Wildland Fire in SW Riparian Areas and the Tamarisk Beetle

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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 → community structure
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
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 \(\rightarrow\) community structure

**Graph:**
- **Time**
- **Abundance or biomass**
- **Flood-pulse regime**
  - Cottonwood
  - Coyote willow
  - Gooding's willow

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

- Flooding regime $\rightarrow$ community structure

![Graph showing flooding regimes](image1)

- 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
Hydrologic modifications alter flooding regimes and community composition.
Hydrologic modifications alter flooding regimes and community composition.

Abundance or biomass

Time

Flood-pulse

Hydrologic change

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

Abundance or biomass

Time

- Flood-pulse
- Hydrologic change
- Tamarix invasion
- Gooding's willow
- Coyote willow
- Cottonwood
- *Tamarix*
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

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

Busch 1995
*Tamarix* introduces fire to desert riparian ecosystems

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

**Abundance or biomass**

**Time**

**Fire**

**Tamarix**

**Natives**
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).
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

- Tamarix invasion
- Hydrologic modification
- Tamarix invasion + fire

Community composition

Time

Natives

Tamarix
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. 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: \( p < 0.001 \)

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

**Fires stopping at the riparian corridor**

- Tamarix absent
- Tamarix present

(Chi-square contingency table ≤ 0.05)

**Figure 5:** A. Contingency table analysis grouping of observations into categories of fire occurrence (no fire, fire) and *Tamarix* presence and absence. The y-axis shows the percent of observations in each x-category (no fire vs. fire). Black bars indicate *Tamarix* presence, and white bars indicate *Tamarix* absence.

**Figure 6:** A. Contingency table analysis grouping of observations into categories of fires stopping at the edge of the riparian corridor (barrier) and fires spreading into the riparian corridor (spread), and *Tamarix* presence and absence. The y-axis shows the percent of observations in each x-category (barrier vs. spread). Black bars indicate *Tamarix* presence, and white bars indicate *Tamarix* absence.

**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**

- **Tamarix** absent
- **Tamarix** present

**Fires stopping at the riparian corridor**

- **Tamarix** absent
- **Tamarix** present

*Common too (human ignitions)*

Why is *Tamarix* so flammable?

(Chi-square contingency table ≤ 0.05)

*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
~75% tam and 25% natives

Warm Springs Fire, NV
Protected SWFFL habitat
Burned 7-2-2010
Toquop wash, NV
Burned
7-9-2009
~100% tam
Hope Ranch, NM
Burned
2009
Native fuel consumption increases with Tamarix density.

Fuel Classes
*1hr < 0.625cm = Foliage
10hr
0.625 – 2.5cm
100hr
2.5 – 7.6cm
1000hr > 7.6cm

(Pyne et al. 1996)

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)
Tamarix mortality is less density dependent.

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

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

- Invasion of *Tamarix*
- Hydrologic modification
- Community composition change
- Natives replacement
The *Tamarix* fire cycle

The invasion of *Tamarix* leads to hydrologic modification, which affects the community composition over time, eventually leading to the dominance of *Tamarix* over native species.
The *Tamarix* fire cycle

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

- **Tamarix invasion**
- **Hydrologic modification**
- **Community composition**

- **Time**
- **Natives**
- **Tamarix**
The *Tamarix* fire cycle

Fire intensity is a positive feedback in other invaded ecosystems.
Prescribed burn experiments

Humboldt 2006

- Humboldt river floodplain
  Lovelock, NV
  – August 2006

Valley of Fire 2008

- Valley of Fire Wash 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
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

- Time
- Community composition
- Hydrologic modification
- Invasion
- Lower intensity fires
- Higher intensity fires
- Natives
- Tamarix
- Tamarix invasion
- Higher intensity fires
The *Tamarix* fire cycle

- **Community composition**
  - **Hydrologic modification**
  - **Tamarix invasion**

- **Time**
  - **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)

Foliar desiccation

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

Foliar desiccation may influence flammability and fire intensity
Foliar desiccation influences flammability at the leaf level

(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)
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)

Dataloggers and Thermocouples

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: \( P < 0.05 \)) within a site.

### Humboldt Herbivory Experiment

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

#### Summer 06
- **No Herbicide:** a
- **Herbicide:** b

#### Fall 06
- **Low Herbivory Impact:** a
- **High Herbivory Impact:** b

### Valley of Fire Herbicide Experiment

- **No Herbicide:** a
- **Herbicide:** b

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

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

~3 years defoliation
Humboldt Site

~3 years defoliation

~7 years defoliation
Diorhabda herbivory depletes starch reserves in Tamarix

Figure 4: a) Pre-fire (summer) percent root crown starch content as a function of Diorhabda herbivory level (N=78). b) Root crown starch content collected post-fire (winter) during dormancy (N = 88). Error bars indicate ± standard error.

