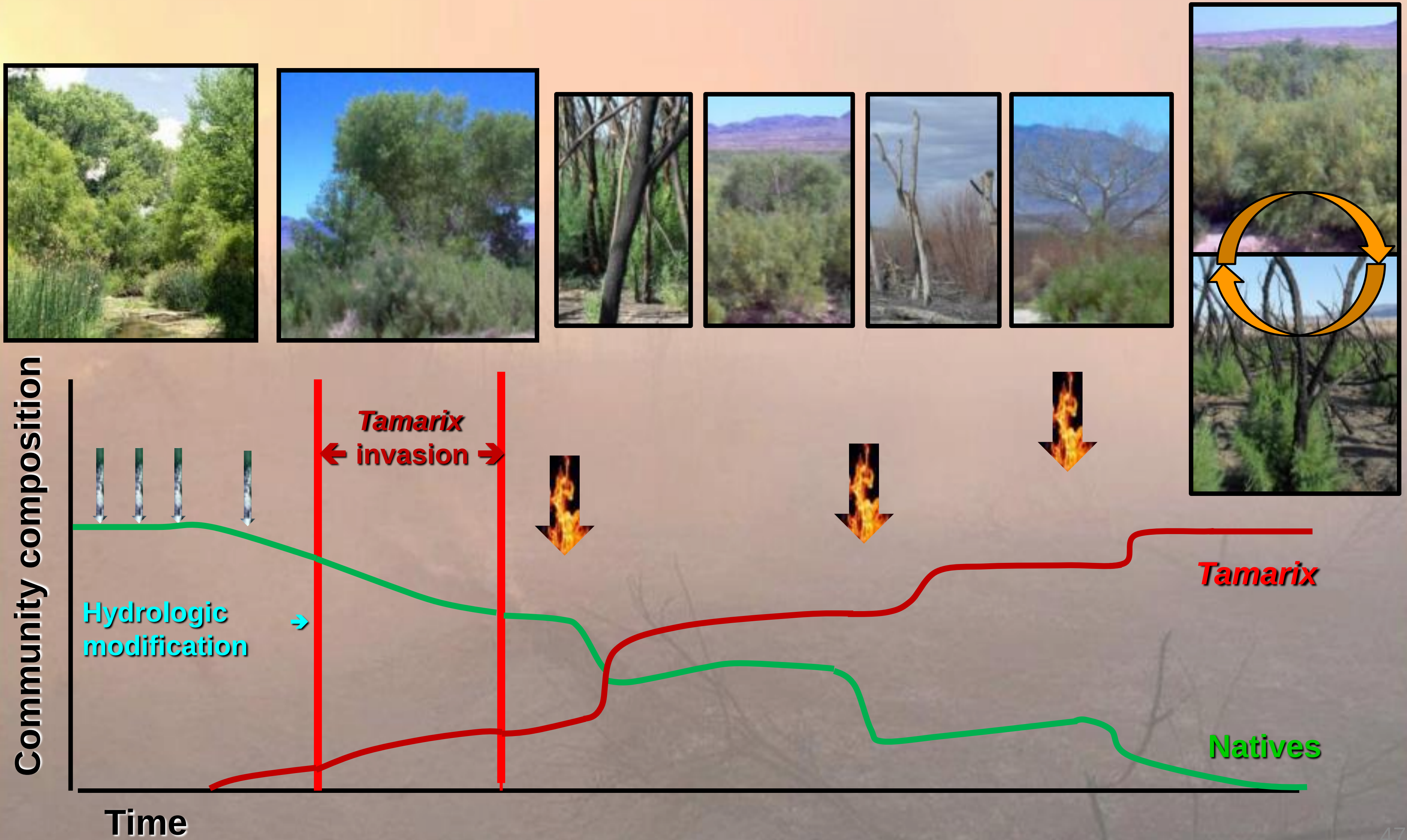


The *Tamarix* fire cycle

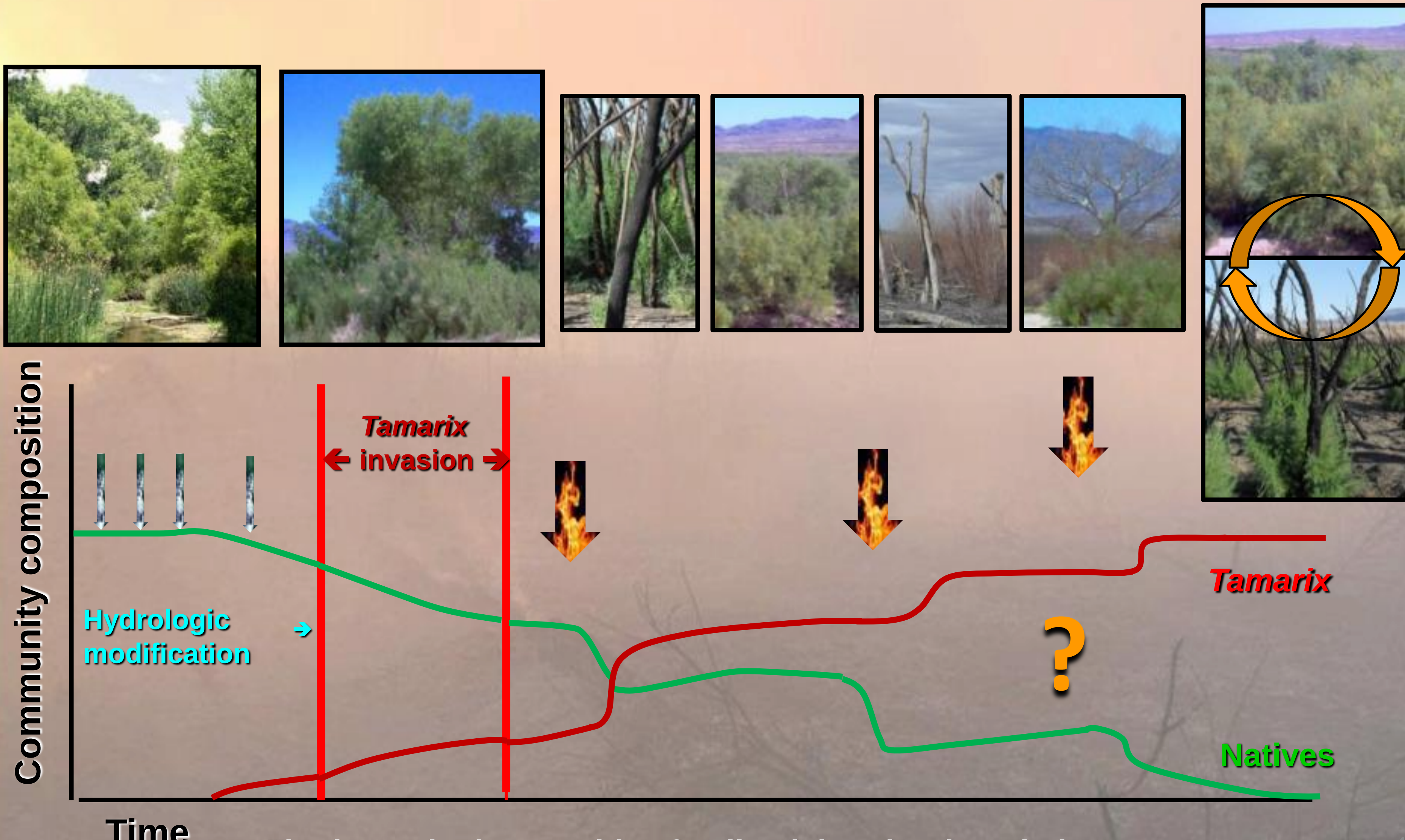


The *Tamarix* fire cycle

The *Tamarix* fire cycle



The *Tamarix* fire cycle

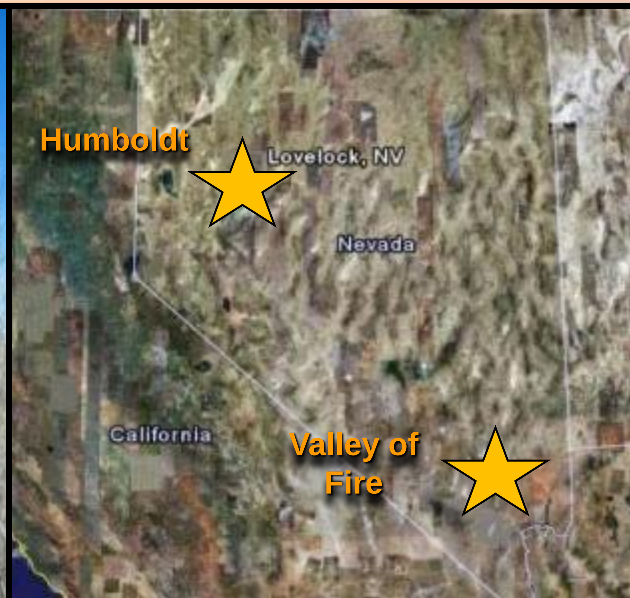


Fire intensity is a positive feedback in other invaded ecosystems.

Prescribed burn experiments

Humboldt 2006

Valley of Fire 2008



- Humboldt river floodplain Lovelock, NV
  - August 2006
- Valley of Fire Wash Overton, NV
  - September 2008

Measurements

Fuel load

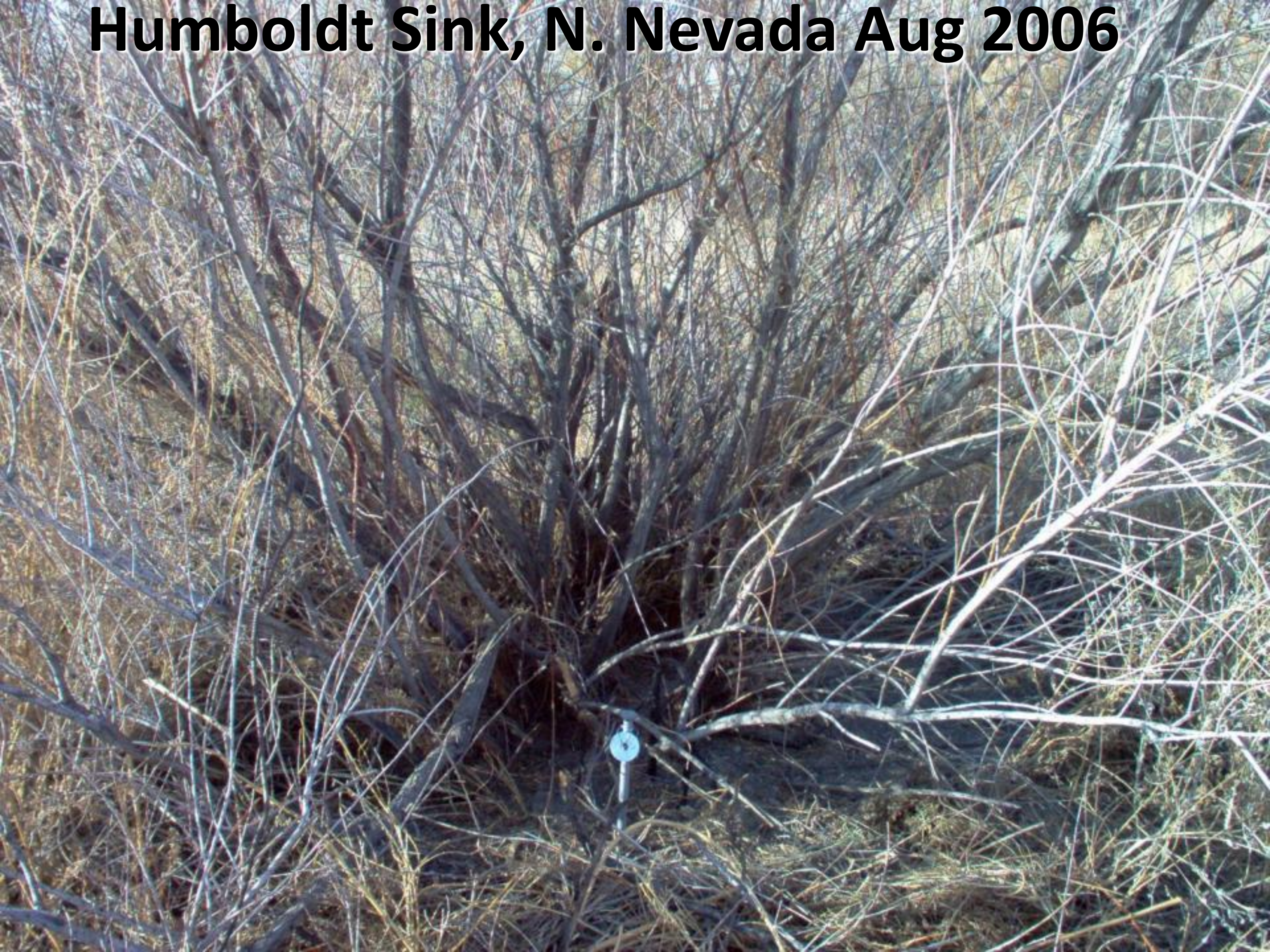
-Destructive sampling

Fire behavior

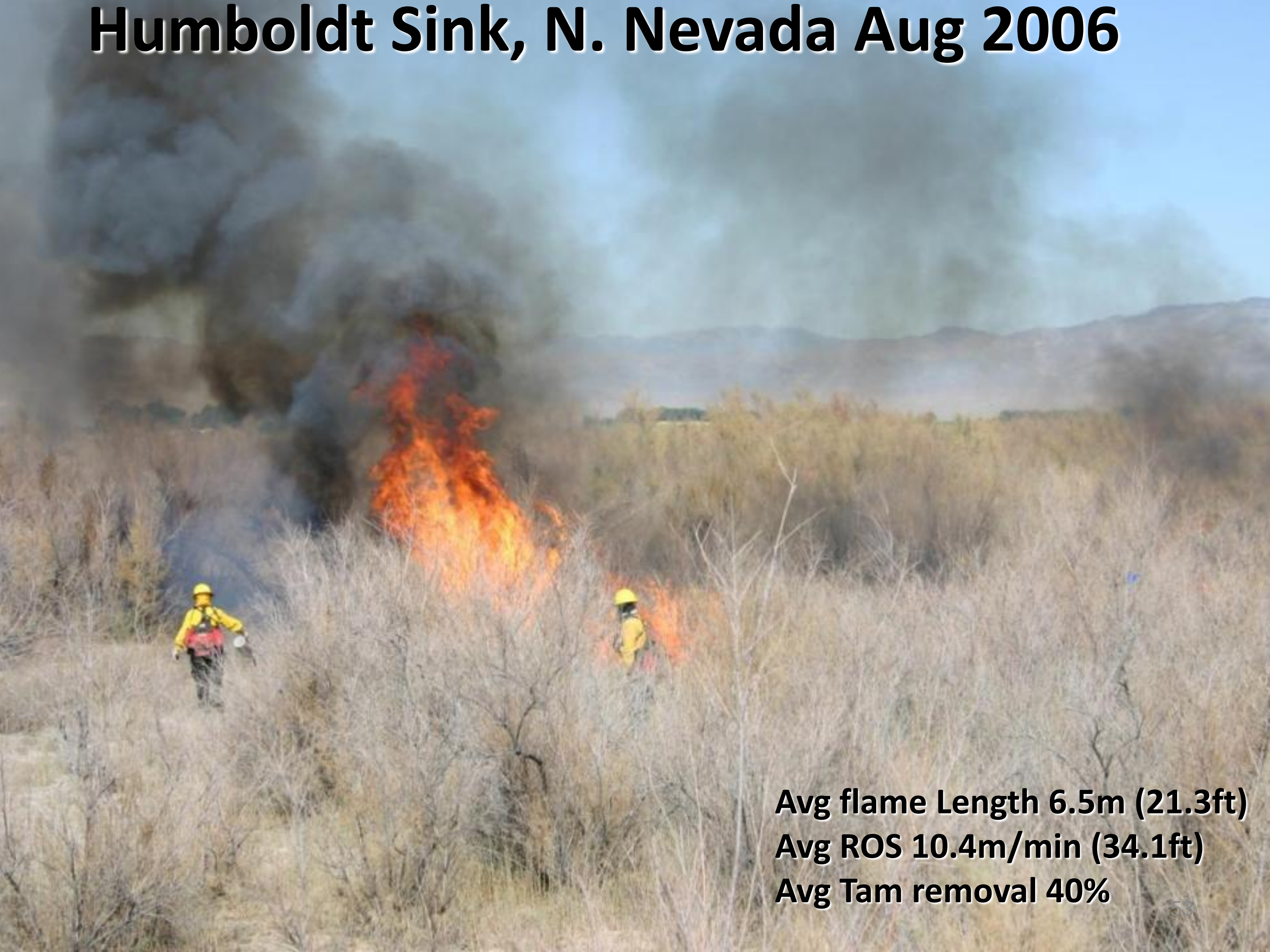
-Rate of spread

-Flame height

Humboldt Sink, N. Nevada Aug 2006


Humboldt Sink, N. Nevada Aug 2006

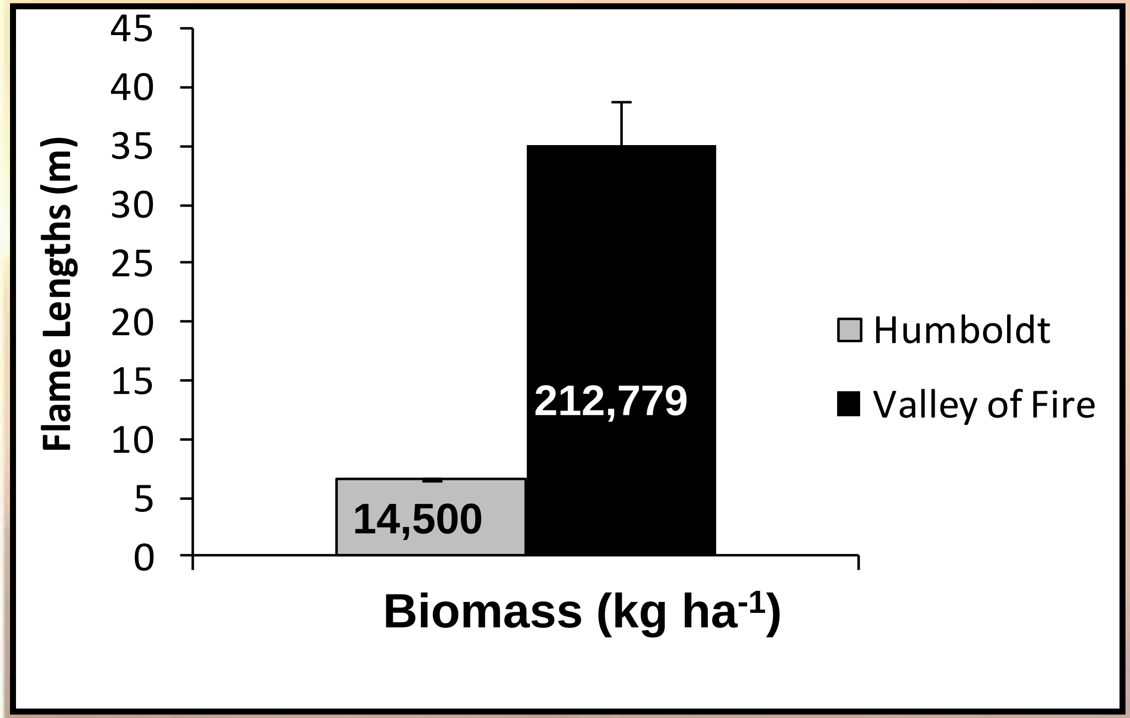
Humboldt Sink, N. Nevada Aug 2006



Valley of fire wash, S. Nevada Sept 2008

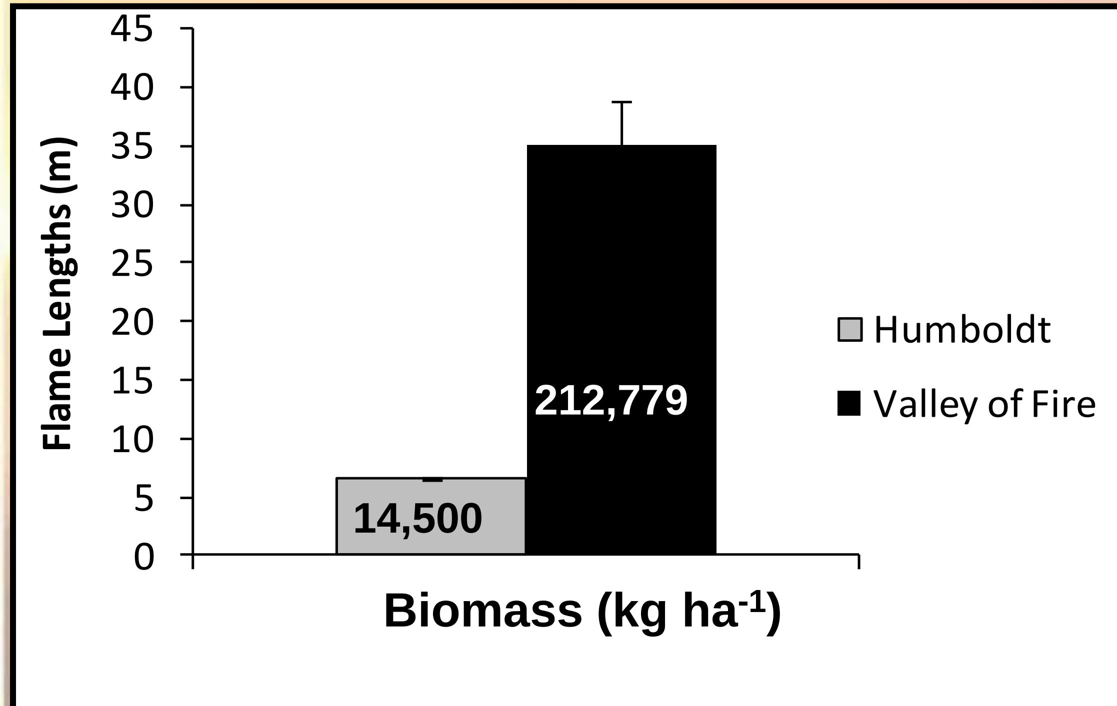
Valley of fire wash, S. Nevada Sept 2008


Valley of fire wash, S. Nevada Sept 2008
Avg flame Length 35m (114.8ft)
Avg ROS 11.7m/min (38.4ft)
Avg Tam removal 55%

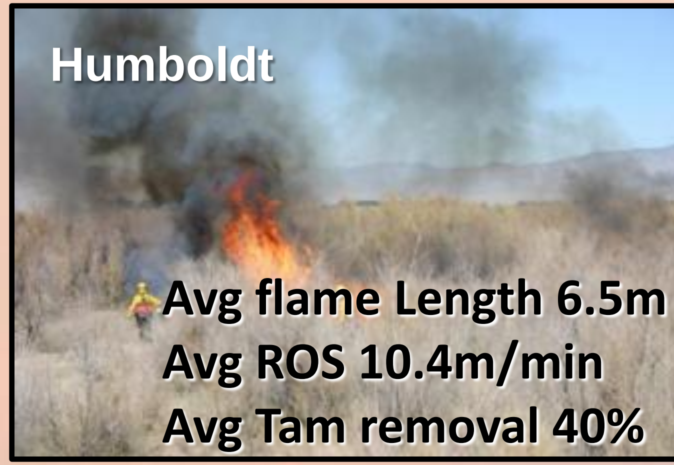


Anova: $p < 0.001$

Tamarix fire intensity is biomass dependent



Anova: $p < 0.001$



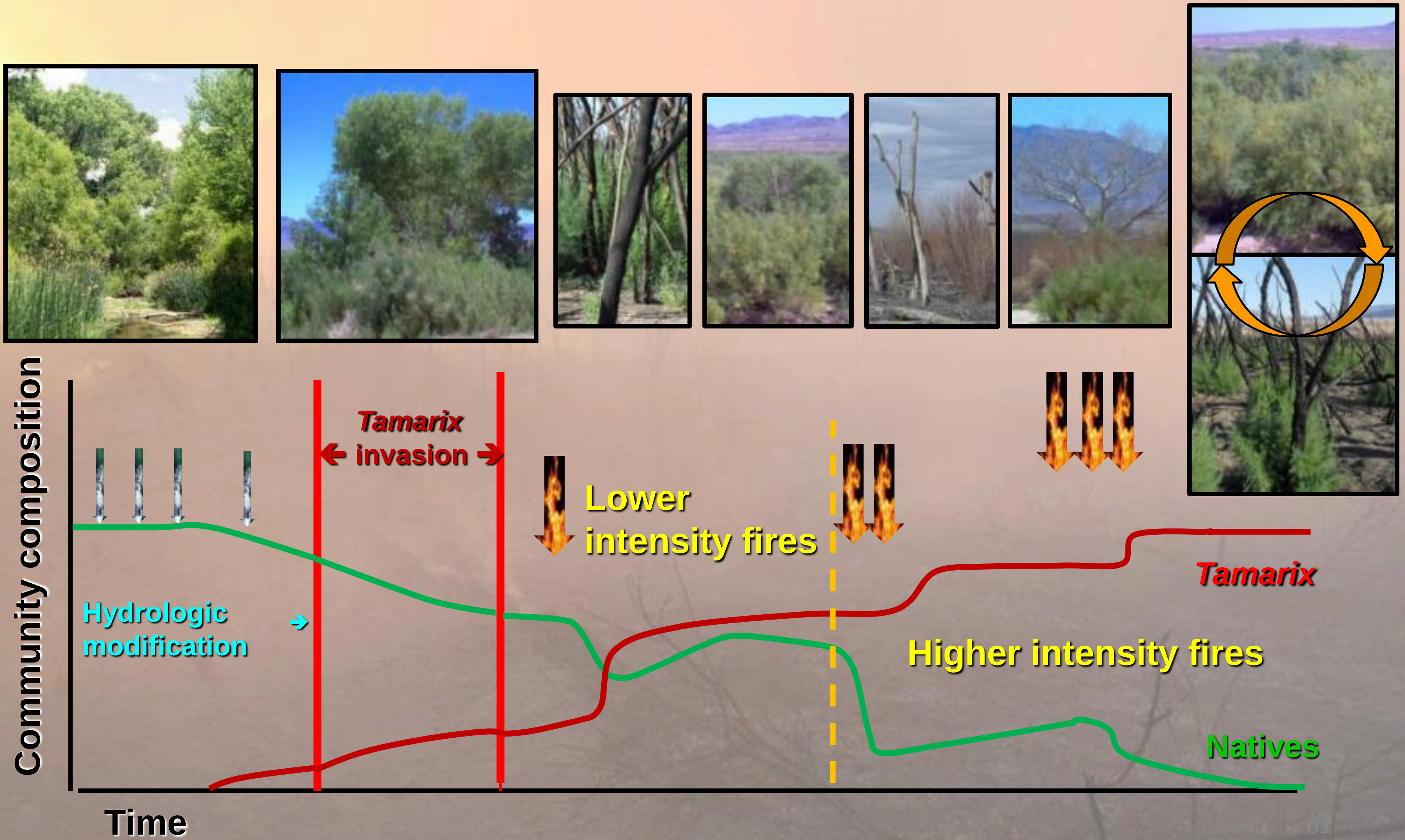
Tamarix fire intensity is biomass dependent

Is *Tamarix* invasion creating a fire cycle that further reduces native species and enhances its own success?

