Wildland Fire in SW Riparian Areas and the Tamarisk Beetle

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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.

- Flooding regime $\Rightarrow$ community structure

Rood et al. 2005

- Flood-pulse regime
  - Coyote willow
  - Gooding's willow
  - Cottonwood

Abundance or biomass

Time
Native gallery forests are adapted to cyclical flooding disturbance.

- Flood-pulse regime

Abundance or biomass vs. Time

- Coyote willow
- Gooding’s willow
- Cottonwood

- Flooding regime $\rightarrow$ community structure

Rood et al. 2005
Native gallery forests are adapted to cyclical flooding disturbance.

- Flooding regime ➔ community structure

Rood et al. 2005
Native gallery forests are adapted to cyclical flooding disturbance.

- Flooding regime → community structure

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<th>Flood-pulse regime</th>
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- Cottonwood
- Coyote willow
- Gooding's willow

Time

Rood et al. 2005
Native gallery forests are adapted to cyclical flooding disturbance

- Flooding regime $\rightarrow$ community structure

**Time**

- Abundance or biomass

- Flood-pulse regime

- Coyote willow

- Gooding's willow

- Cottonwood

Rood et al. 2005
Human activities have modified desert riparian ecosystems

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

Rood et al. 2005
Hydrologic modifications alter flooding regimes and community composition.

Abundance or biomass

Flood-pulse

Time

Positive relationship between flood pulse and abundance or biomass of different species:
- Populus decline
- Gooding’s willow
- Coyote willow
- Cottonwood
- Tamarix

Populus decline
Hydrologic modifications alter flooding regimes and community composition.

Flood-pulse

Hydrologic change

Abundance or biomass

Time

- Gooding’s willow
- Coyote willow
- Cottonwood
- Tamarix
- Populus decline
Tamarix invasion
Altered flooding regimes promote *Tamarix* invasion and dominance

- Flood-pulse
- Hydrologic change
- *Tamarix* invasion
Altered flooding regimes promote *Tamarix* invasion and dominance

Flood-pulse

Hydrologic change

*Tamarix* invasion

Abundance or biomass

Time

- Gooding's willow
- Coyote willow
- Cottonwood
- *Tamarix*
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

- Native riparian zone ~ fire resistant
- Limited data on patterns and mechanisms
*Tamarix* introduces fire to desert riparian ecosystems

**Abundance or biomass**

- **Flood-pulse**
- **Hydrologic change**
- **Tamarix invasion**

**Fire**

**Tamarix**

**Natives**

**Time**
Tamarisk is highly flammable

- High fuel load
- Ladder fuel structure
Extreme fire behavior

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).

Valley of Fire S. NV Sept 2008
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.

Diagram showing the impact of Tamarix invasion and fire on community composition over time. The graph illustrates the influence of hydrologic modification and the subsequent invasion of Tamarix, leading to changes in the community composition with native species potentially being replaced.
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

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 ≤ 0.05).
Gaps (lacunae) create air pockets

USDA APHIS Archives, www.forestryimages.org
*Tamarix* foliage ignites more quickly than foliage from native riparian species.

Anova: p < 0.001

Time to ignition at 650°C

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)

**Fire occurrence**

- Tamarix absent
- Tamarix present

% Fire occurrence

(Chi-square contingency table ≤ 0.05)

**Fires stopping at the riparian corridor**

- Tamarix absent
- Tamarix present

% Fires stopping at riparian corridor

(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

![Bar chart showing fire occurrence](chart1)

- Tamarix absent
- Tamarix present

(Chi-square contingency table ≤ 0.05)

Fires stopping at the riparian corridor

![Bar chart showing fires stopping at the riparian corridor](chart2)

- Tamarix absent
- Tamarix present

(Chi-square contingency table ≤ 0.05)

**Common too (human ignitions)**

- Why is *Tamarix* so flammable?

Drus et al. in prep.
What does all of this mean to the native species?
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
Rio Grande at NMSU
Burned 3/18/2008

~50% tam
~50% native
Warm Springs Fire, NV
Protected SWFFL habitat
Burned 7-2-2010

~75% tam and 25% natives
Toquop wash, NV
Burned
7-9-2009

~100% tam
Hope Ranch, NM
Burned 2009

Hope Ranch 2009 Transect 2
Tamarix density ➔

Native fuel consumption increases with Tamarix density

Tamarisk Density Classes
Low <10%
Medium 20-50%
High > 50%

(ANOVA ≤ 0.05)
Native mortality increases with *Tamarix* density

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

**Tamarix** mortality is less density dependent.
Highly fire tolerant

Toquop wash S. NV
July 2009
The *Tamarix* fire cycle

- **Time**
- **Community composition**
- **Hydrologic modification**
- **Tamarix invasion**
- **Tamarix**
- **Natives**
The *Tamarix* fire cycle

- **Community composition**
- **Time**
- **Tamarix**
- **Natives**

- **Hydrologic modification**
- **Tamarix invasion**
The *Tamarix* fire cycle

- **Community composition**
- **Time**
- **Tamarix invasion**
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- **Tamarix**
- **Natives**
The *Tamarix* fire cycle

- **Community composition**
- **Time**
- **Hydrologic modification**
- **Tamarix invasion**
- **Tamarix**
- **Natives**
The *Tamarix* fire cycle

Fire intensity is a positive feedback in other invaded ecosystems.