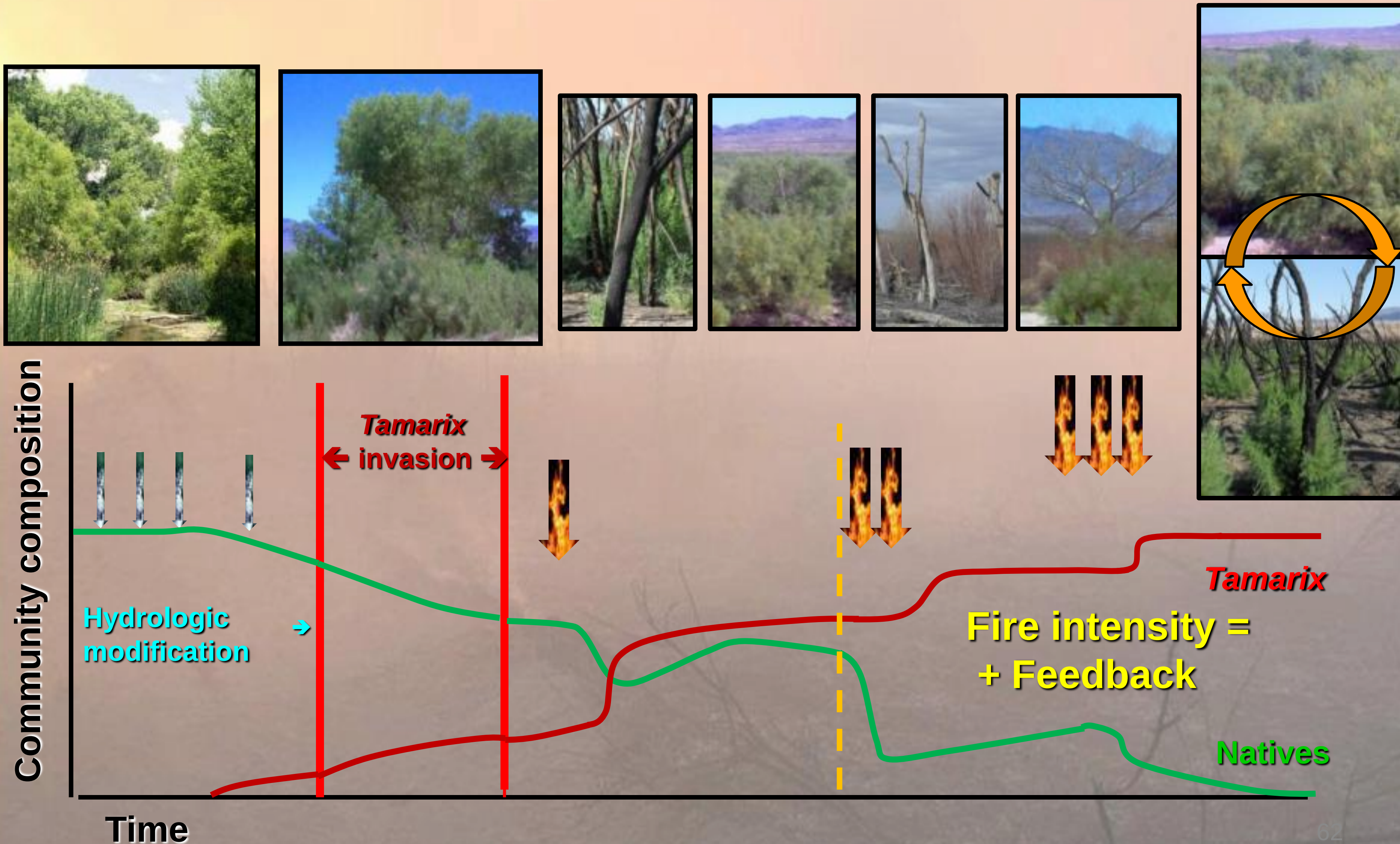
Is *Tamarix* invasion creating a fire cycle that further reduces native species and enhances its own success?

-*Tamarix* > flammable than native species.
-Native survival ↓ with ↑ pre-fire *Tamarix* density.
-*Tamarix* fire intensity is biomass dependent.

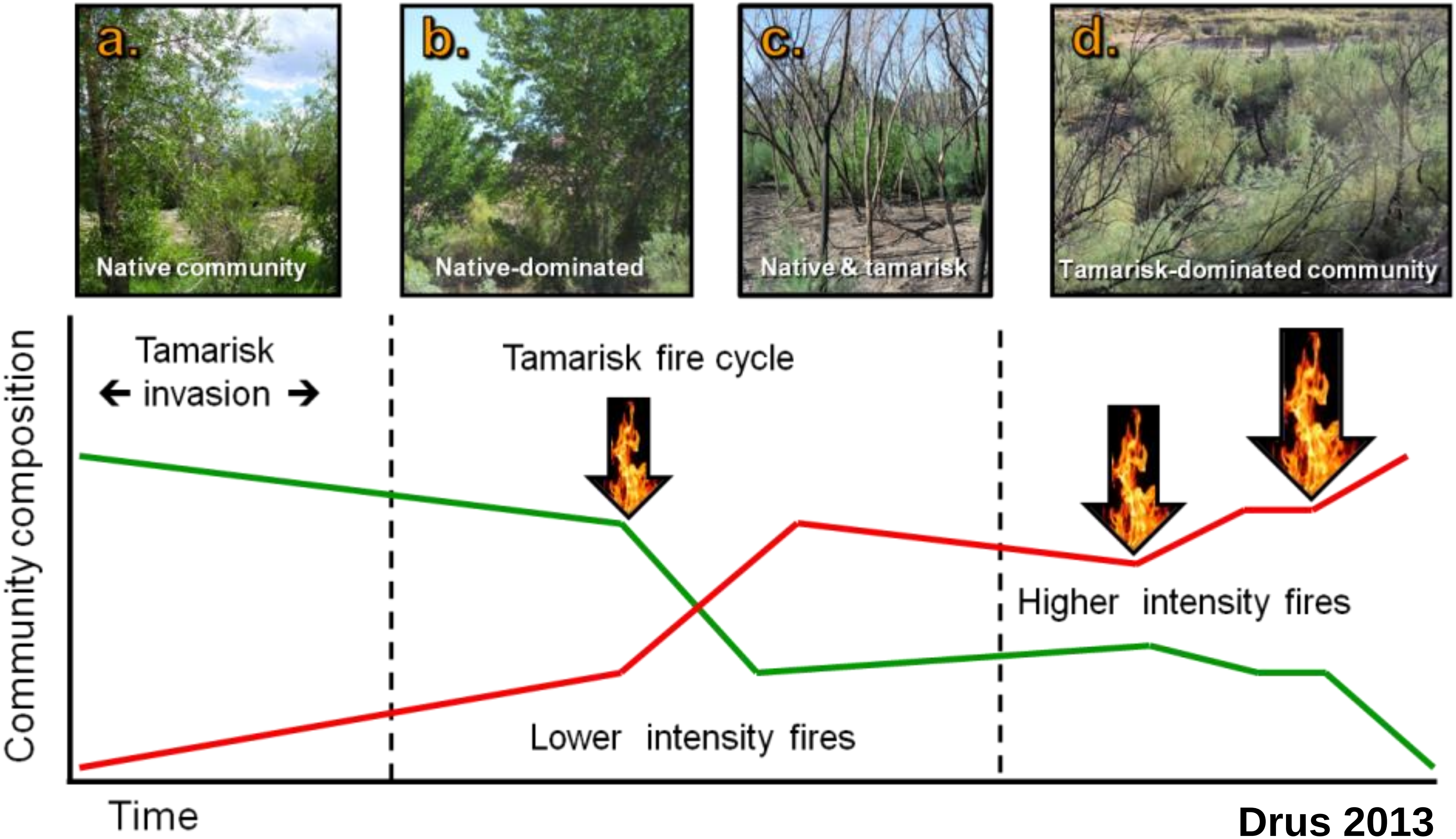
The *Tamarix* fire cycle



The *Tamarix* fire cycle



Tamarix fire trajectory



Drus 2013

Can the course of the trajectory change to allow native coexistence?

Can the *Tamarix* fire trajectory be altered to allow the coexistence of natives?

Can the *Tamarix* fire trajectory be altered to allow the coexistence of natives?

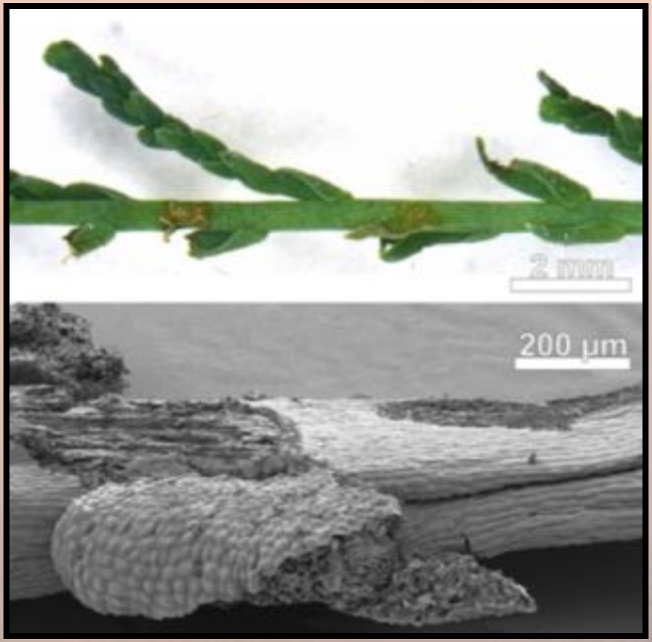
Physical and physiological effects of biocontrol

Diorhabda carinulata
(tamarisk leaf beetle)

- Native to Eurasia
- Approved for release (APHIS) in 1996
  - Years of testing (non-target species)

Diorhabda carinulata

(tamarisk leaf beetle)



Snyder et al. 2010

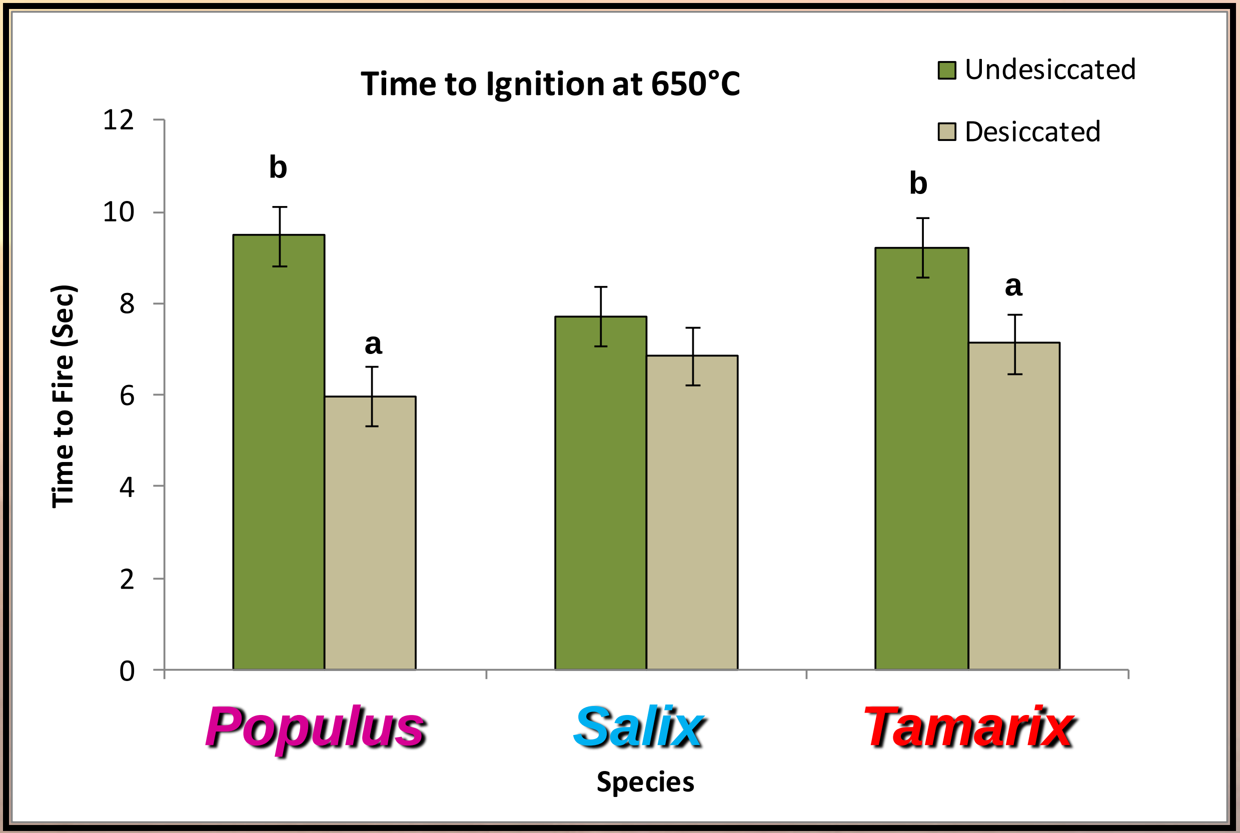
- Native to Eurasia
- Approved for release (APHIS) in 1996
  - Years of testing (non-target species)

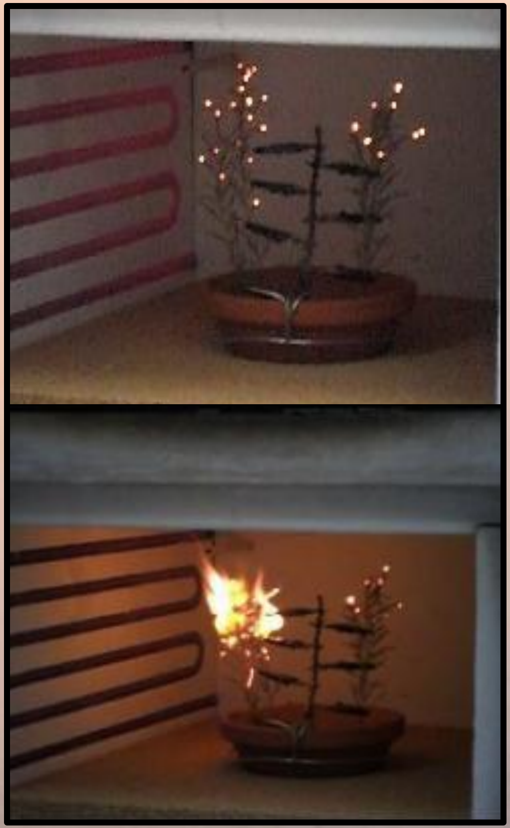
Tamarix biological control may further promote fire in riparian systems




Foliar desiccation may influence flammability and fire intensity

Muffle-furnace trials





(ANOVA P ≤ 0.05)

Foliar desiccation influences flammability at the leaf level

Prescribed burn experiments

Humboldt 2006

- Humboldt Sink Lovelock, NV
  - Summer and Fall burn, unburned control
  - 3 + seasons of biocontrol

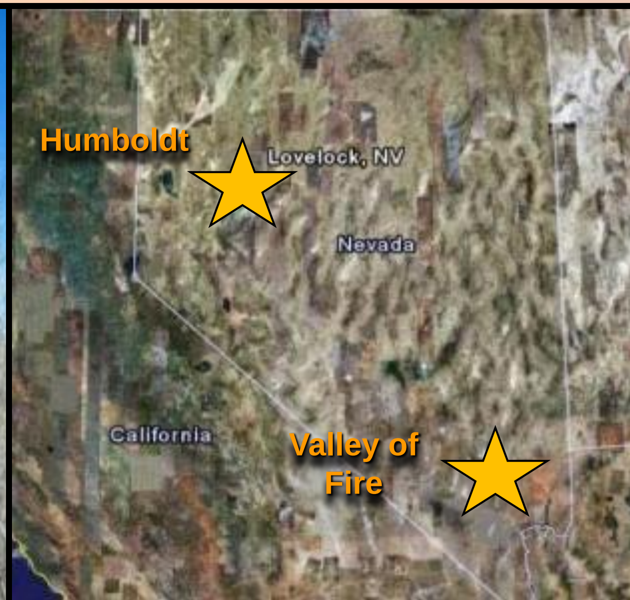
Gradient of desiccation

Humboldt Sink, N. Nevada Aug & Oct 2006

3+ seasons of *Diorhabda* herbivory

Prescribed burn experiments

Humboldt 2006 | **Valley of Fire 2008**

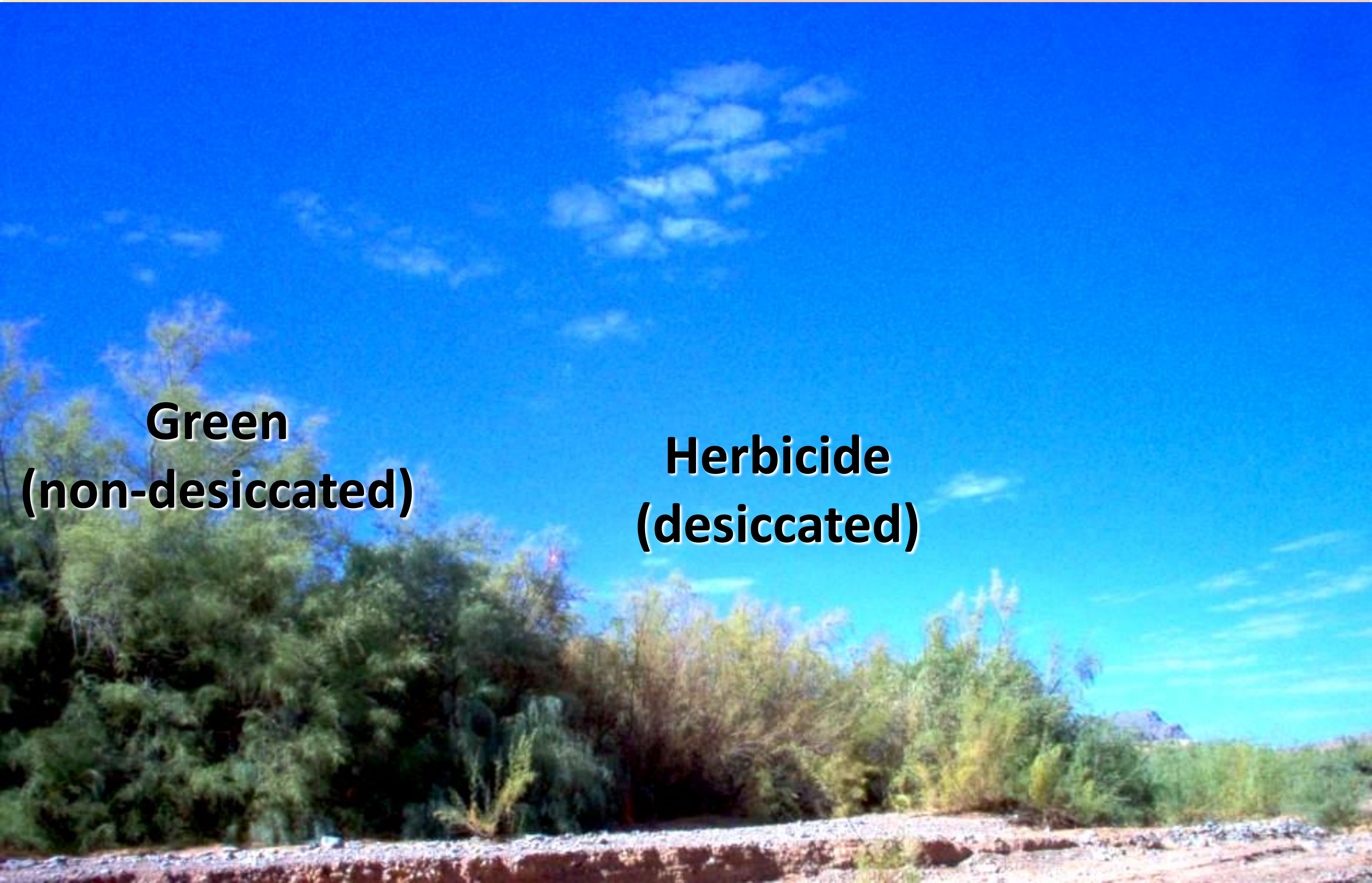


- Humboldt Sink Lovelock, NV
  - Summer and Fall burn, unburned control
  - 3 + seasons of biocontrol

- Valley of Fire Wash Overton, NV
  - Summer burn only
  - Simulated biocontrol

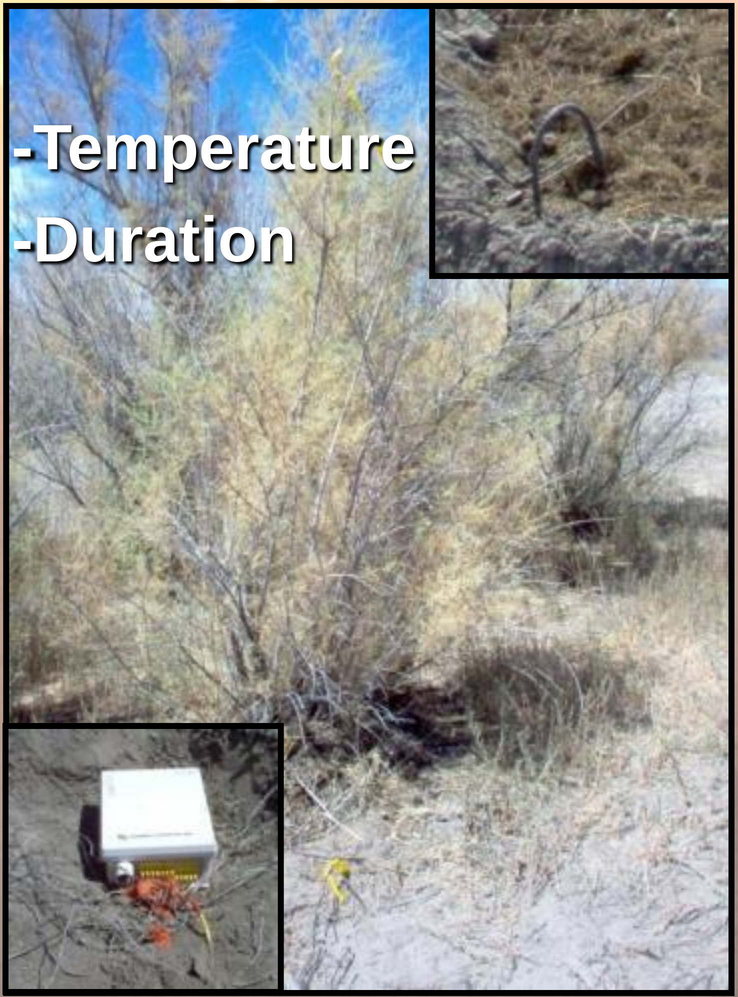
Gradient of desiccation **Discrete desiccation levels**

Valley of fire wash, S. Nevada 2008
Simulated herbivory experiment (initial beetle colonization)



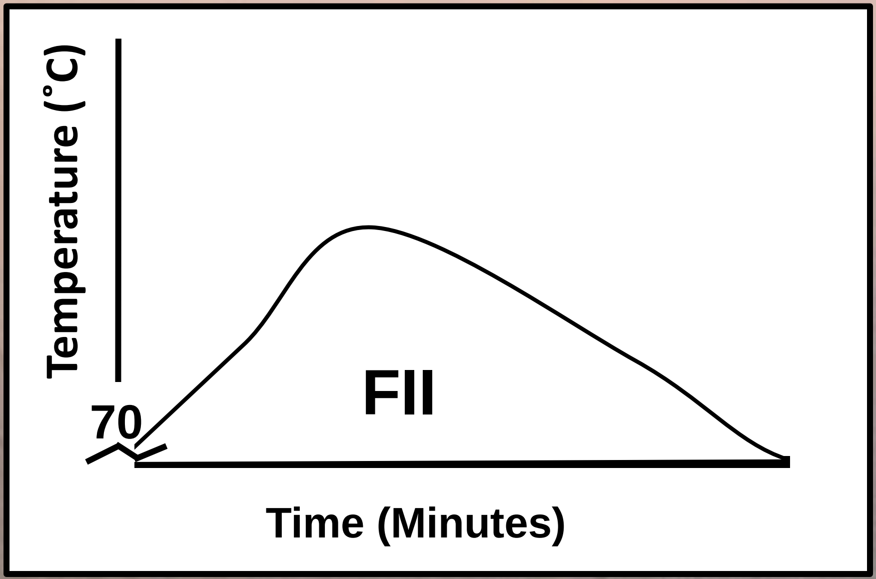
Measurements

Dataloggers and Thermocouples



Fire Intensity Index (FII)

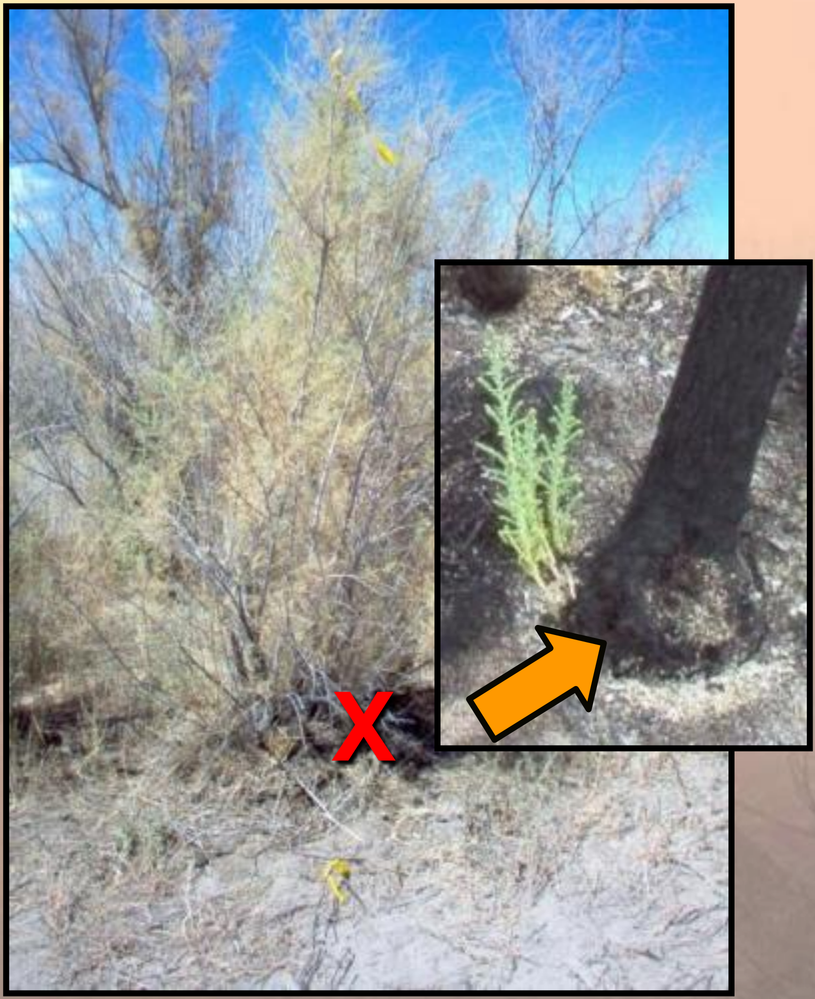
Dataloggers and Thermocouples

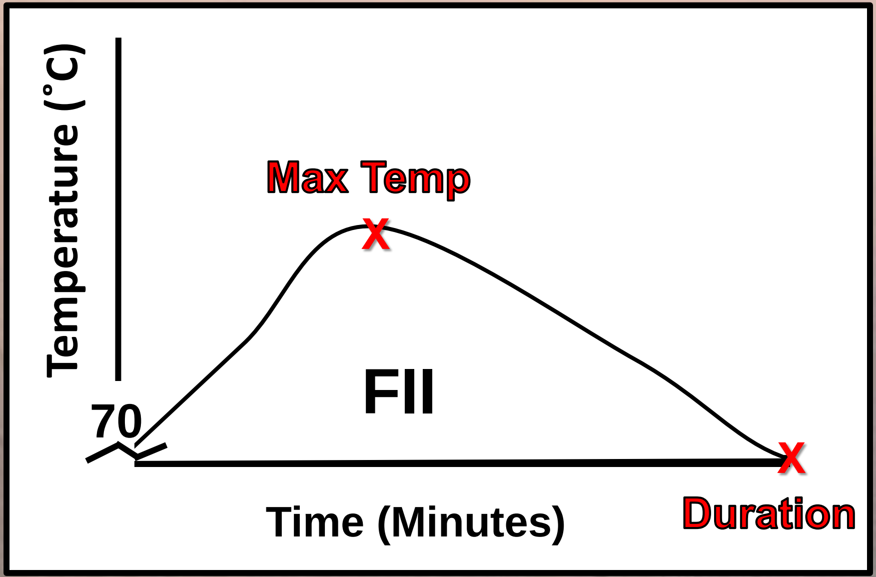


FII = heat damage index

Fire Intensity Index (FII)

Dataloggers and Thermocouples

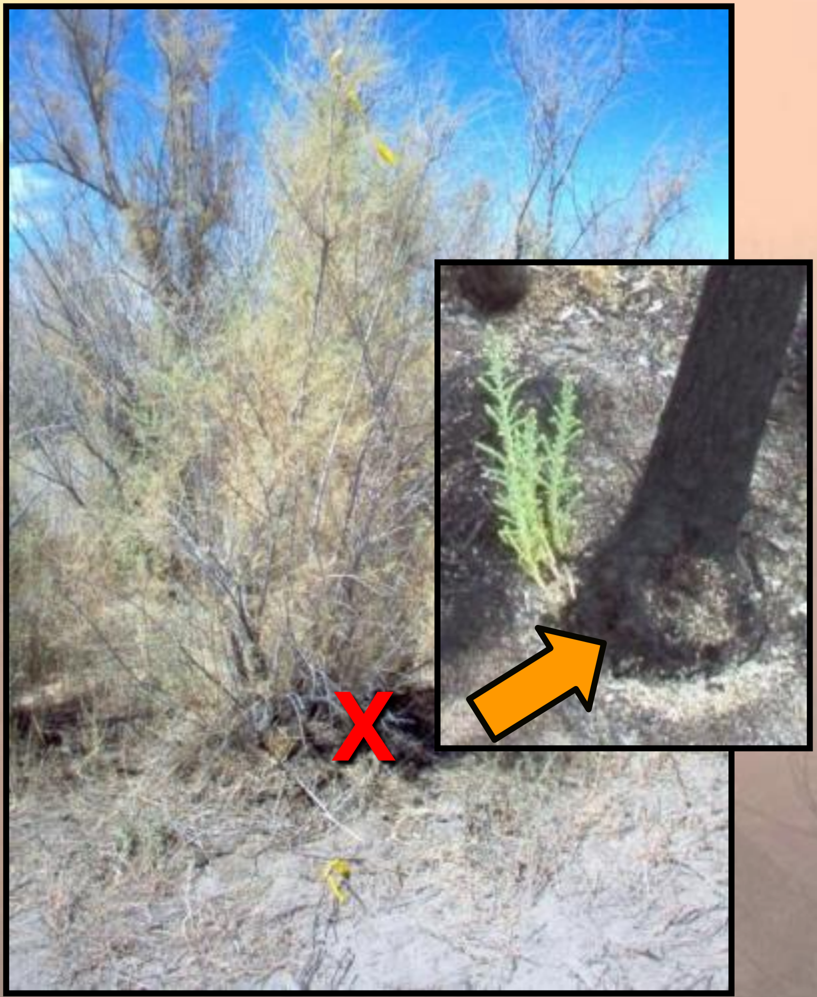


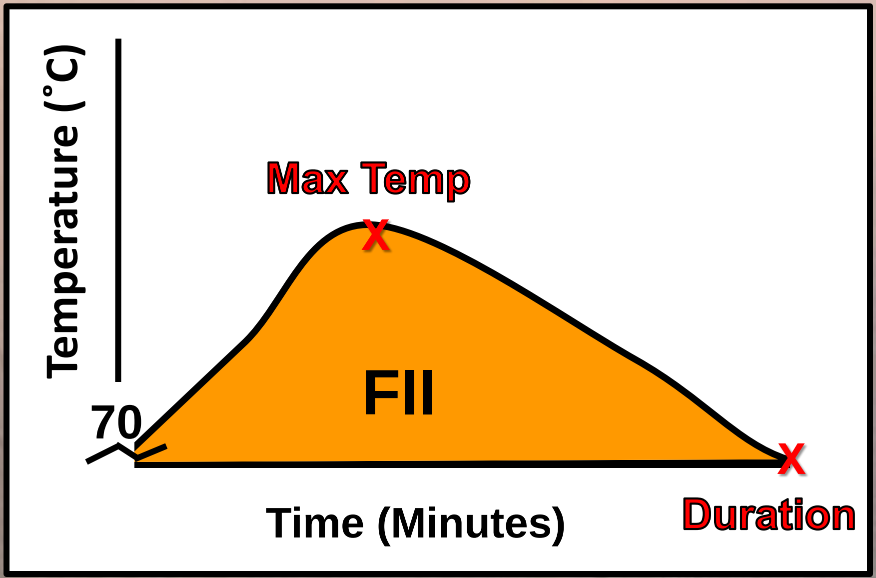


FII = heat damage index

Fire Intensity Index (FII)

Dataloggers and Thermocouples

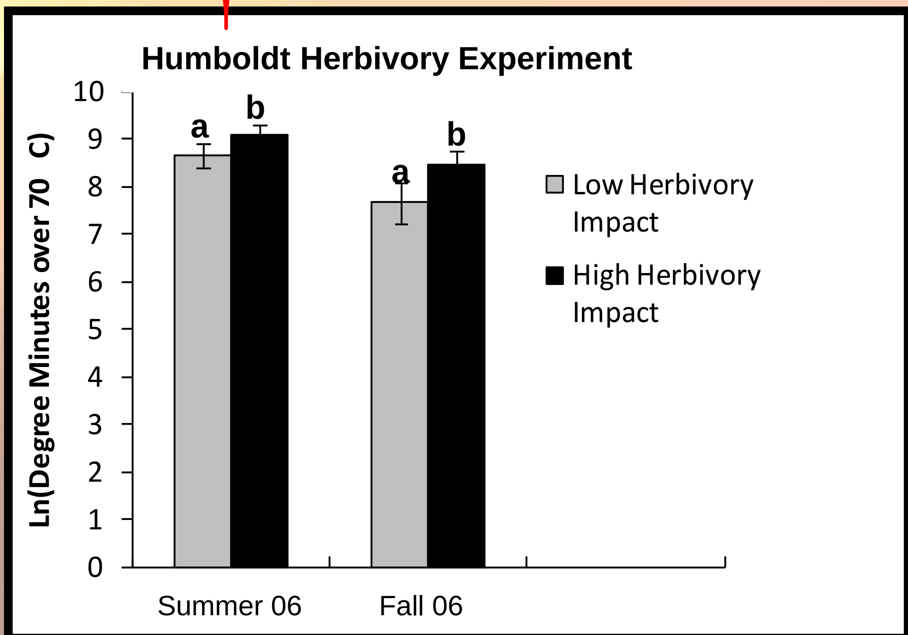


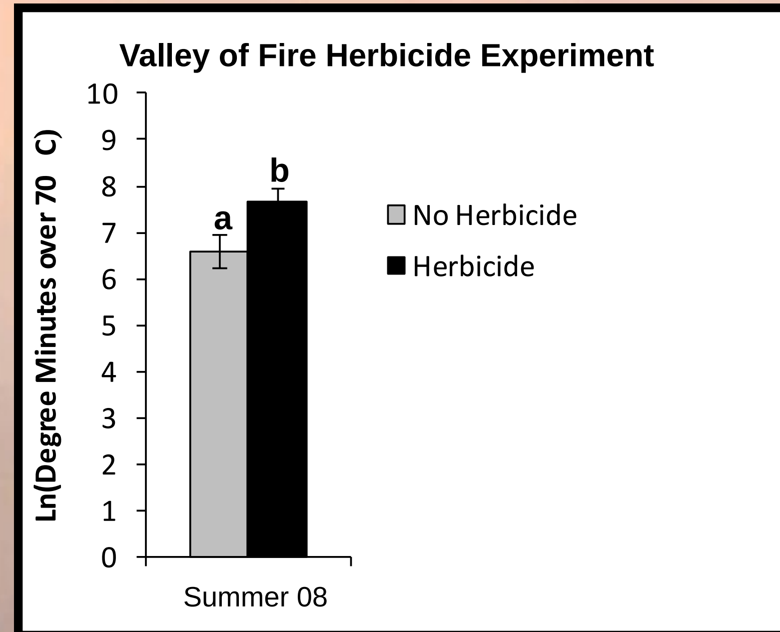


FII = heat damage index

Foliar desiccation and weather conditions influence fire intensity at the tree level

Our focus



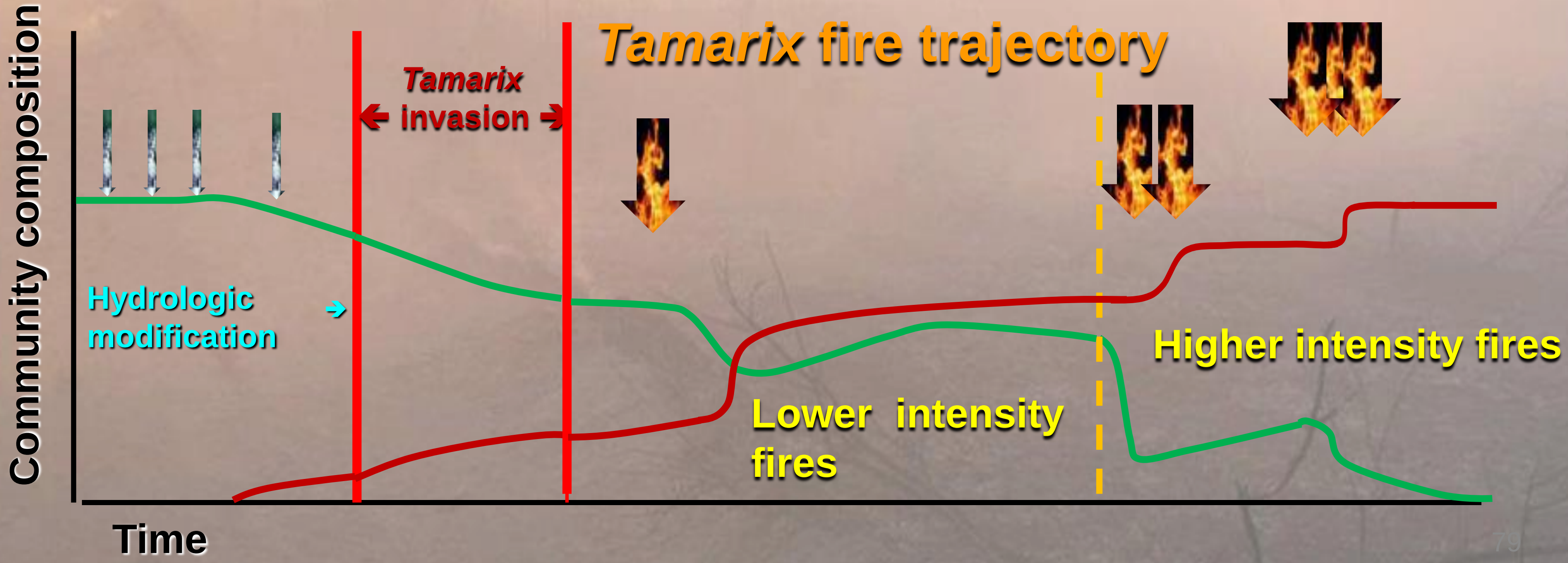


Letters (a & b) indicate differences in FII between foliar desiccation treatments, and within burn season (ANOVA: $P \leq 0.05$) within a site.

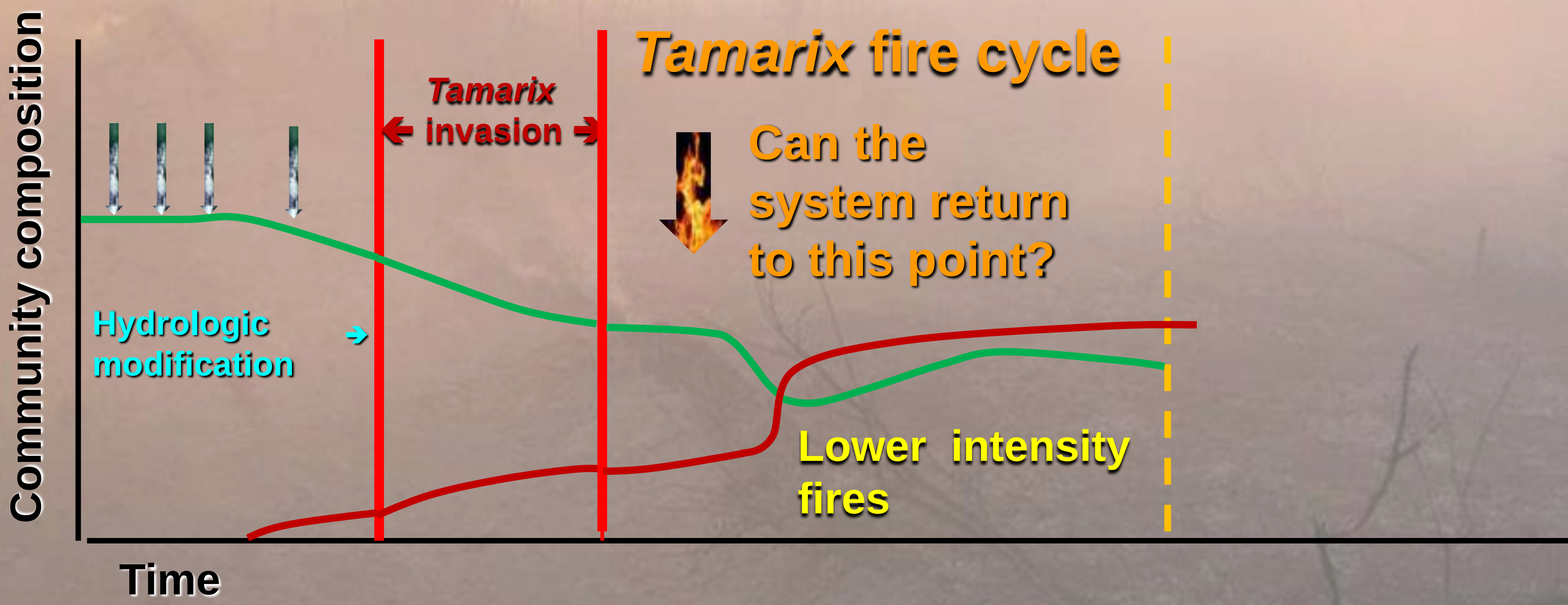
- **Humboldt: gradient of desiccation**
- **VOF: discrete levels of desiccation (>influence of desiccation)**

Drus et al. 2012

Tamarix biocontrol herbivory may alter the system's response to fire



Tamarix biocontrol herbivory may alter the system*'s* response to fire



Site: Humboldt 2006

Gradient of desiccation

- Summer burn, Fall Burn, Control
- Root-crown carbohydrate sampling

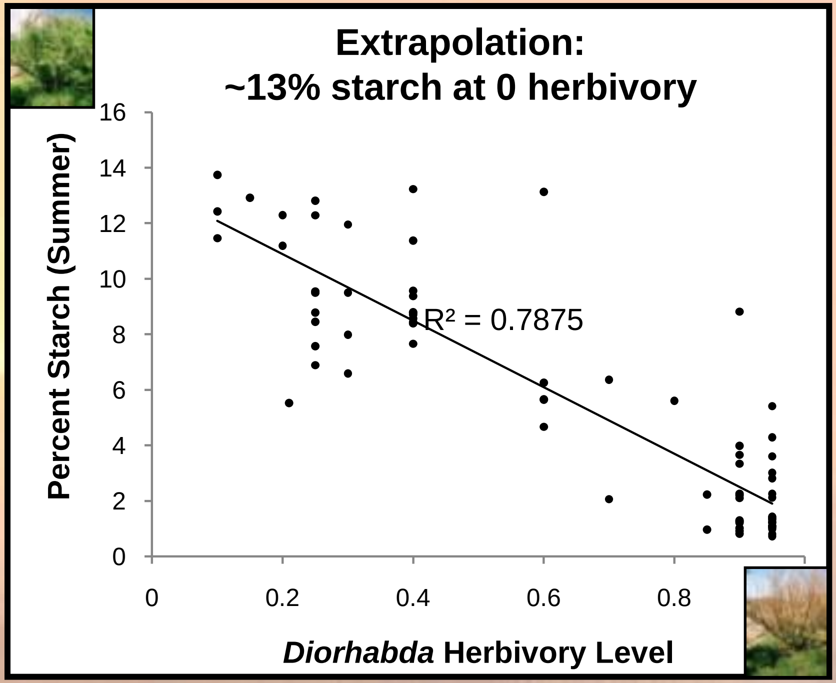
Humboldt Site

~3 years defoliation

Humboldt Site

~3 years defoliation

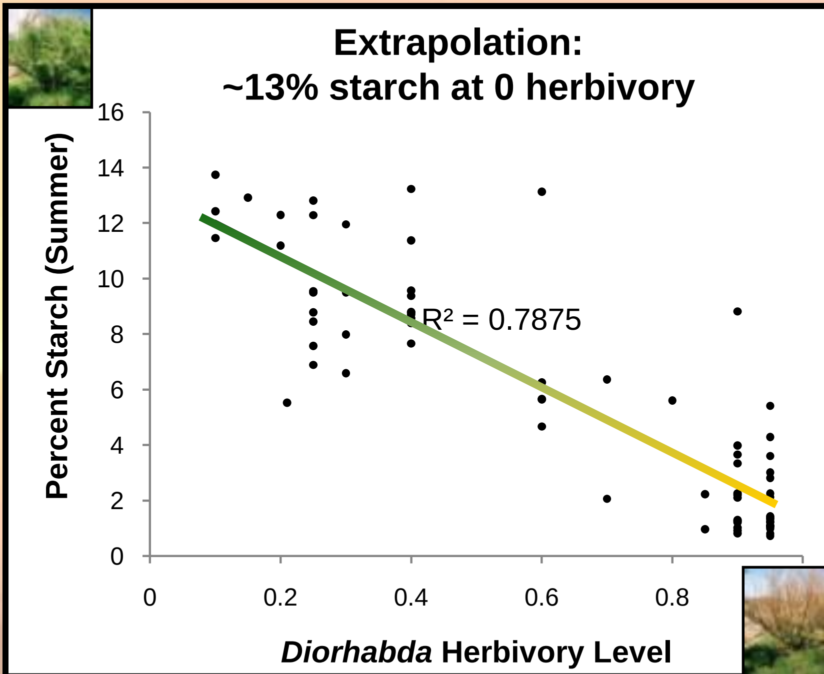
~7 years defoliation

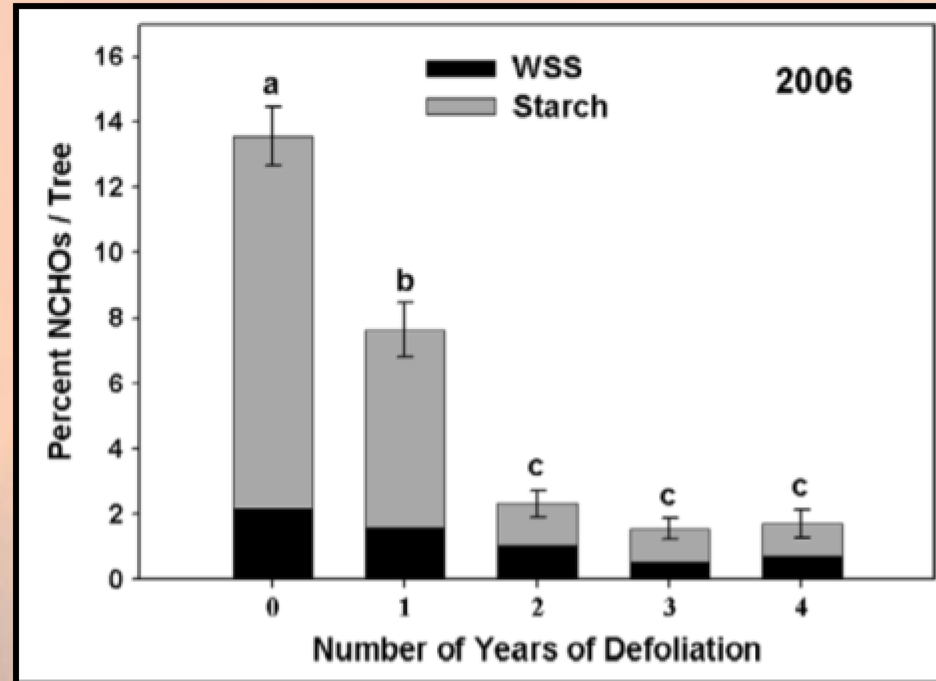


- **Root-crown starch ↓ with ↑ herbivory level**

(Linear regression <0.0001, R^2 = 0.79)