The *Tamarix* fire cycle involves the following steps:

1. **Community composition**
2. **Hydrologic modification**
3. **Tamarix invasion**
4. *Tamarix*
5. *Natives*
Prescribed burn experiments

- 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
Avg flame Length 6.5m (21.3ft)
Avg ROS 10.4m/min (34.1ft)
Avg Tam removal 40%
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%
Tamarix fire intensity is biomass dependent
Tamarix fire intensity is biomass dependent

Anova: p < 0.001

<table>
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<tr>
<th>Biomass (kg ha⁻¹)</th>
<th>Humboldt</th>
<th>Valley of Fire</th>
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<td>14,500</td>
<td>212,779</td>
<td></td>
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Average flame length: Humboldt 6.5m, Valley of Fire 35m
Average ROS: Humboldt 10.4m/min, Valley of Fire 11.7m/min
Average Tam removal: Humboldt 40%, Valley of Fire 55%
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

- **Community composition**
- **Time**

**Tamarix invasion**

- **Hydrologic modification**
- **Lower intensity fires**
- **Higher intensity fires**

**Natives**

**Tamarix**
The *Tamarix* fire cycle

**Community composition**

**Time**

**Hydrologic modification**

**Tamarix invasion**

**Fire intensity** = + **Feedback**

**Tamarix**

**Natives**
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)

Foliar desiccation
Diorhabda carinulata
(tamarisk leaf beetle)

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

Snyder et al. 2010
Foliar desiccation
*Tamarix* biological control may further promote fire in riparian systems.

Foliar desiccation may influence flammability and fire intensity.
Muffle-furnace trials

Foliar desiccation influences flammability at the leaf level

Time to Ignition at 650°C

(ANOVA P ≤ 0.05)
Prescribed burn experiments

Humboldt 2006

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

Gradient of desiccation
3+ seasons of *Diorhabda* herbivory
Prescribed burn experiments

Humboldt 2006

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

Valley of Fire 2008

• 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)

Green (non-desiccated)
Herbicide (desiccated)
Measurements

Dataloggers and Thermocouples

- Temperature
- Duration

Visual fire behavior estimates

- Rate of spread
- Flame height
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)

FII = heat damage index
Foliar desiccation and weather conditions influence fire intensity at the tree level

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

Tamarix fire cycle

Can the system return to this point?

Lower intensity fires

Community composition

Time

Hydrologic modification

Tamarix invasion
Site: Humboldt 2006

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

Gradient of desiccation
Humboldt Site

~3 years defoliation
Root-crown starch ↓ with ↑ herbivory level

(Linear regression <0.0001, R² = 0.79)

Diorhabda herbivory depletes starch reserves in Tamarix
Root-crown starch ↓ with ↑ herbivory level

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\textit{Diorhabda} herbivory depletes starch reserves in \textit{Tamarix}
Diorhabda herbivory depletes starch reserves in Tamarix.

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

- Physiological stress

Extrapolation: ~13% starch at 0 herbivory

Hudgeons et al. 2007

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 )
Fire & herbivory have interactive effects

What is the nature of this interaction?
- Multiple stresses interact synergistically in other systems

![Graph showing observed vs. predicted Tamarix mortality rates as a function of Diorhabda defoliation.](image)

- Observed vs. predicted probabilities of mortality.
- Predicted mortality rates determined using the multiplicative model.
- Magnitude of synergism between fire and herbivory determined by subtracting predicted from observed probabilities of mortality.

![Starch levels at different times.](image)

- Summer: ~13% starch
- Fall: ~2% starch
- Control: ~88% starch
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

Franceschi et al. 2005
Fire & herbivory have interactive effects

Are fire and herbivory synergistic?

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

- Additive theory of probability:
  \[ P(A \text{ and } B) = P(A) + P(B) - P(AB) \]
Fire & herbivory have interactive effects

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- 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

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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)
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*
**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?

**Tamarix fire cycle**
- Can the system return to this point?
- Lower intensity fires
- Higher intensity fires
- Hydrologic modification
- *Tamarix* invasion
Can the *Tamarix* fire cycle be altered to allow the coexistence of natives?

*Tamarix* fire cycle

Invasion of *Tamarix* -> Mortality of *Tamarix*, some native recovery

Lower intensity fires

Higher intensity fires

Hydrologic modification

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

*Tamarix* fire cycle:
- Invasion
- Mortality of *Tamarix*
- Some native recovery

Hydrologic modification

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

**Tamarix** fire cycle:
- *Tamarix* invasion
- *Tamarix* mortality, some native recovery
- Lower intensity fires

**Community composition**
- Hydrologic modification
Synergism between fire and herbivory may alter the trajectory from perpetuation of *Tamarix* to coexistence.
“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.
Patches of tamarisk/willow/cottonwood 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

\[
\frac{1}{1 + \exp(-6.43333444 \times (\text{PercCovTamarix} - 0.8147))}
\]
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

\[ \text{% Fire Mortality Index} = \% \text{ Fire Canopy Removal Index} \times (\% \text{ Tamarisk Fire Mortality Index} + \% \text{ Willow Mortality Index} + \% \text{ Cottonwood Mortality Index}) \]
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.
-Little overlap with tamarisk at the site and good resprouting ability would lead to rapid willow recovery with a little assistance from the beetles.
- Post-fire tamarisk recovery would be inhibited by beetles, but possible inhibition does not accurately predict synergisms between fire and herbivory stress.
-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?
- 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
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!

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