Diorhabda **herbivory depletes starch reserves in** ***Tamarix***



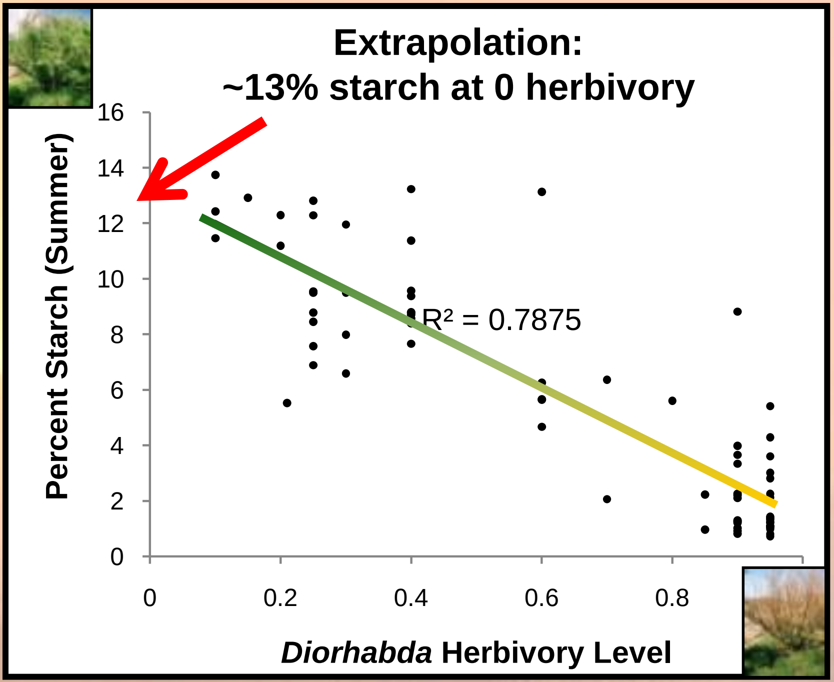


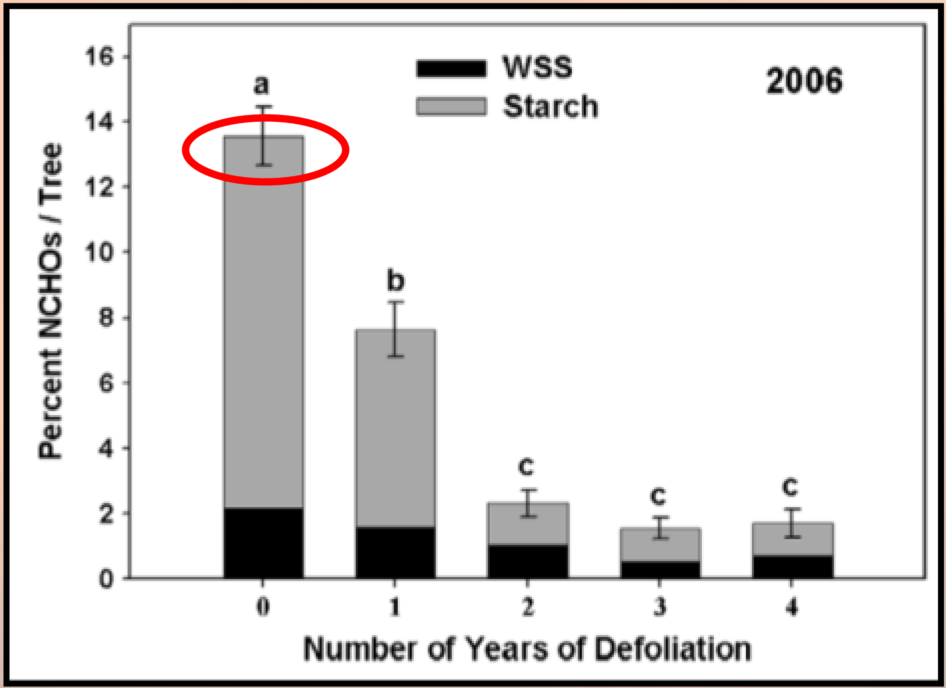
Hudgeons et al. 2007

- **Root-crown starch ↓ with ↑ herbivory level**

(Linear regression <0.0001, R^2 = 0.79)

Diorhabda **herbivory depletes starch reserves in *Tamarix***



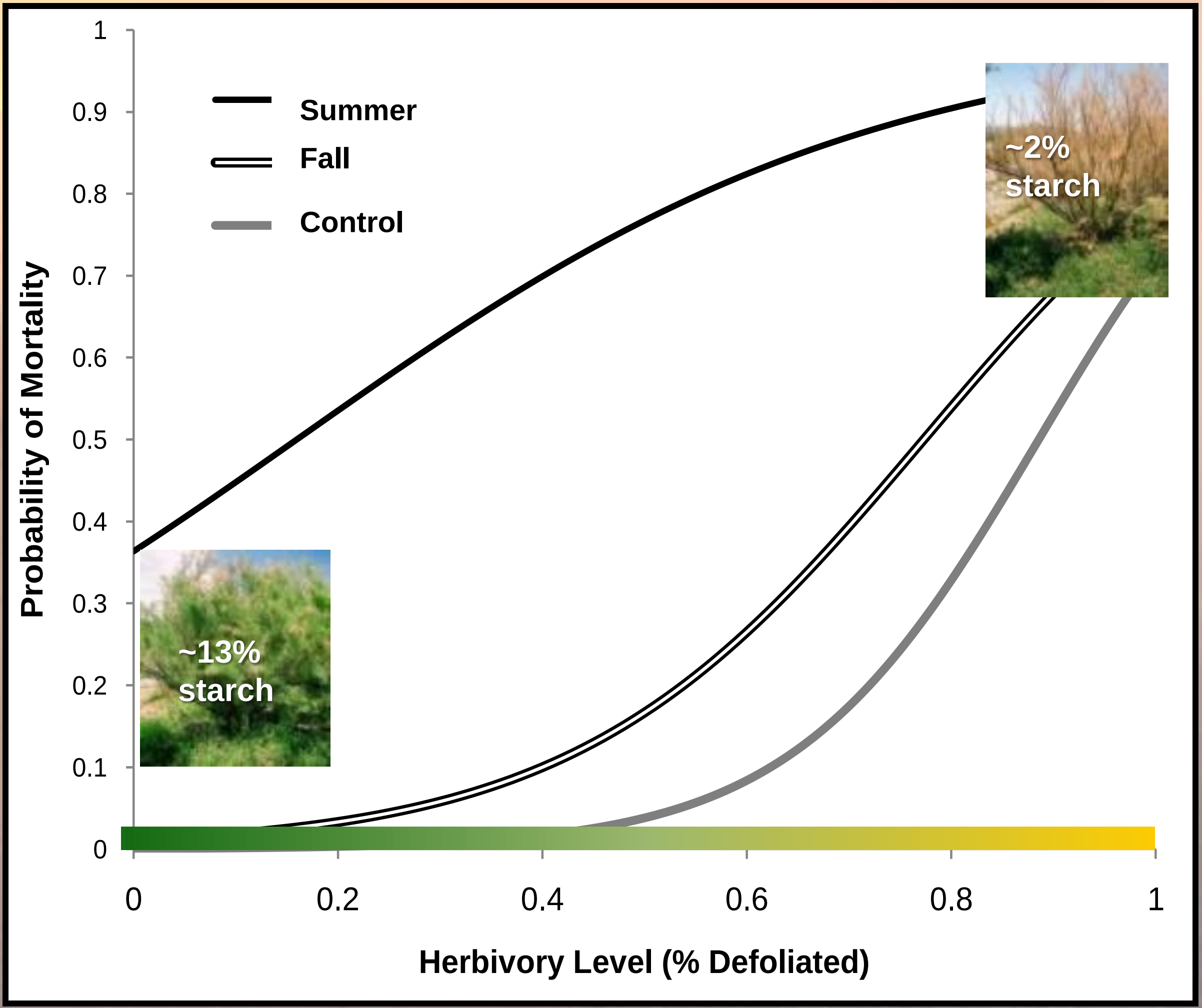


Hudgeons et al. 2007

- **Root-crown starch ↓ with ↑ herbivory level**
  (Linear regression <0.0001, R^2 = 0.79)
- **Physiological stress**

Diorhabda **herbivory depletes starch reserves in *Tamarix***

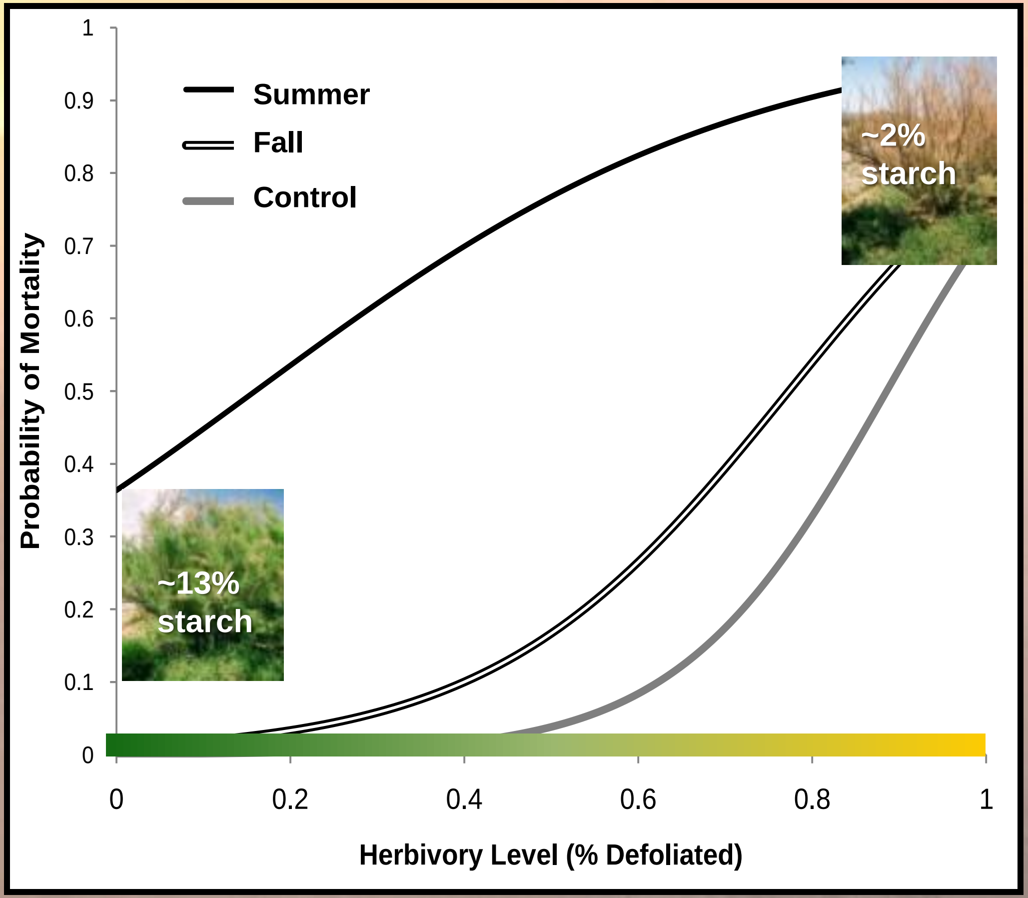
Tamarix mortality increases with *Diorhabda* herbivory impact



(Logistic Regression: Summer; $p = 0.003$ Fall; $p < 0.0001$ Control; $p < 0.001$)

Drus et al. 2014

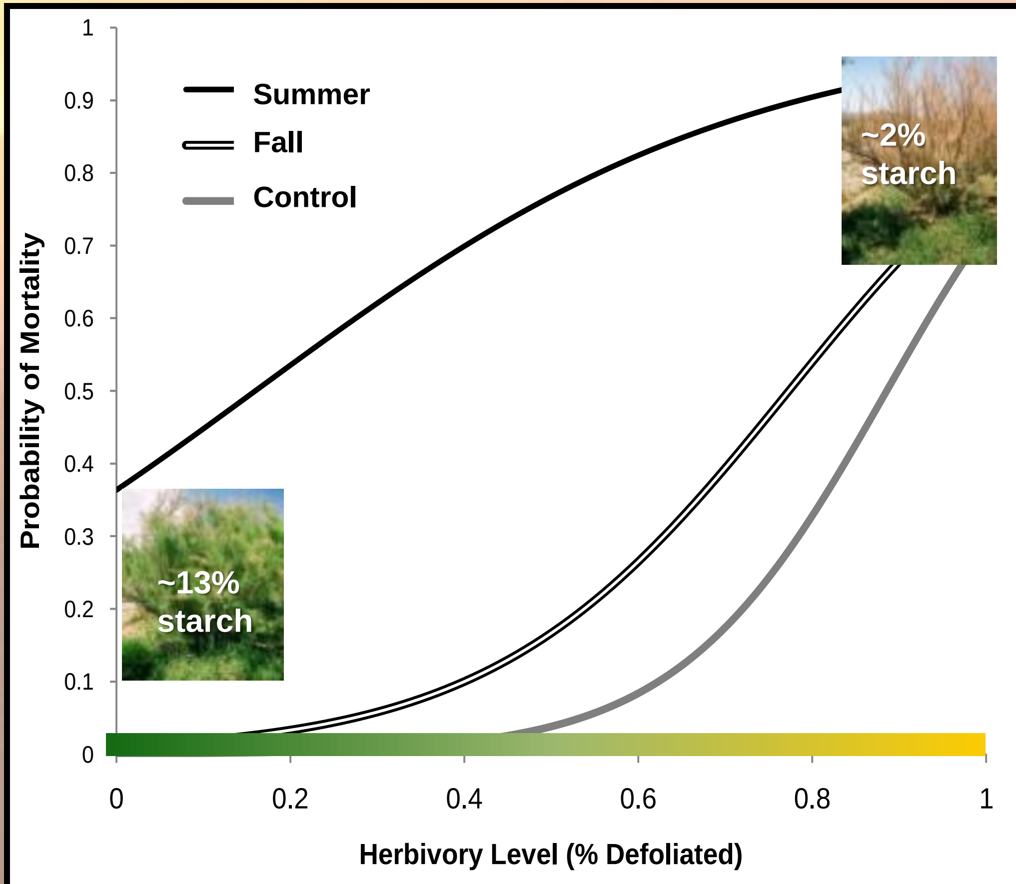
Fire & herbivory have interactive effects



What is the nature of this interaction?

- Multiple stresses interact synergistically in other systems

Fire & herbivory have interactive effects

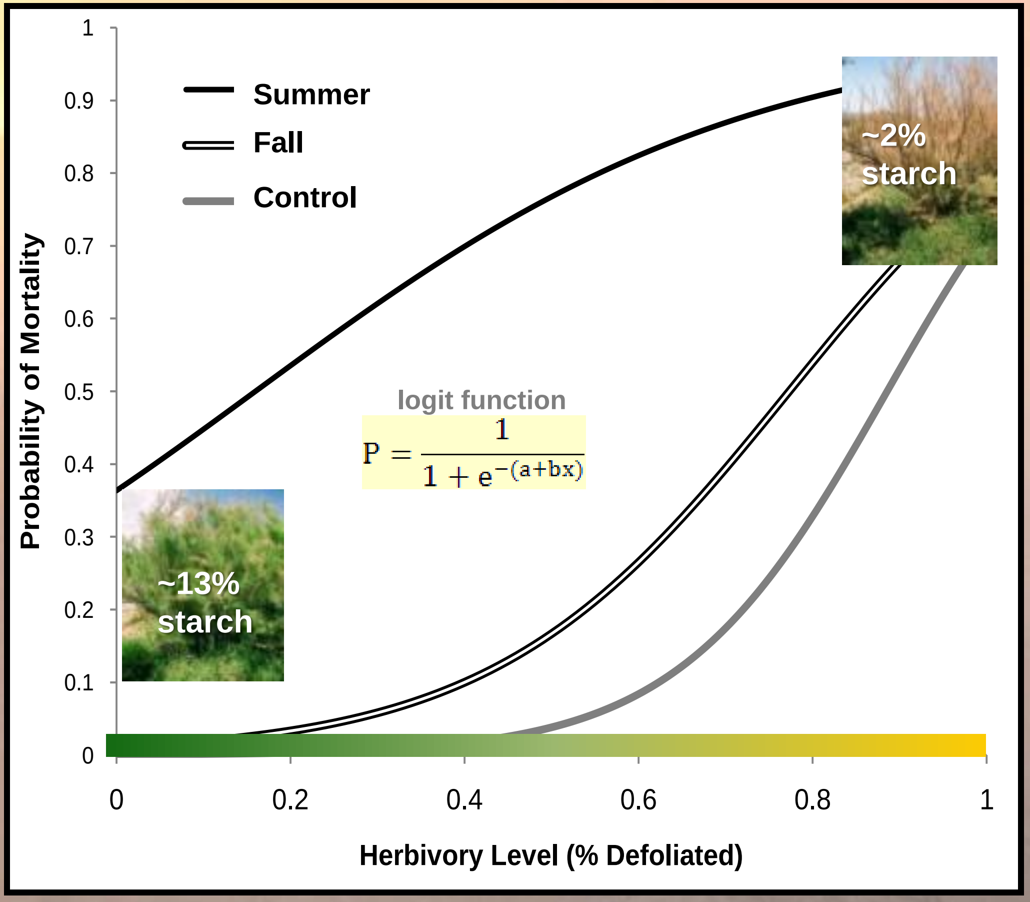


What is the nature of this interaction?

- Multiple stresses interact synergistically in other systems
- Synergy = result > sum of parts (non-additive)

Bark boring beetles enhance post-fire mortality in conifers

Fire & herbivory have interactive effects



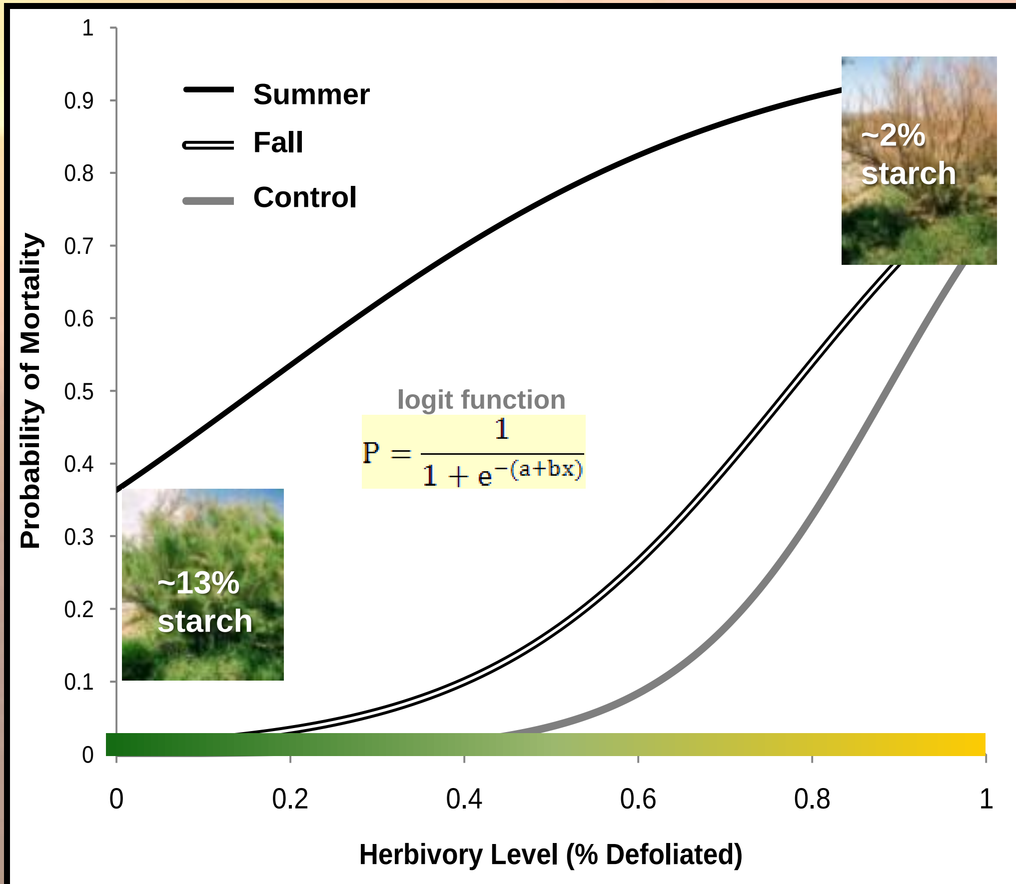
Are fire and herbivory synergistic?

- **Multiplicative risk model**
  (Soluk 1993, Sih et al. 1998)

  - Additive theory of probability:

  P(A and B) = P(A) + P(B) – P(AB)

Fire & herbivory have interactive effects



Are fire and herbivory synergistic?

- **Multiplicative risk model** (Soluk 1993, Sih et al. 1998)

  - **Additive theory of probability:**

    P(A and B) = P(A) + P(B) – P(AB)

- **If FII and herbivory are additive, then the following is true:**

$$M_{BF} = P_B + P_F - P_B P_F$$

- **If observed mortality > than M_{BF}, the factors are synergistic**

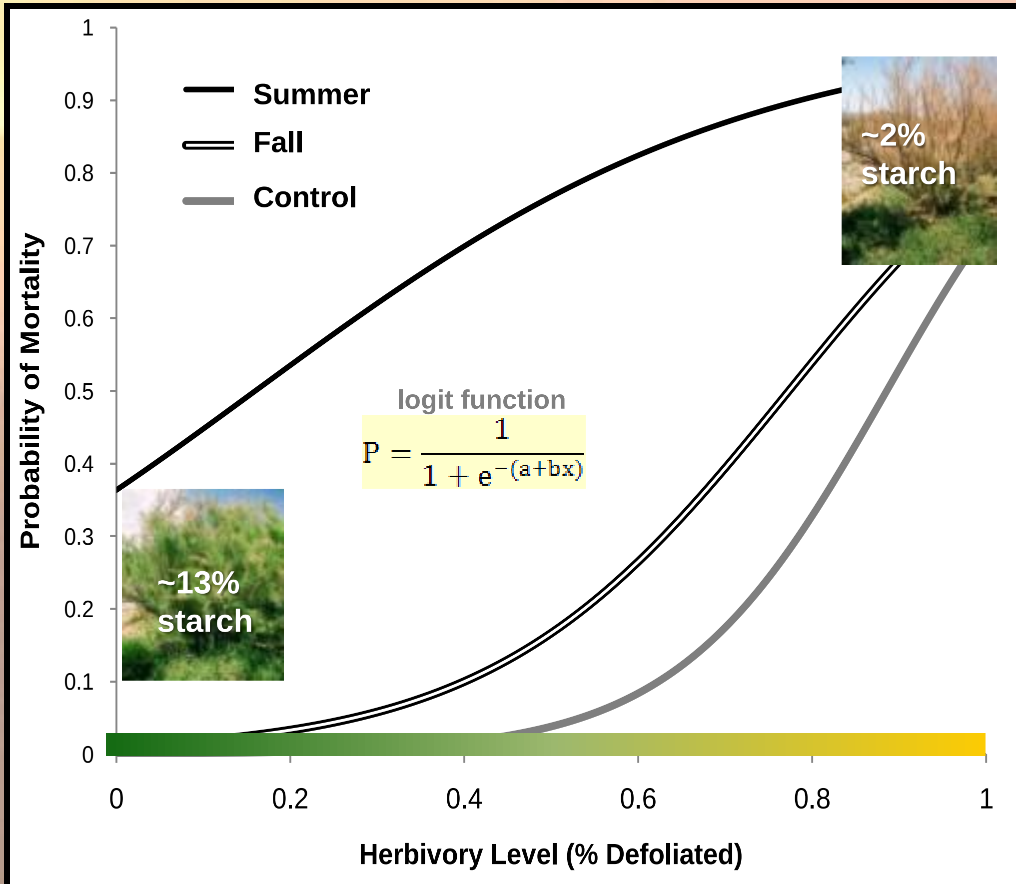
M_{BF} = mortality if fire and herbivory are additive

P_B = mortality due to biocontrol only (control)

P_F = mortality due to fire alone (extrapolated to 0% herbivory using logit function)

$P_B P_F$ = product of P_B and P_F

Fire & herbivory have interactive effects



Are fire and herbivory synergistic?

- **Multiplicative risk model**
  (Soluk 1993, Sih et al. 1998)

  - Additive theory of probability:

  P(A and B) = P(A) + P(B) – P(AB)

- If FII and herbivory are **additive,** then the following is true:

$$M_{BF} = P_B + P_F - P_B P_F$$

- If observed mortality > than M_{BF}, the factors are synergistic

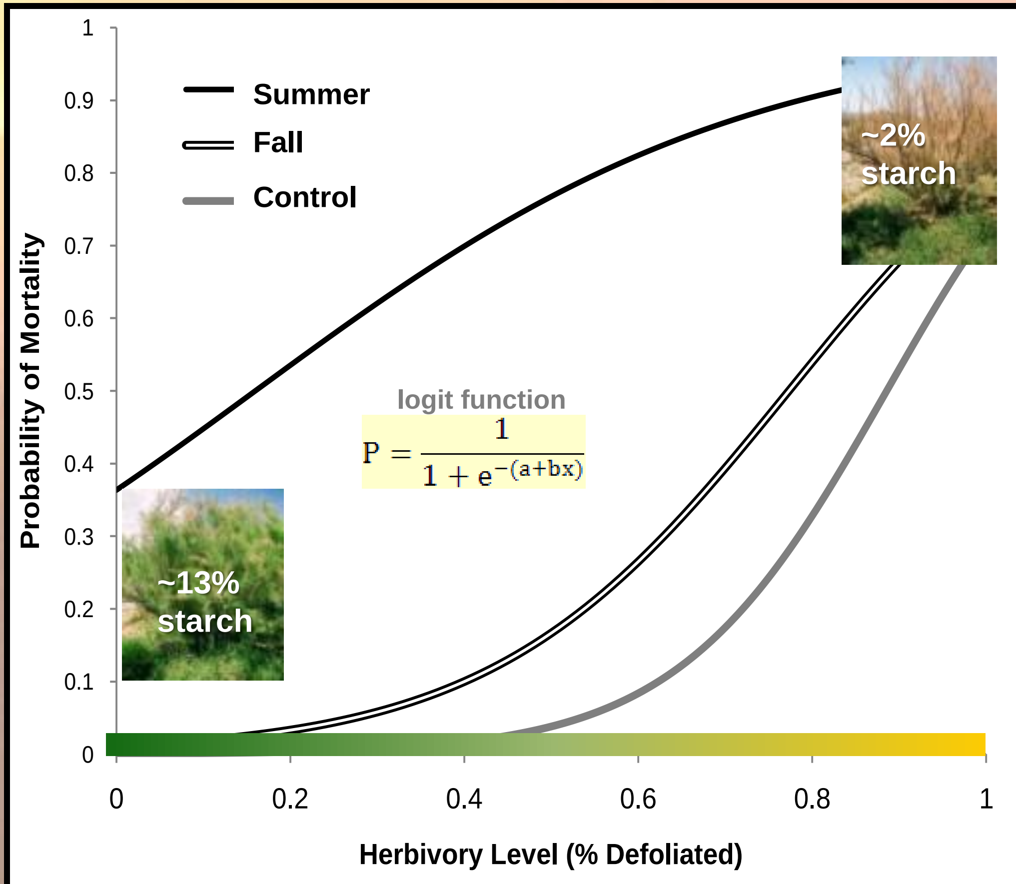
M_{BF} = mortality if fire and herbivory are additive

P_B = mortality due to biocontrol only (control)

P_F = mortality due to fire alone (extrapolated to 0% herbivory using logit function)

$P_B P_F$ = product of P_B and P_F

Fire & herbivory have interactive effects



M_{BF} = mortality if fire and herbivory are additive

P_B = mortality due to biocontrol only (control)

P_F = mortality due to fire alone (extrapolated to 0% herbivory using logit function)

$P_B P_F$ = product of P_B and P_F

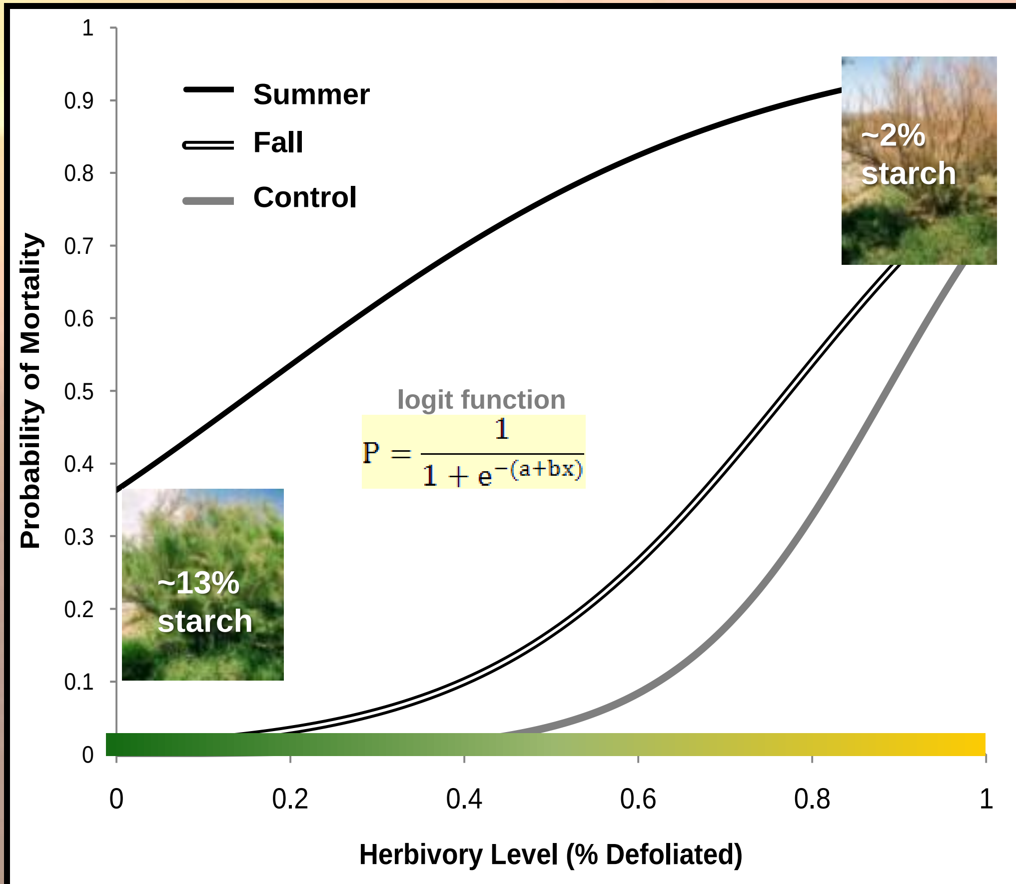
Are fire and herbivory synergistic?

- **Multiplicative risk model** (Soluk 1993, Sih et al. 1998)
  - Additive theory of probability:
    P(A and B) = P(A) + P(B) – P(AB)
- If FII and herbivory are additive, then the following is true:

$$M_{BF} = P_B + P_F - P_B P_F$$

- If observed mortality > than M_{BF}, the factors are synergistic

Fire & herbivory have interactive effects



Are fire and herbivory synergistic?

- **Multiplicative risk model** (Soluk 1993, Sih et al. 1998)

  - Additive theory of probability:

    P(A and B) = P(A) + P(B) – P(AB)

- If FII and herbivory are **additive,** then the following is true:

$$M_{BF} = P_B + P_F - P_B P_F$$

- If observed mortality > than M_{BF}, the factors are synergistic

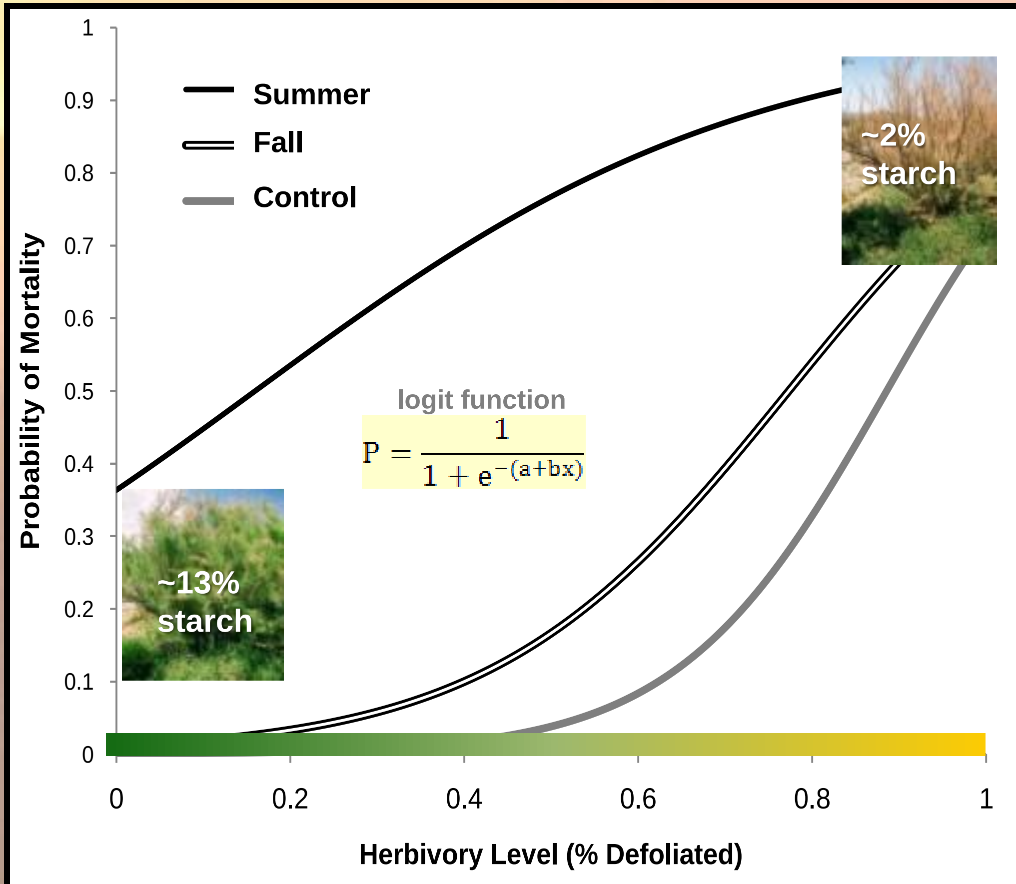
M_{BF} = mortality if fire and herbivory are additive

P_B = mortality due to biocontrol only (control)

P_F = mortality due to fire alone (extrapolated to 0% herbivory using logit function)

$P_B P_F$ = product of P_B and P_F

Fire & herbivory have interactive effects



Are fire and herbivory synergistic?

- **Multiplicative risk model** (Soluk 1993, Sih et al. 1998)
  - Additive theory of probability:
    P(A and B) = P(A) + P(B) – P(AB)
- If FII and herbivory are additive, then the following is true:

$$M_{BF} = P_B + P_F - P_B P_F$$

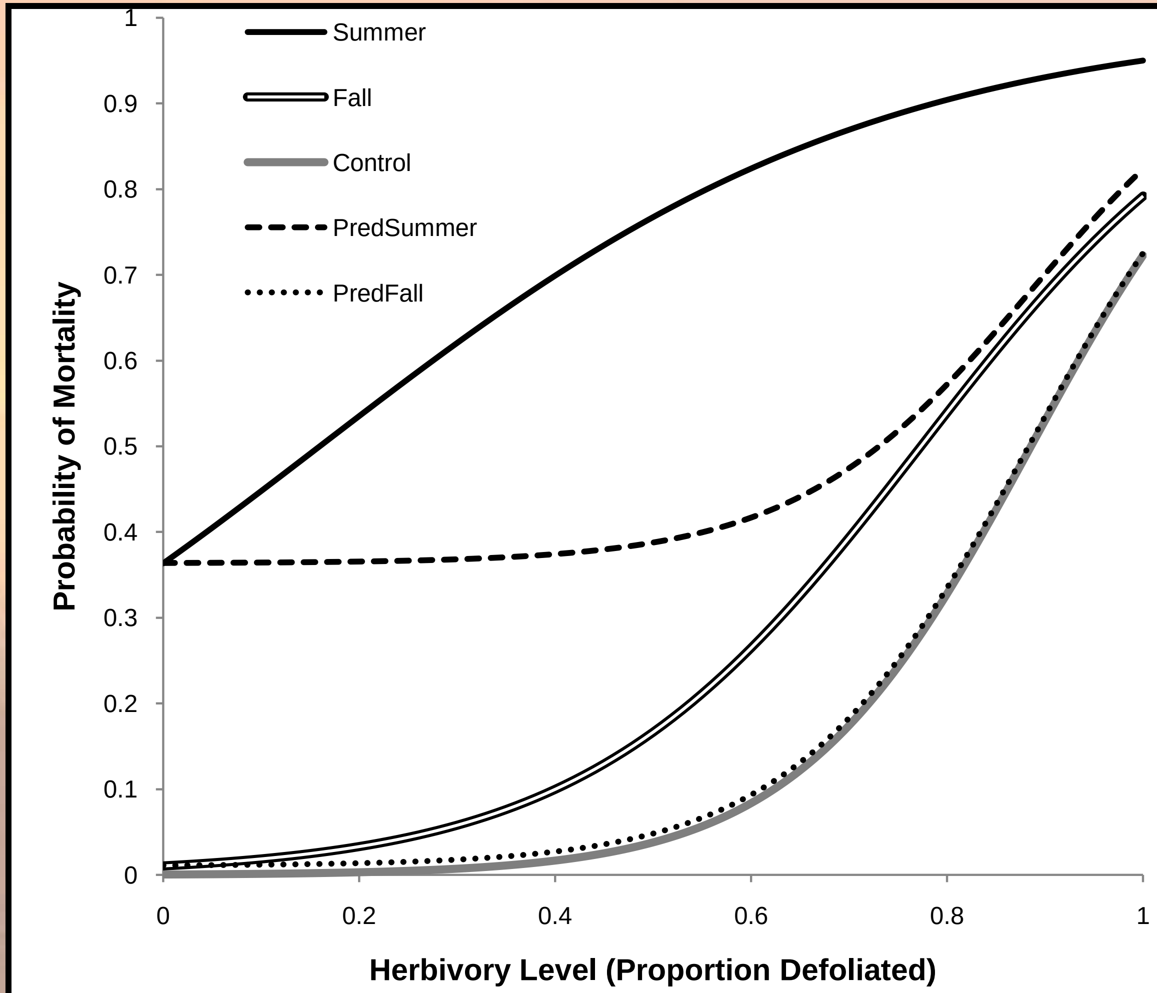
- If observed mortality > than M_{BF}, the factors are synergistic

M_{BF} = mortality if fire and herbivory are additive

P_B = mortality due to biocontrol only (control)

P_F = mortality due to fire alone (extrapolated to 0% herbivory using logit function)

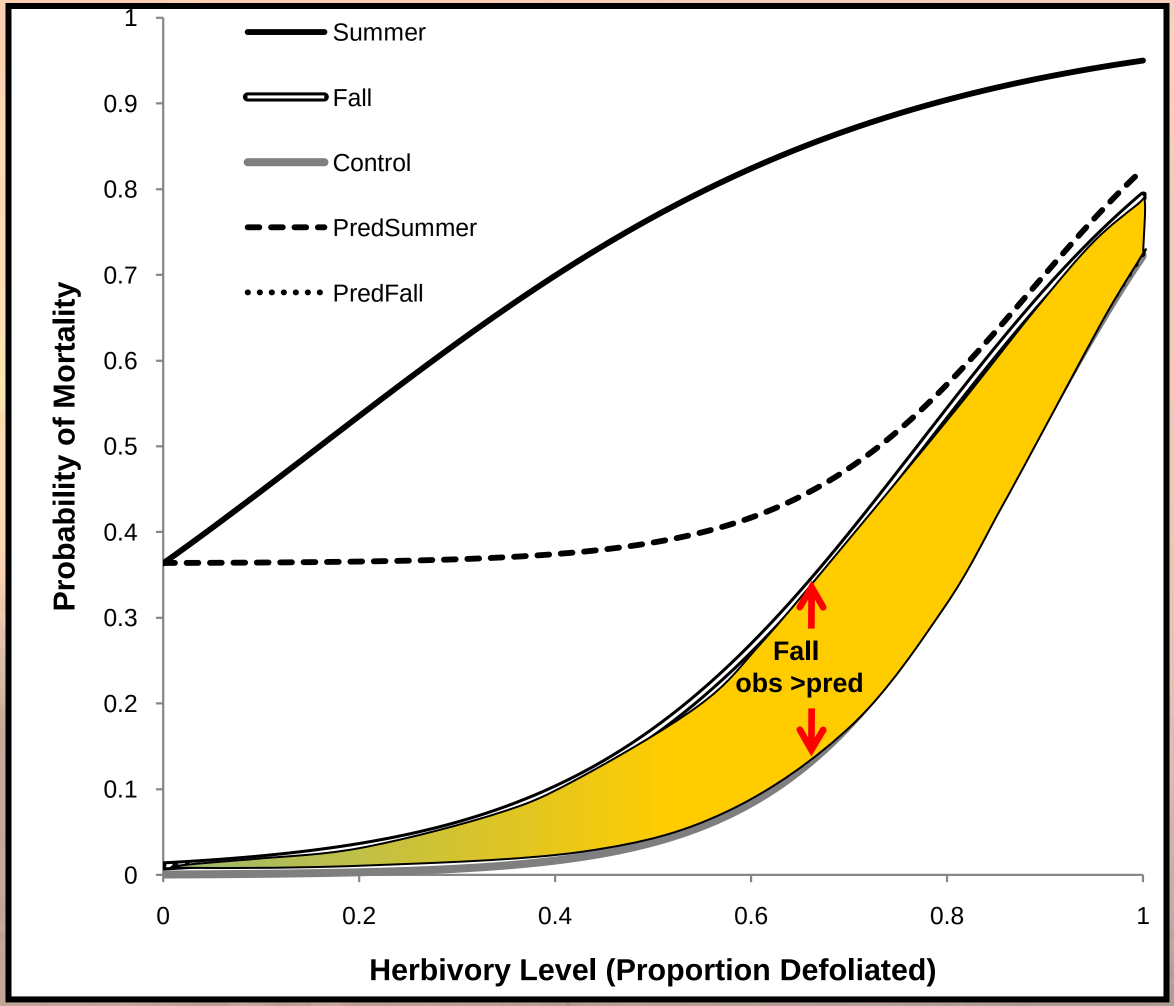
$P_B P_F$ = product of P_B and P_F



Synergy: **Observed (logistic regression) is > than predicted (multiplicative model)**

(Wilcoxon Paired Sample Test $\leq$ 0.05)

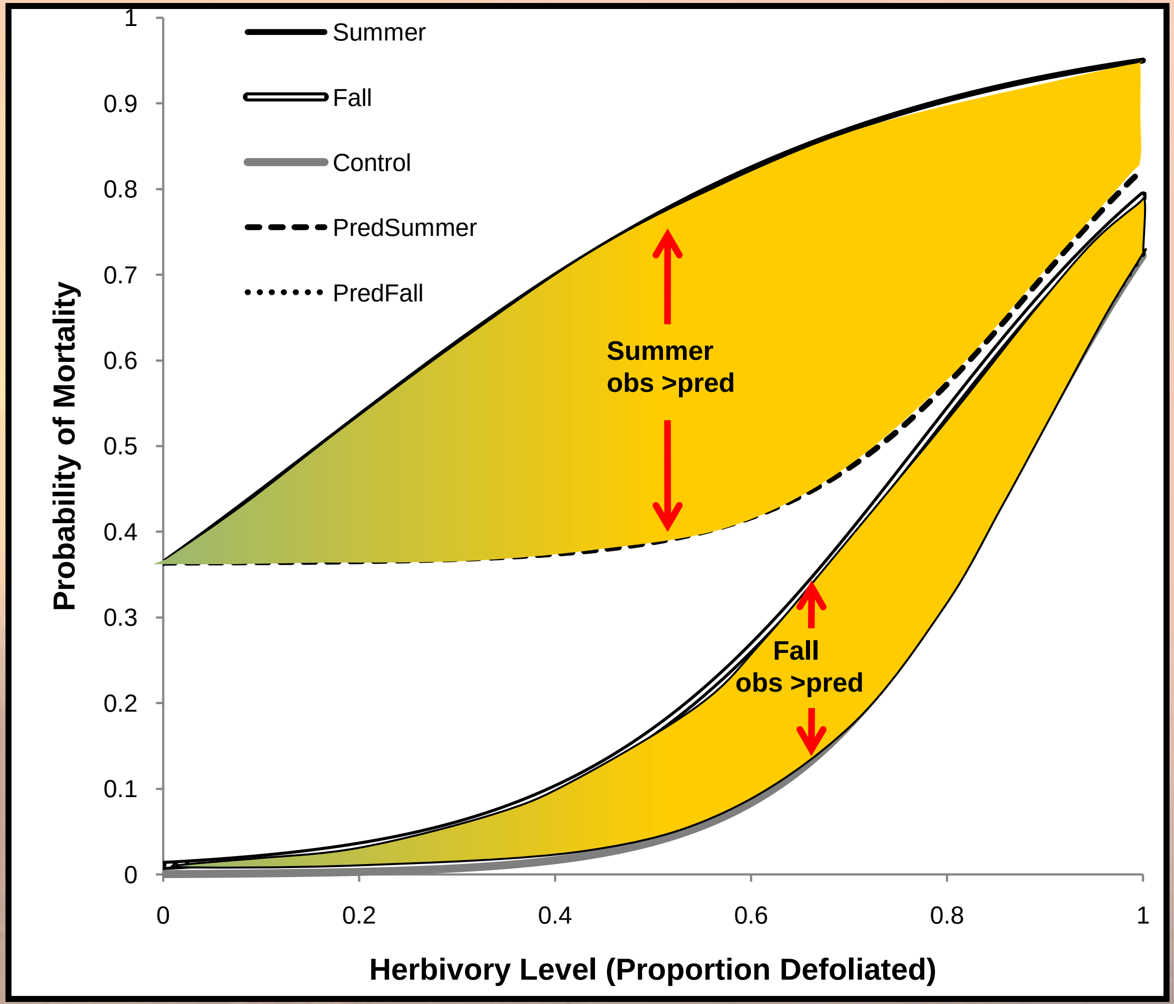
Diorhabda* herbivory & fire interact synergistically to enhance fire-induced mortality in *Tamarix



Synergy: Observed (logistic regression) is > than predicted (multiplicative model)

(Wilcoxon Paired Sample Test $\leq$ 0.05)

Diorhabda herbivory & fire interact synergistically to enhance fire-induced mortality in *Tamarix*

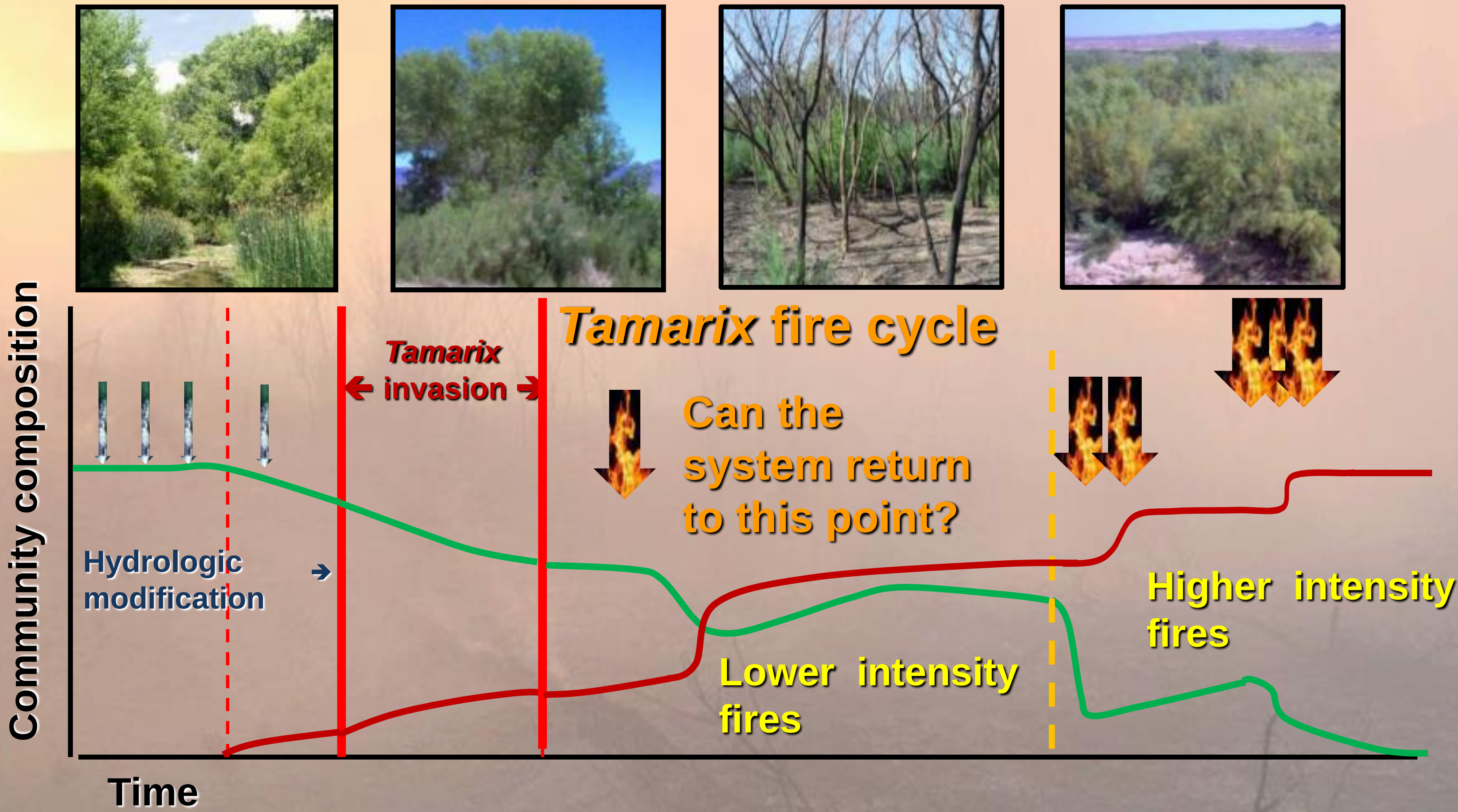


Synergy: **Observed (logistic regression) is > than predicted (multiplicative model)**

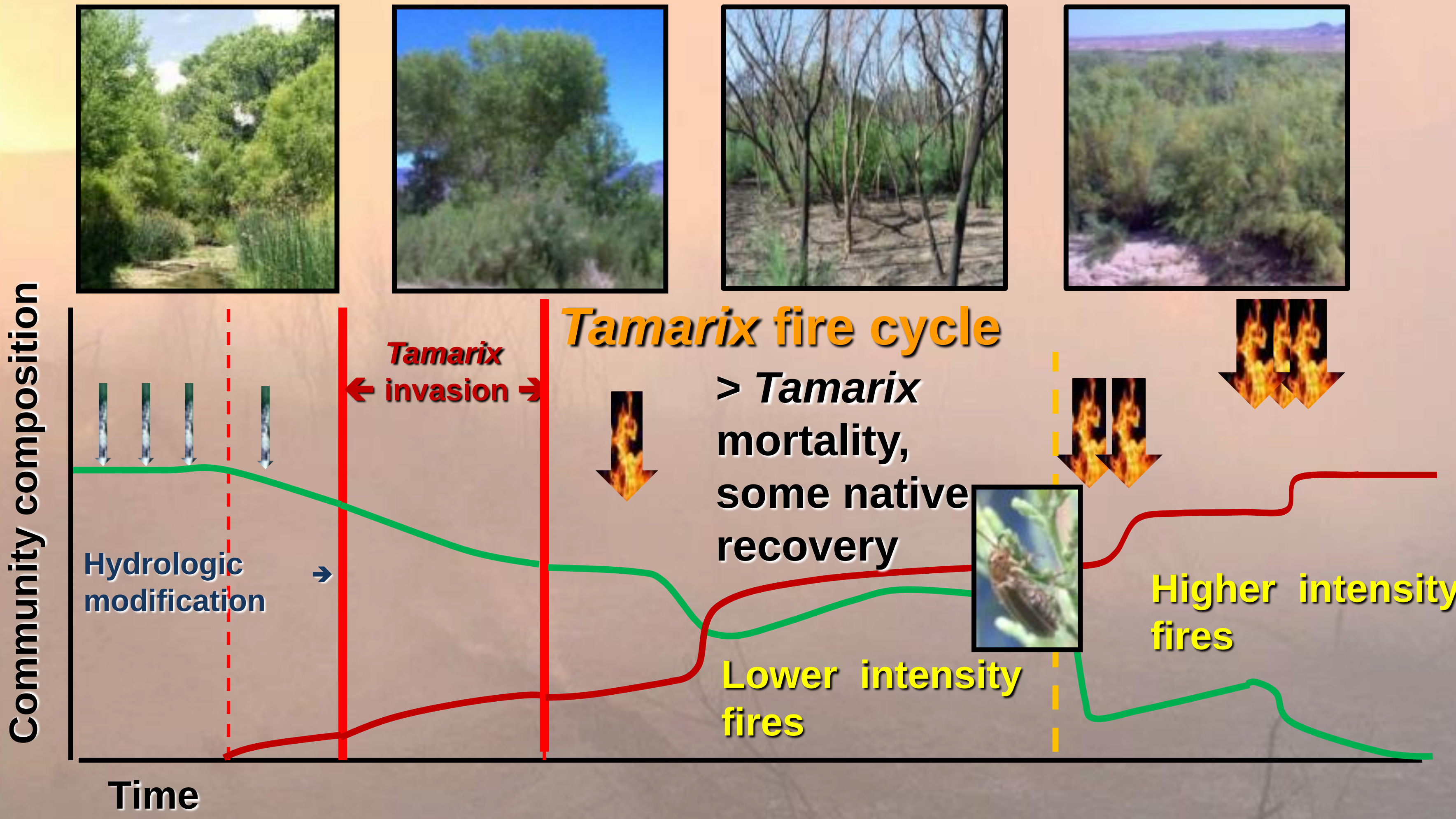
(Wilcoxon Paired Sample Test < 0.05)

Diorhabda **herbivory & fire interact synergistically to enhance fire-induced mortality in** ***Tamarix***

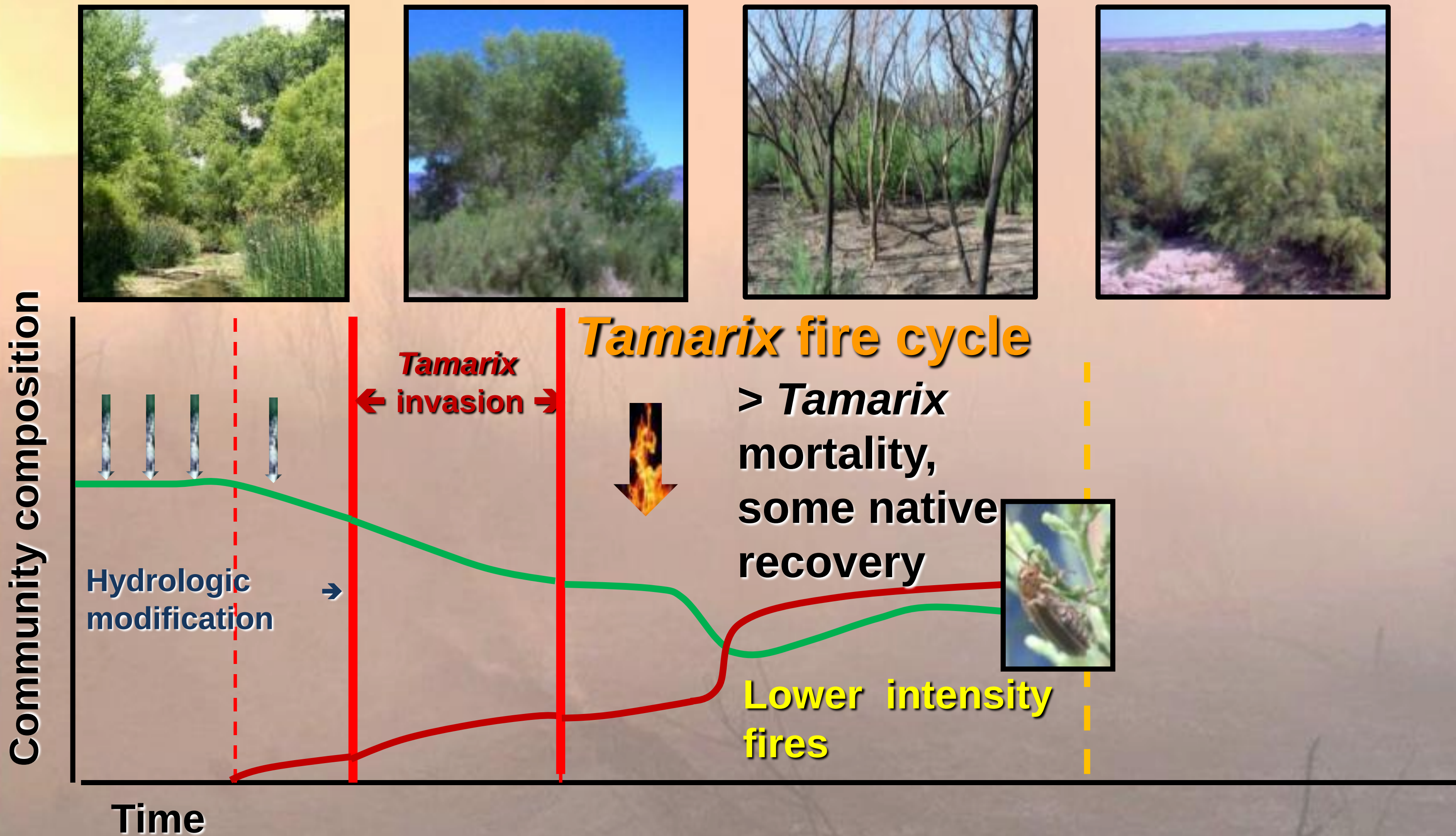
Can the *Tamarix* fire cycle be altered to allow the coexistence of natives?



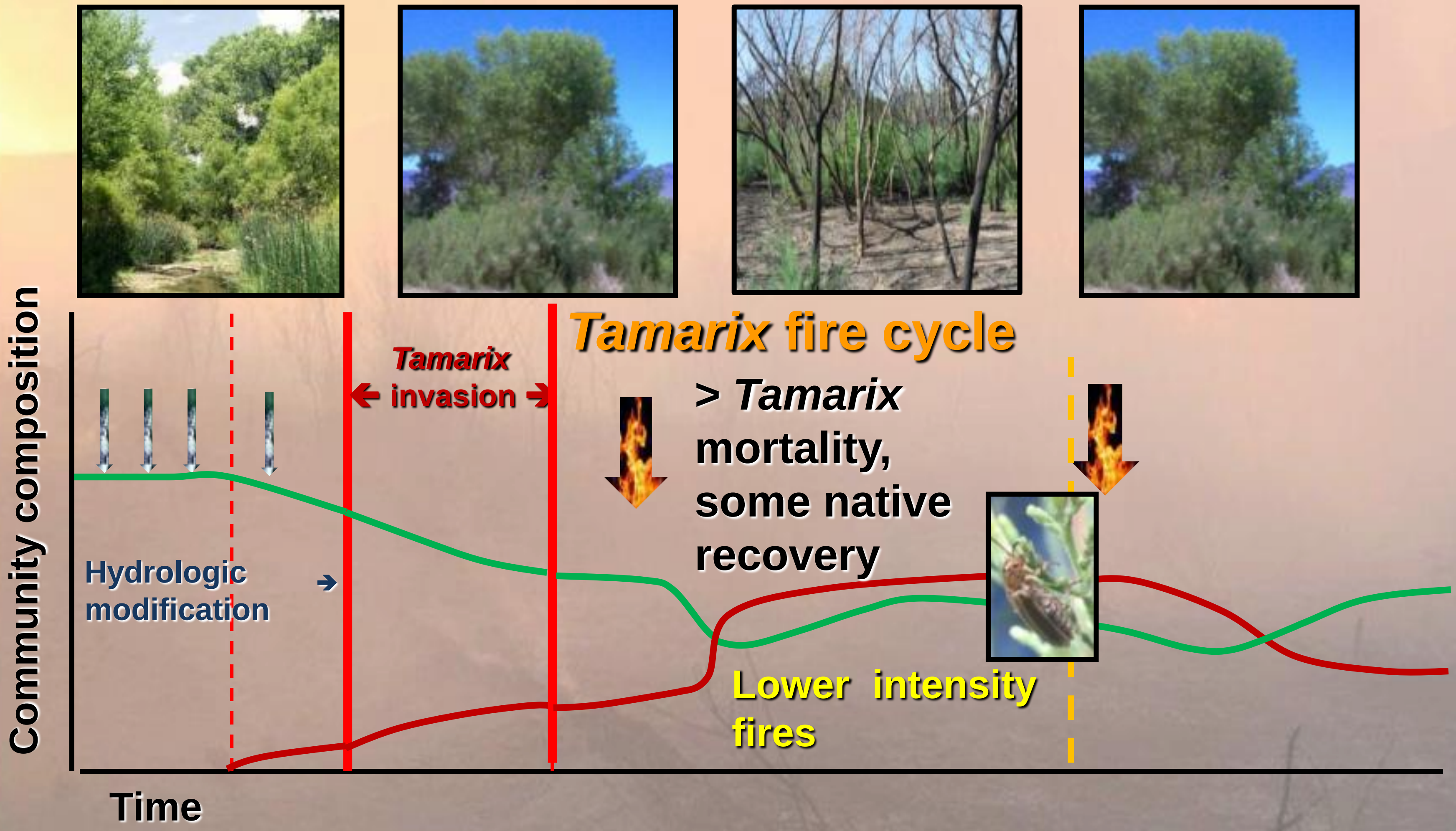
Can the *Tamarix* fire cycle be altered to allow the coexistence of natives?



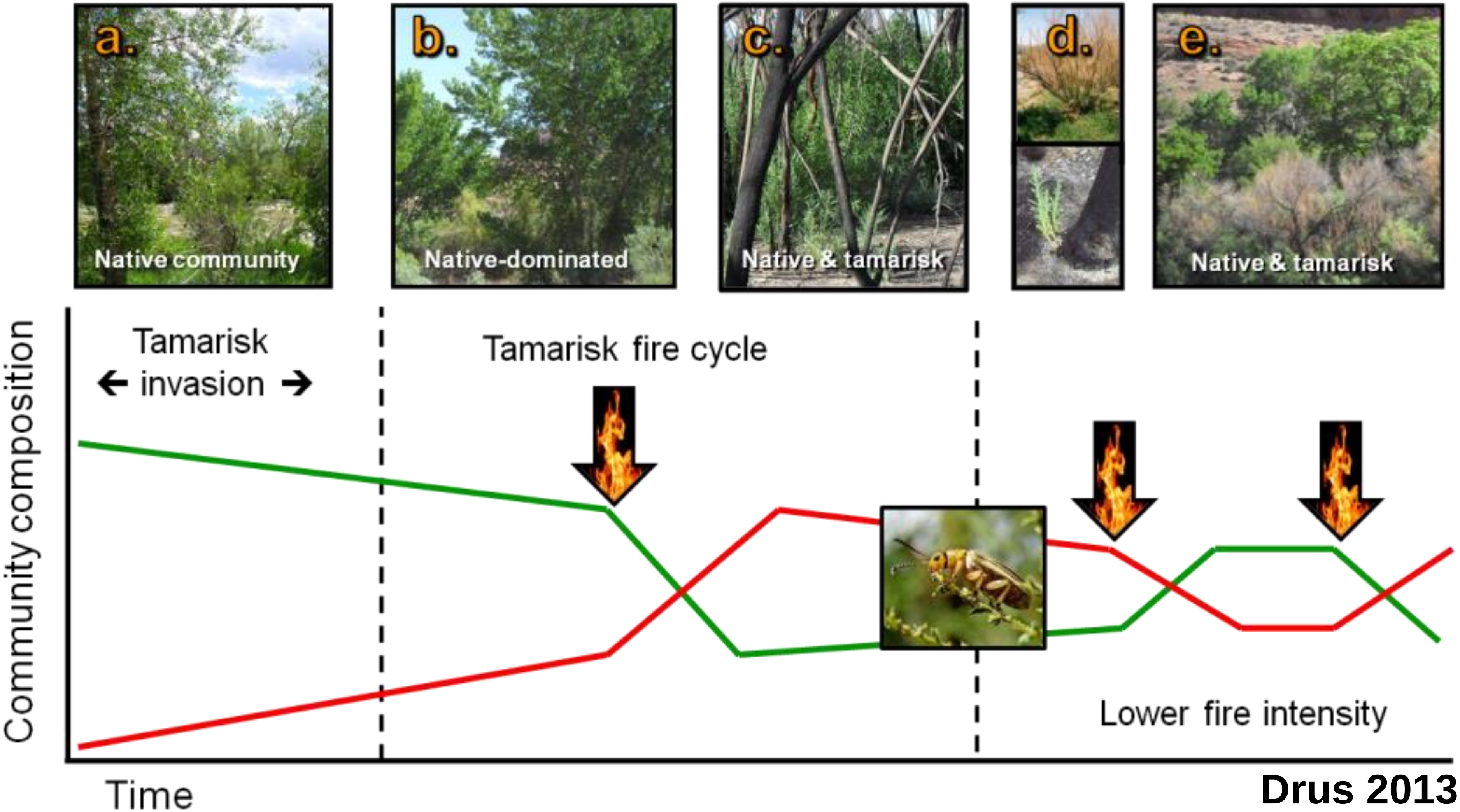
Can the *Tamarix* fire cycle be altered to allow the coexistence of natives?



Can the *Tamarix* fire cycle be altered to allow the coexistence of natives?



Possibility for coexistence



Drus 2013

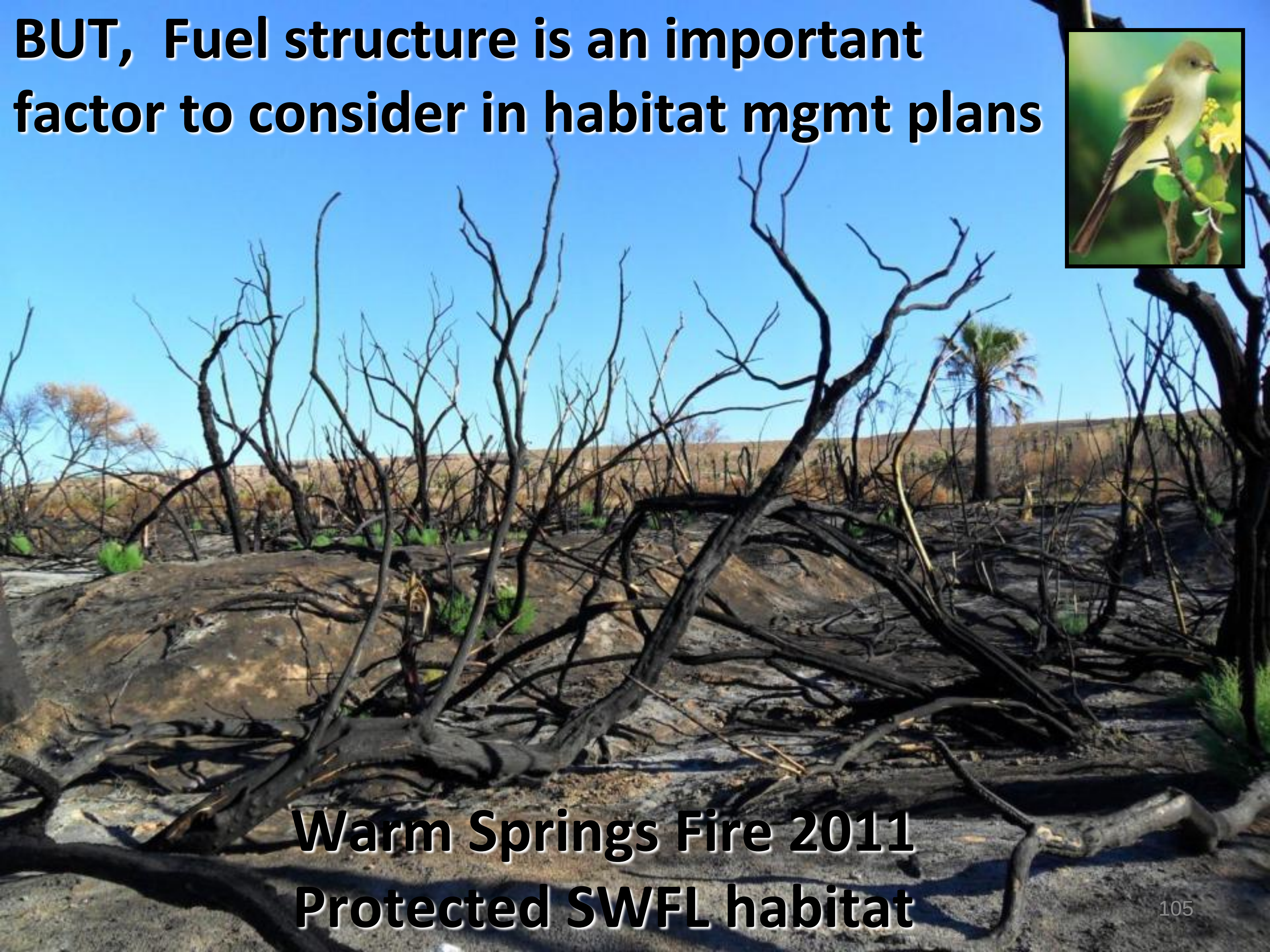
Synergism between fire and herbivory may alter the trajectory from perpetuation of *Tamarix* to coexistence.

Coexistence may be enough to restore some wildlife habitat value

"Native bird populations can be supported when a small component of native vegetation (~20-40%) is present in tamarisk dominated habitats." (Van Riper et al. 2010)

~50% supported by my data

BUT, Fuel structure is an important factor to consider in habitat mgmt plans



Warm Springs Fire 2011
Protected SWFL habitat

Fire Smart SW Riparian Landscape Mgmt

Grant: “*Fire-smart southwestern riparian landscape management and restoration of native biodiversity in view of species of conservation concern and the impacts of tamarisk beetles*.”

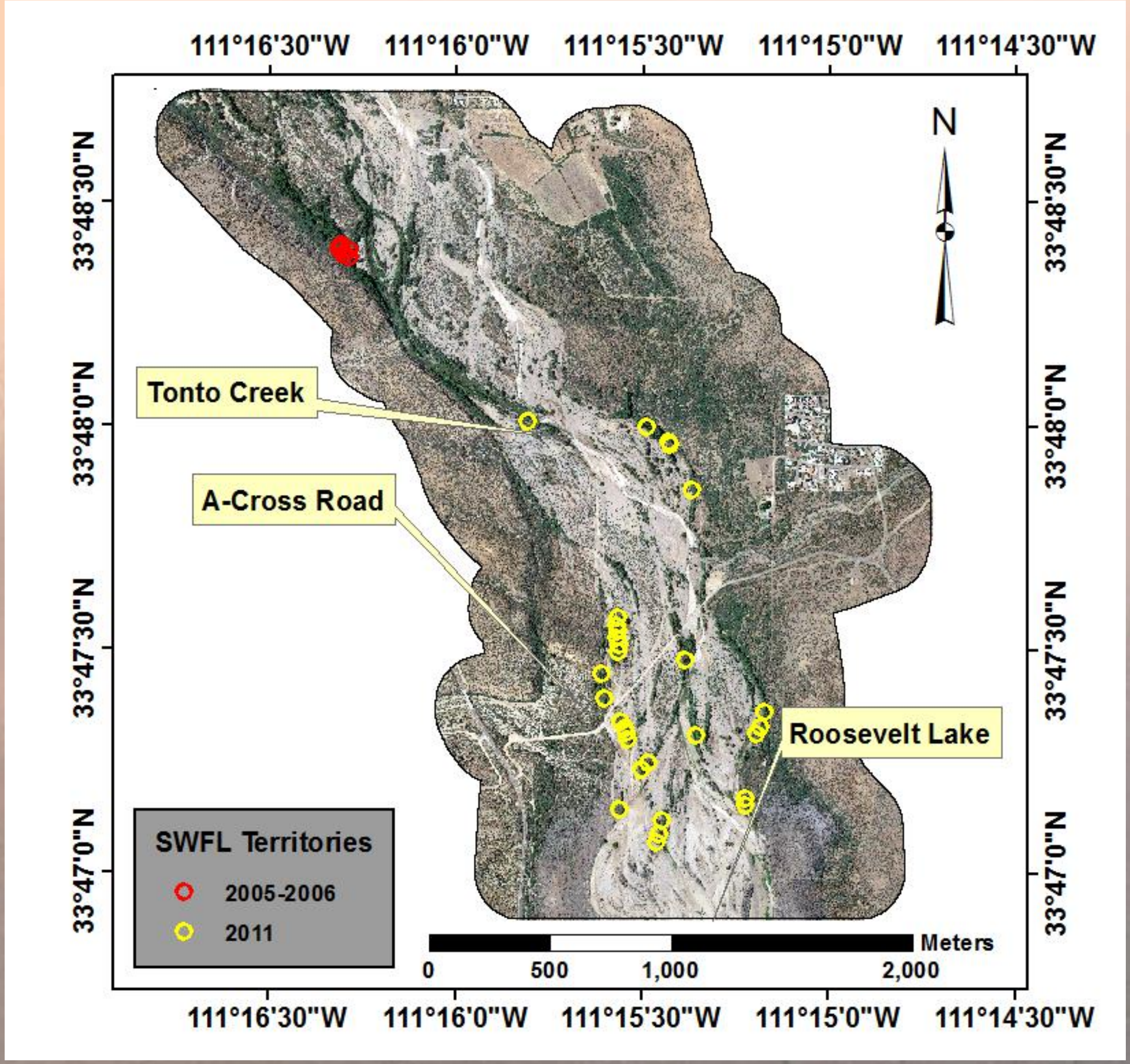
P.I. Dr. Robert Coulson, Professor Texas A&M Univ.

My role: *Develop fine scale baseline niches for riparian woodland fire susceptibility, cottonwood/willow restoration suitability, and three focal species at monitored study sites along the Rio Grande, Gila River, and Tonto Creek.*

Example Site: Tonto Creek A-Cross Road, AZ

Critical habitat for the endangered Southwestern Willow Flycatcher

Proposed critical habitat for the threatened Western Yellow-Billed Cuckoo



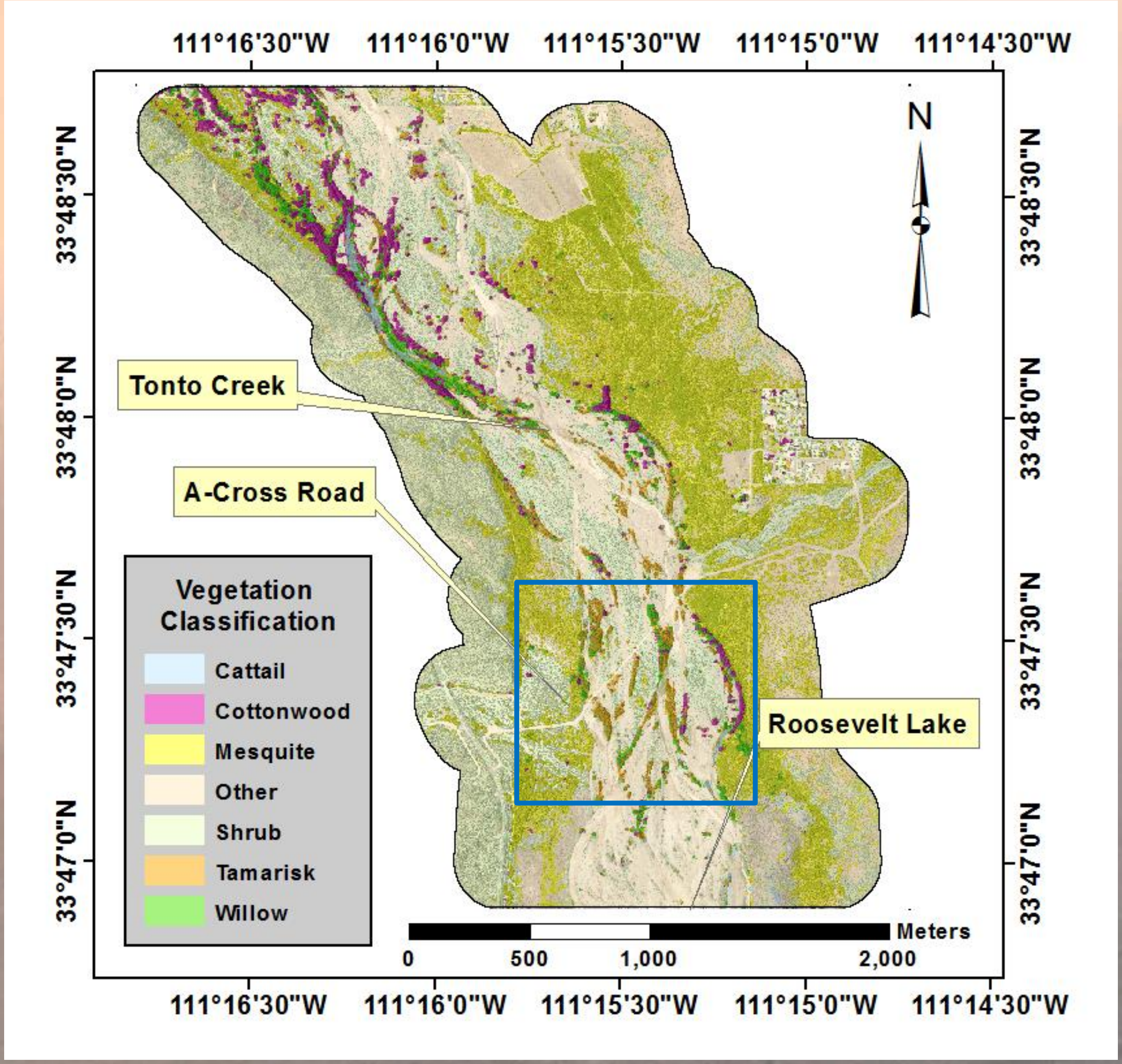
Tonto Creek A-Cross Road Study Site, AZ

5 August 2015

Tonto Creek Vegetation Classification

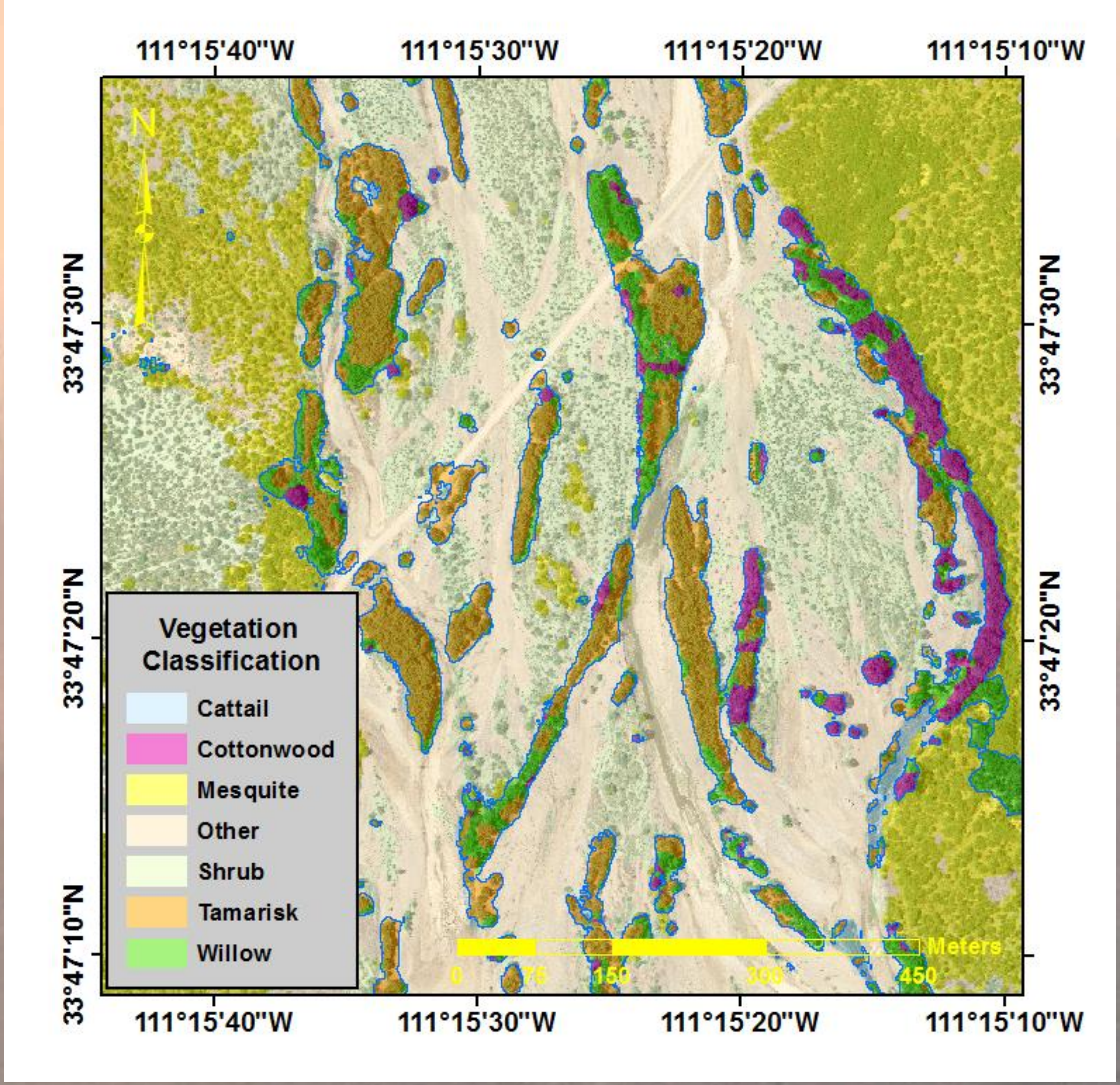
Classified with random forest algorithm for 1 m resolution multitemporal imagery of 3 dates, including leaf-on and leaf-off.

Several dozen spectral indices employed.

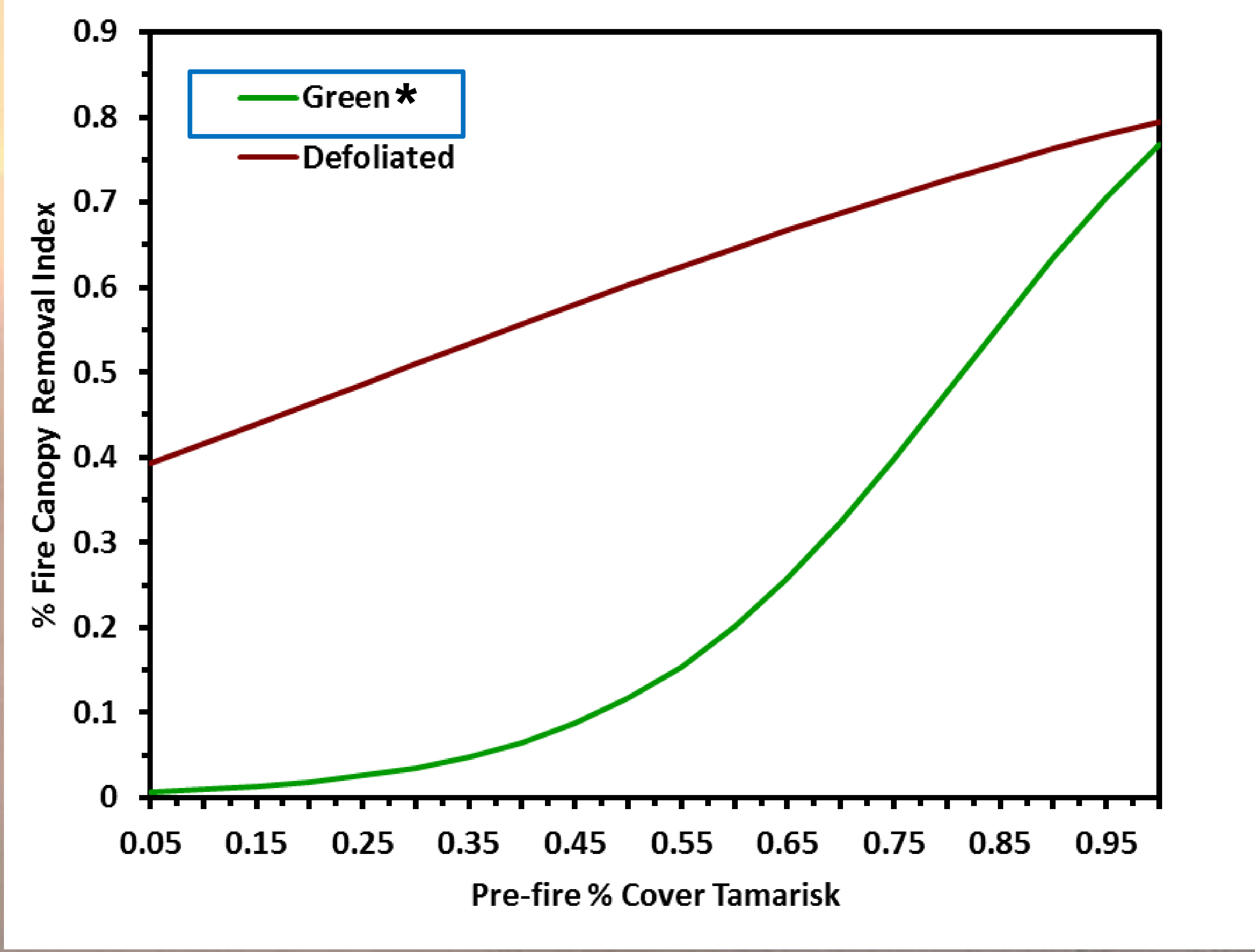


Tonto Creek Vegetation Classification

Patches of tamarisk/willow/cot-tonwood outlined in blue were analyzed for fire cover loss and fire mortality indices based upon relationships with pre-fire percent tamarisk cover per patch



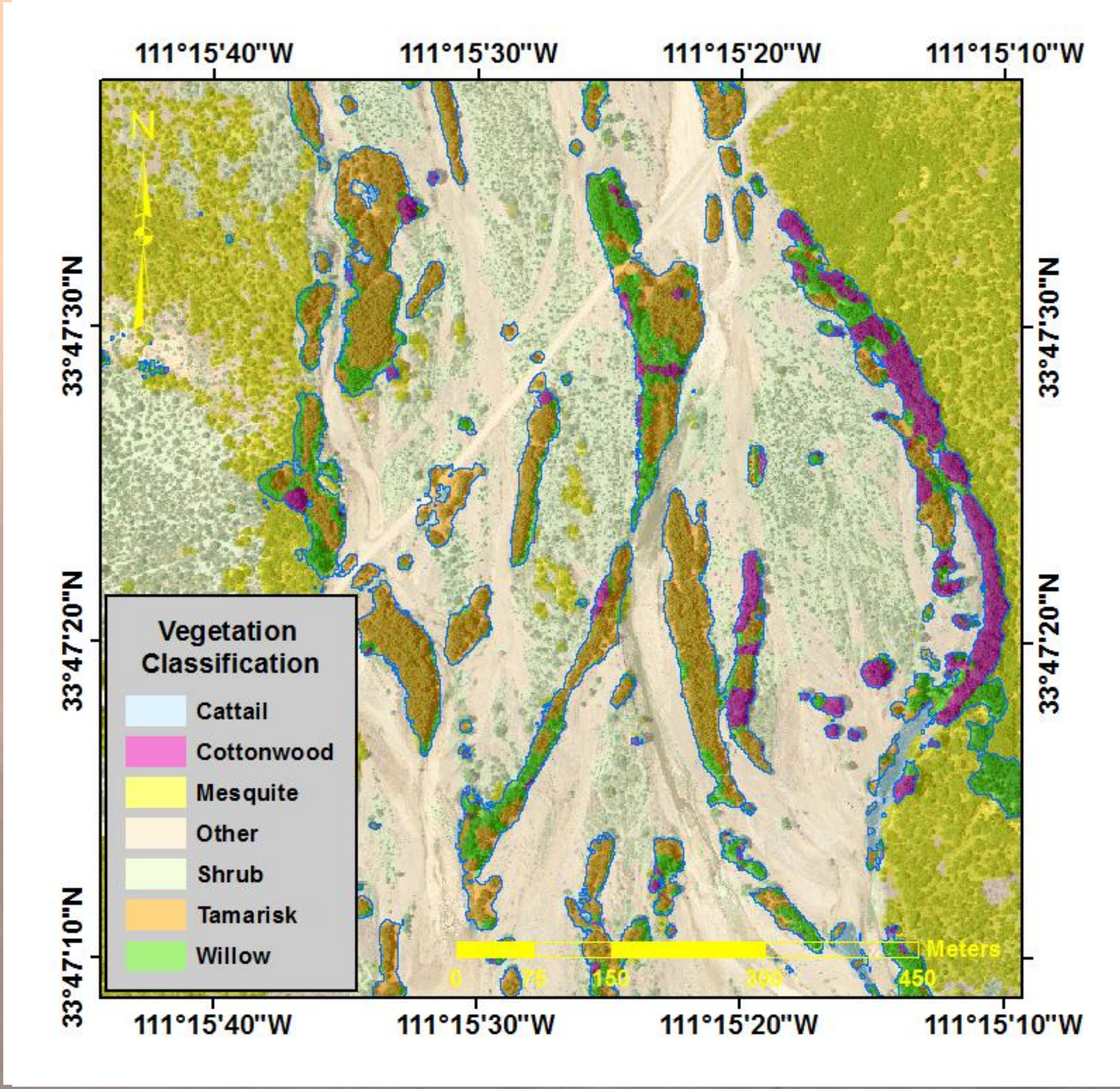
% Fire Canopy Removal Index for Tamarisk/Willow/Cottonwood Patches



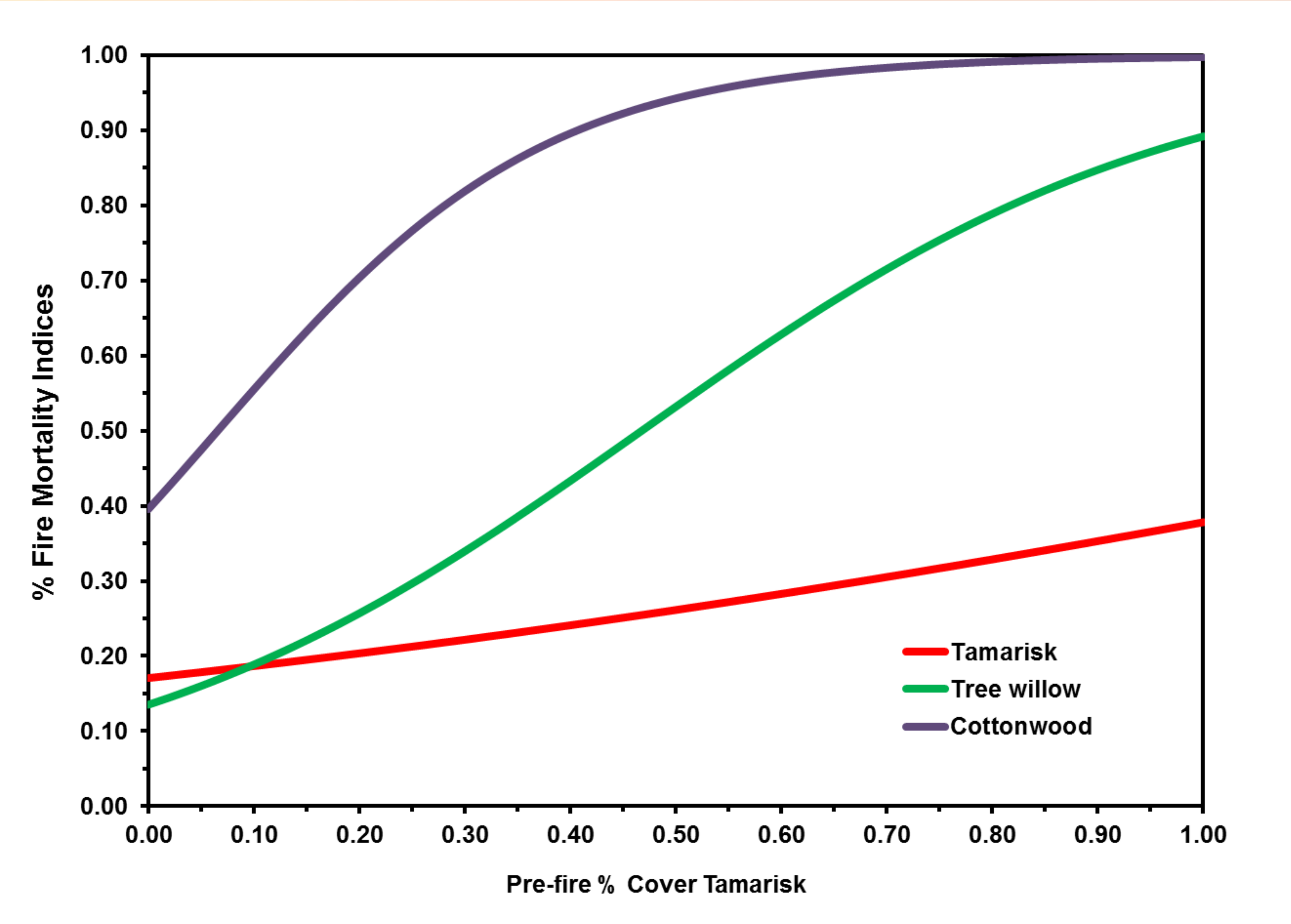
1/*(1+Exp(-6.43333444 × (PercCovTamarix-0.8147)))

Tonto Creek % Fire Canopy Removal Index

% Canopy removal in tamarisk/willow/cot-tonwood patch in relation to pre-fire percent cover of tamarisk

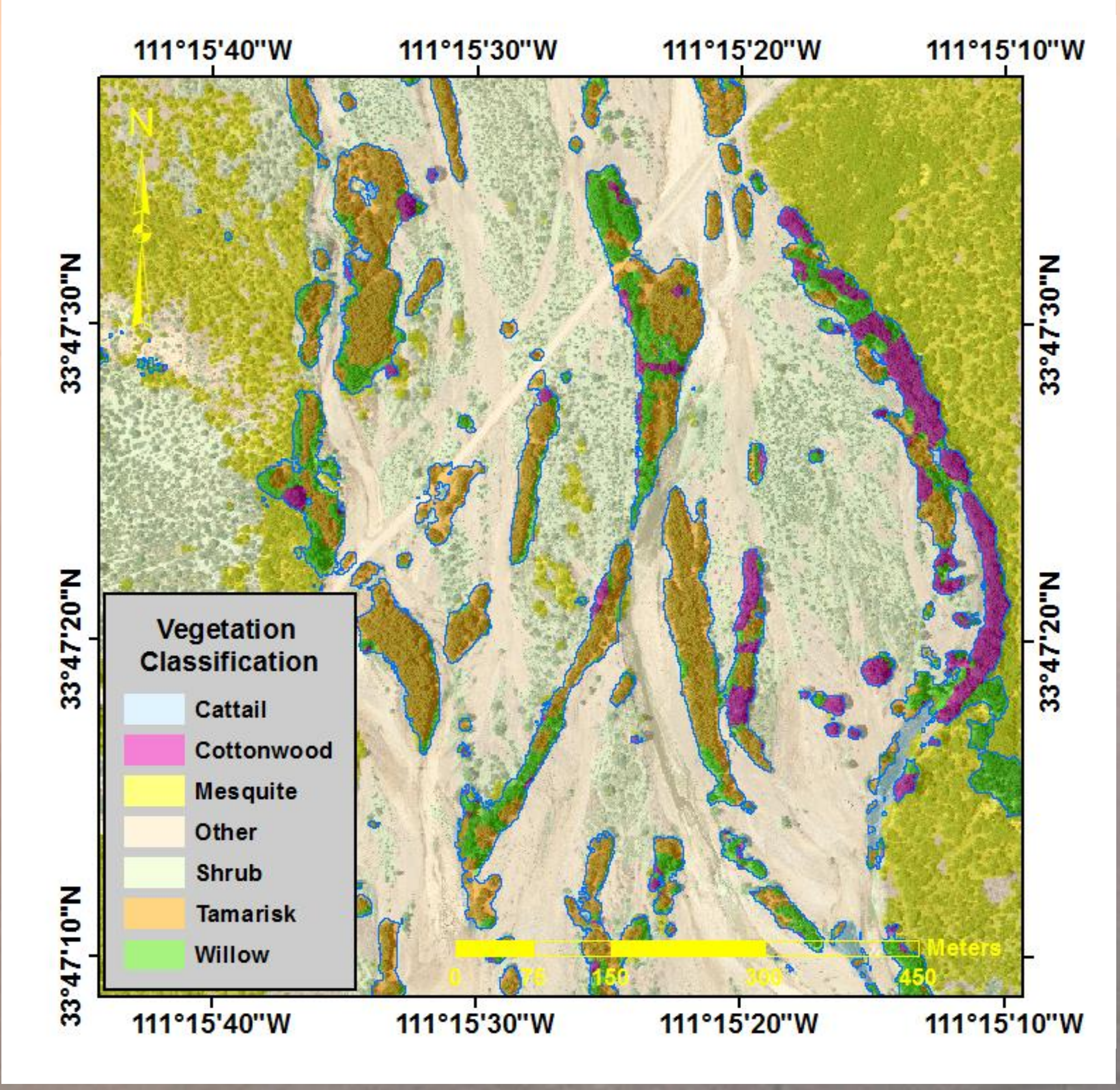


% Fire Mortality Indices for Tamarisk/Willow/Cottonwood Patches

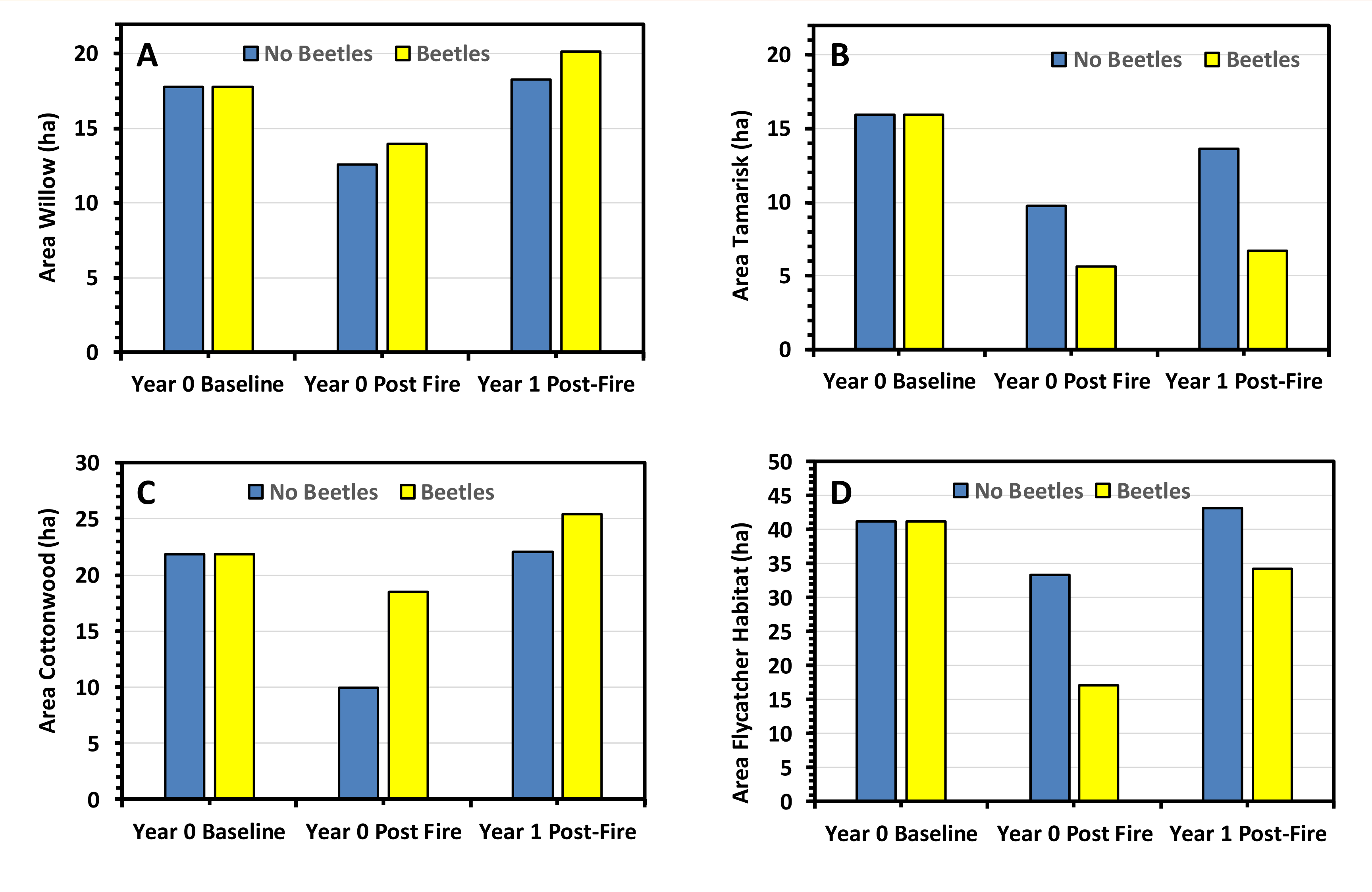


Tonto Creek % Fire Mortality Index

= % Fire Canopy Removal Index x (% Tamarisk Fire Mortality Index + % Willow Mortality Index + % Cottonwood Mortality Index)

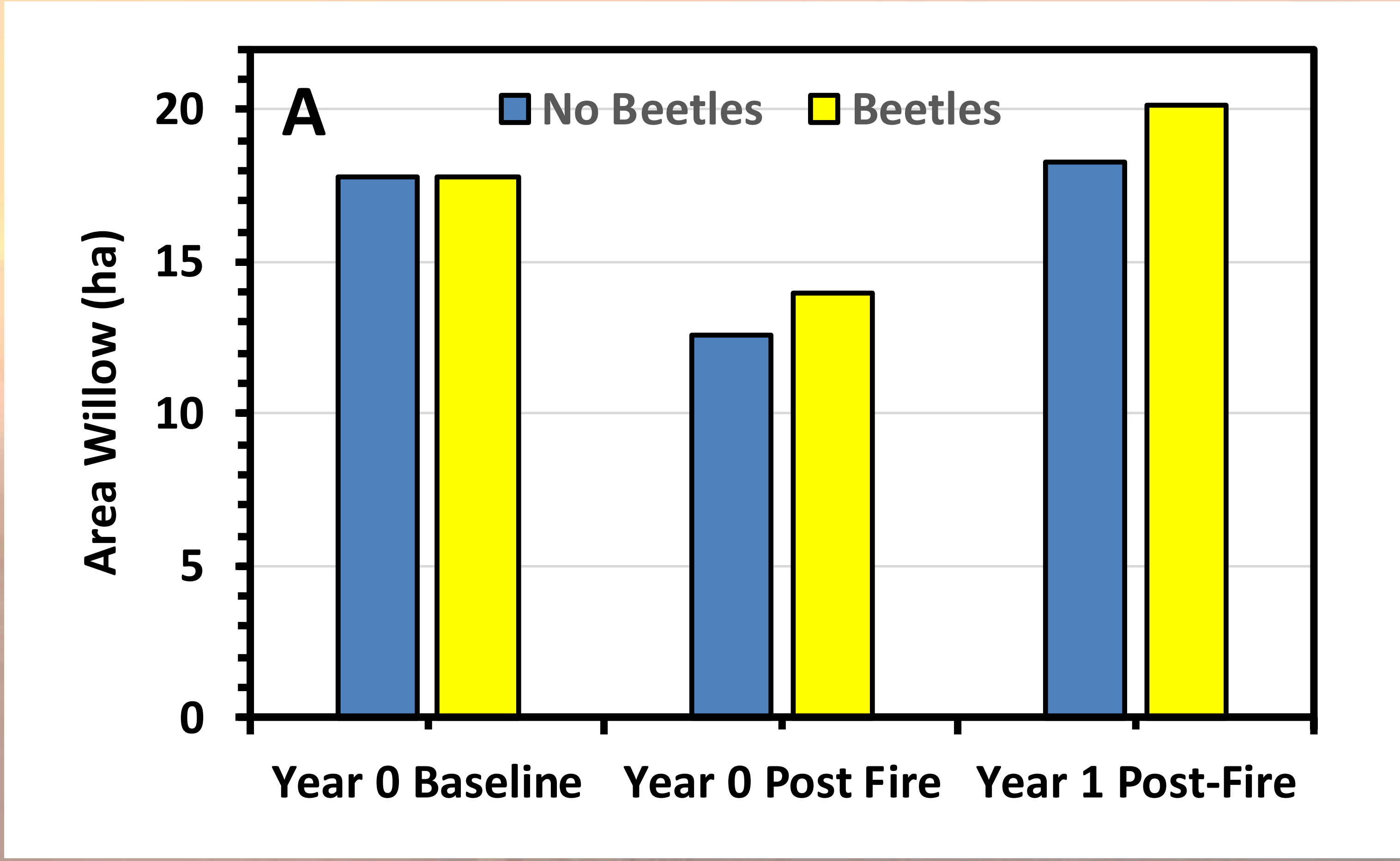


Tonto Creek Fire Scenarios



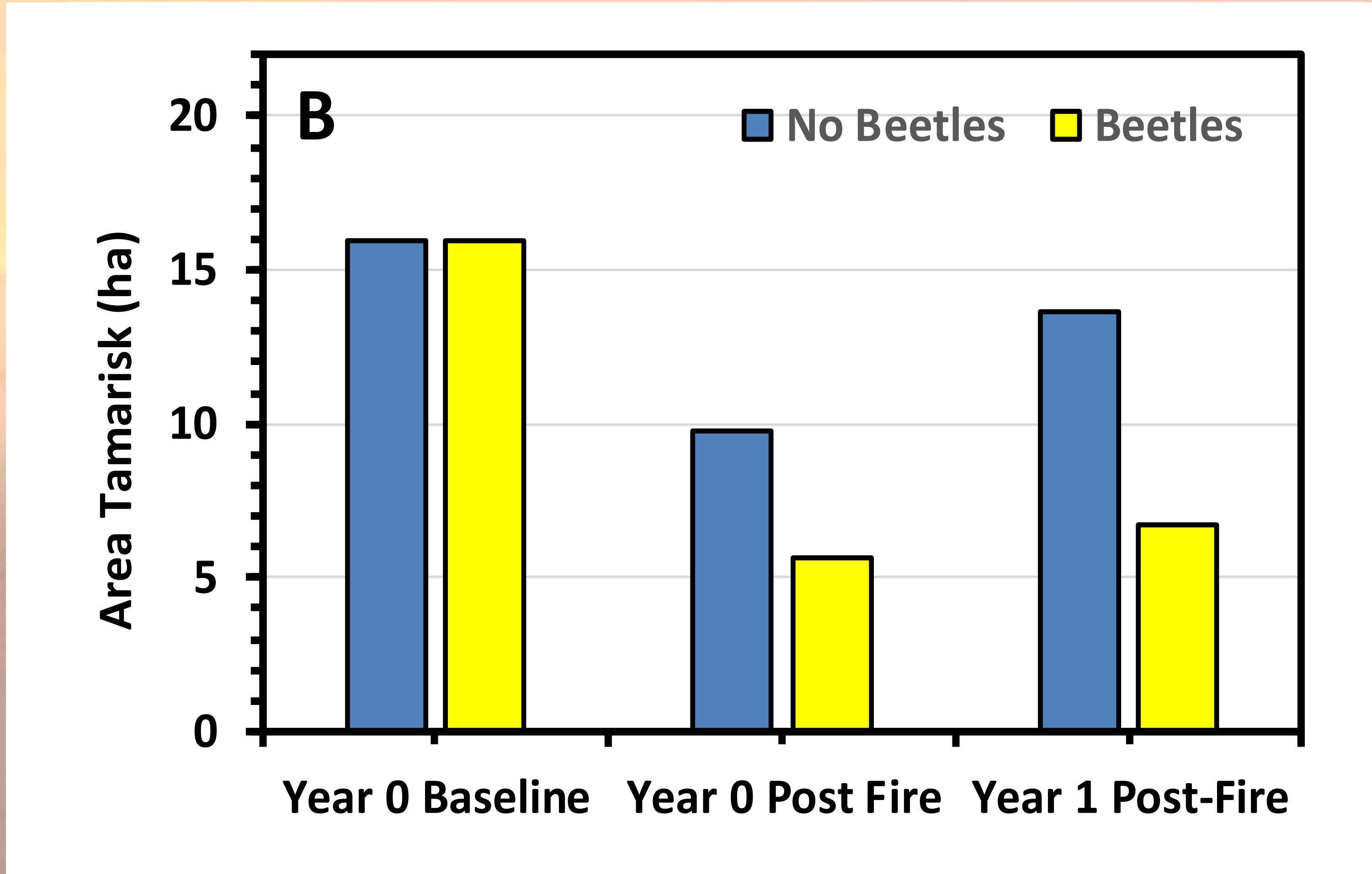
Areas with and without *Diorhabda carinulata* beetles at Year 0 Baseline, Year 0 Post-fire and Year 1 Post-fire for A) Willow, B) Tamarisk, C) Cottonwood, and D) Flycatcher habitat.

Tonto Creek Fire Scenarios



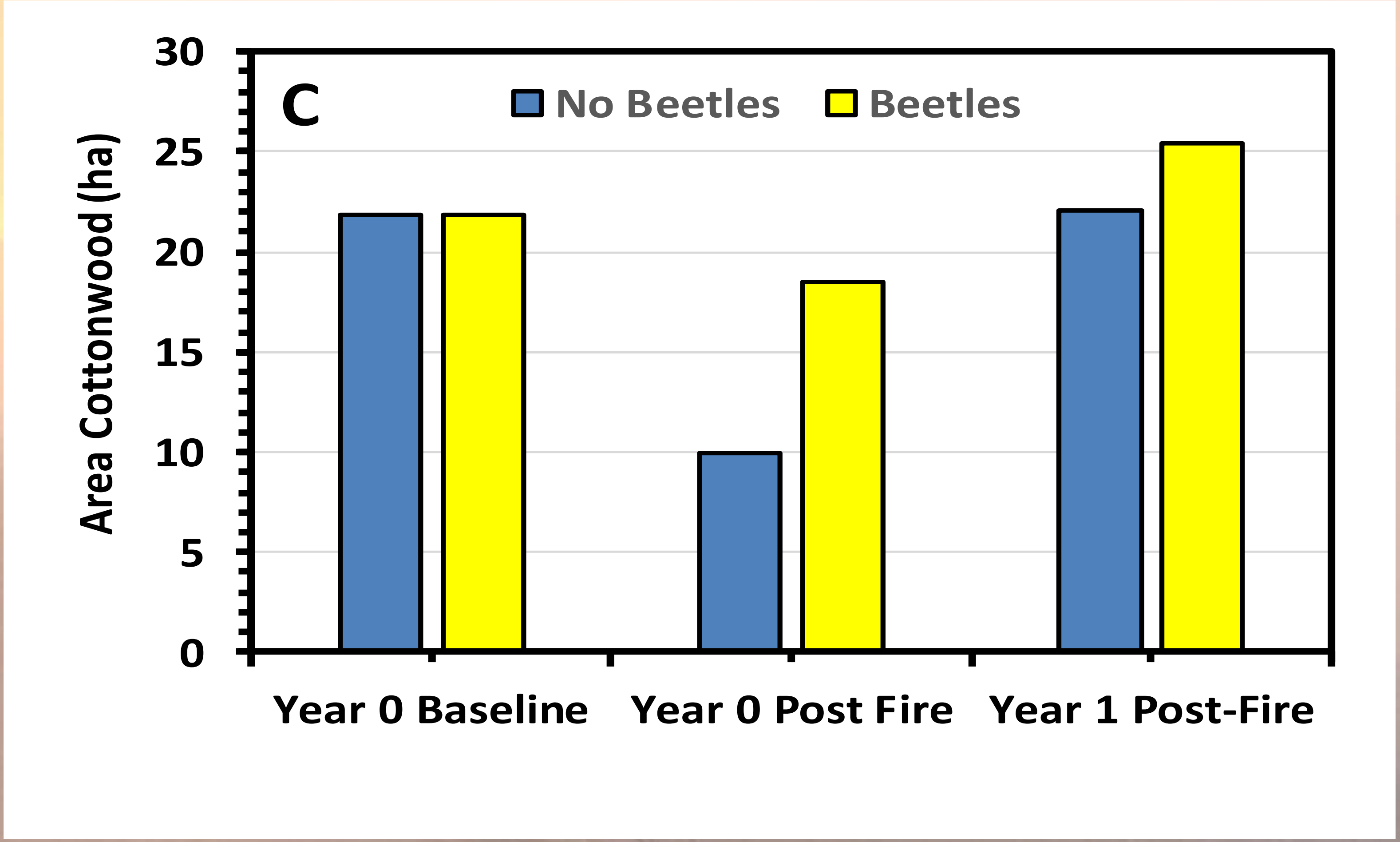
-Little overlap with tamarisk at the site and good resprouting ability would lead to rapid willow recovery with a little assistance from the beetles.

Tonto Creek Fire Scenarios



-Post-fire tamarisk recovery would be inhibited by beetles, but possible inhibition does not accurately predict synergisms between fire and herbivory stress.

Tonto Creek Fire Scenarios

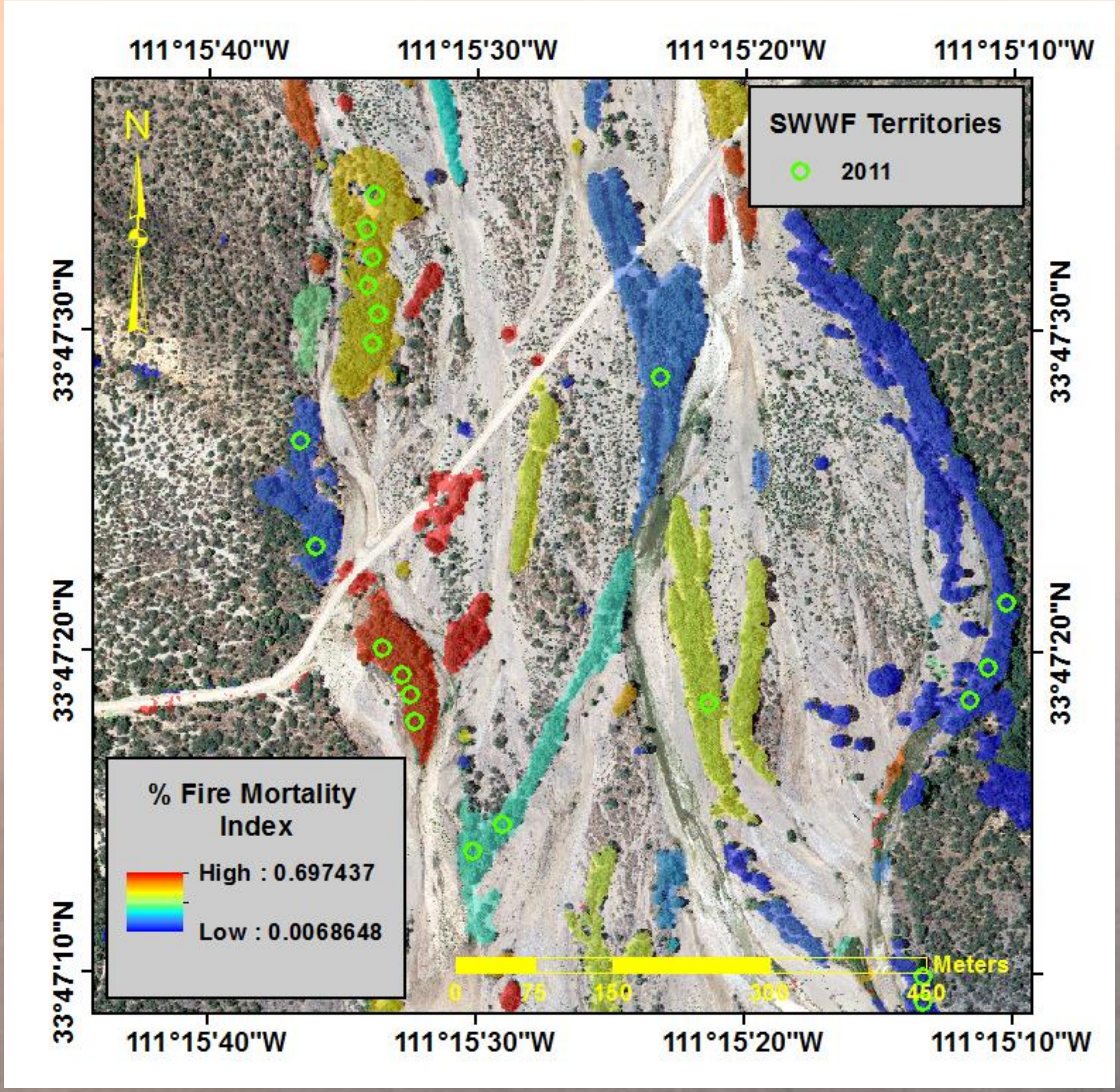


-Little overlap with tamarisk and resprouting ability would allow recovery of cottonwood. By reducing biomass at the site, the beetle would greatly enhance recovery at year 0.

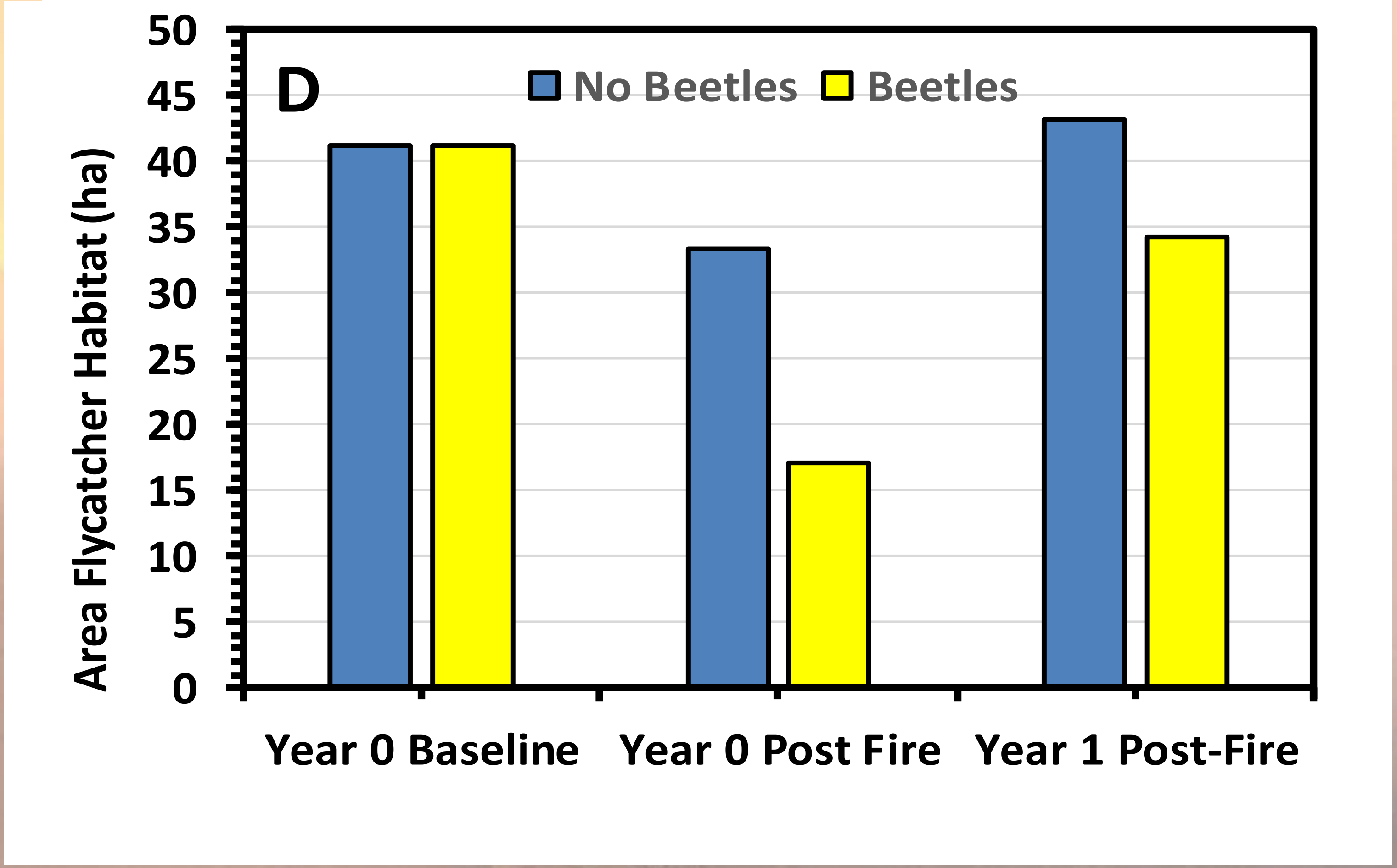
Tonto Creek % Fire Mortality Index and Southwestern Willow Flycatcher

Potential loss of flycatcher habitat due to fire risk from tamarisk

What should we expect in the future as the beetle continues to disperse and defoliate tamarisk?



Tonto Creek Fire Scenarios



- Beetles would inhibit flycatcher habitat recovery by increasing consumption, but recovery of habitat from Year 0 to Year 1 post-fire is steeper: short-term loss may result in long-term gain of more less flammable native species.


Should expect > frequent fires with > extreme behavior in areas following initial defoliation
Fire frequency and intensity should decrease as foliage drops and trees die back
St. George Utah
June 1, 2014
(photo by Maysen Fielding)

Meadow Valley Wash (N. Nevada)

Burned July 2009, 1+ year defoliation

Fort Thomas Fire 2018

Unmanaged

Understory thinned

Management tools

- **Beetle: preservation of ecological and economic value in a highly modified ecosystem.**
- **Fire niche models: first step towards decision support tools that can be applied to riparian vegetation throughout the DLCC region.**

Thank you!

gdrus@francis.edu