Root-crown starch ↓ with ↑ herbivory level
(Linear regression <0.0001, R² = 0.79)

Extrapolation: ~13% starch at 0 herbivory
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- Root-crown starch ↓ with ↑ herbivory level
  (Linear regression <0.0001, $R^2 = 0.79$)

- Physiological stress

Figure 4: a) Pre-fire (summer) percent root crown starch content as a function of Diorhabda herbivory level (N=78). b) Root crown starch content collected post-fire (winter) during dormancy (N = 88). Error bars indicate +/- standard error.

Extrapolation: ~13% starch at 0 herbivory
Tamarix mortality increases with Diorhabda herbivory impact

![Graph showing observed vs. predicted Tamarix mortality rates as a function of Diorhabda defoliation. Probabilities were determined using polynomial regression, and the logit function was used to graph the curves. Predicted mortality rates were determined using the multiplicative model.](image)

Figure 5: a) Observed vs. predicted Tamarix mortality rates as a function of Diorhabda defoliation. Probabilities were determined using polynomial regression, and the logit function was used to graph the curves. Predicted mortality rates were determined using the multiplicative model.

b) Magnitude of synergism between fire and herbivory determined by subtracting predicted from observed probabilities of mortality.

Drus et al. 2014
What is the nature of this interaction?

- Multiple stresses interact synergistically in other systems

**Figure 5:** a) Observed vs. predicted *Tamarix* mortality rates as a function of *Diorhabda* defoliation. Probabilities were determined using polynomial regression, and the logit function was used to graph the curves. Predicted mortality rates were determined using the multiplicative model. b) Magnitude of synergism between fire and herbivory determined by subtracting predicted from observed probabilities of mortality.
What is the nature of this interaction?

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

**Figure 5:** a) Observed vs. predicted *Tamarix* mortality rates as a function of *Diorhabda* defoliation. Probabilities were determined using polynomial regression, and the logit function was used to graph the curves. Predicted mortality rates were determined using the multiplicative model. b) Magnitude of synergism between fire and herbivory determined by subtracting predicted from observed probabilities of mortality.

**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:
    \[ P(A \text{ and } B) = P(A) + P(B) - P(AB) \]

**Figure 5:** a) Observed vs. predicted *Tamarix* mortality rates as a function of *Diorhabda* defoliation. Probabilities were determined using polynomial regression, and the logit function was used to graph the curves. Predicted mortality rates were determined using the multiplicative model. b) Magnitude of synergism between fire and herbivory determined by subtracting predicted from observed probabilities of mortality.
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  - Additive theory of probability:
    \[ P(A \text{ and } B) = P(A) + P(B) - P(AB) \]

- 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

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Figure 5: a) Observed vs. predicted *Tamarix* mortality rates as a function of *Diorhabda* defoliation. Probabilities were determined using polynomial regression, and the logit function was used to graph the curves. Predicted mortality rates were determined using the multiplicative model and extrapolated to 0% herbivory using the logit function.

- **\( M_{BF} \)** = 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

Figure 5: a) Observed vs. predicted Tamarix mortality rates as a function of Diorhabda defoliation. Probabilities were determined using polynomial regression, and the logit function was used to graph the curves. Predicted mortality rates were determined using the multiplicative model. b) Magnitude of synergism between fire and herbivory determined by subtracting predicted from observed probabilities of mortality.

Are fire and herbivory synergistic?

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    \[ P(A \text{ and } B) = P(A) + P(B) - P(AB) \]

- If FII and herbivory are additive, then the following is true:
  \[ M_{BF} = P_B + P_F - P_BP_FP_F \]

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

Figure 5: a) Observed vs. predicted Tamarix mortality rates as a function of Diorhabda defoliation. Probabilities were determined using polynomial regression, and the logit function was used to graph the curves. Predicted mortality rates were determined using the multiplicative model. Predicted mortality rates were then compared to observed mortality rates. Mortality to 0% herbivory was predicted from observed probabilities of mortality.
Fire & herbivory have interactive effects

Are fire and herbivory synergistic?

- **Multiplicative risk model**
  (Soluk 1993, Sih et al. 1998)
  
  \[ P(A \text{ and } B) = P(A) + P(B) - P(AB) \]

- 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

\[ M_{BF} = \text{mortality if fire and herbivory are additive} \]
\[ P_B = \text{mortality due to biocontrol only (control)} \]
\[ P_F = \text{mortality due to fire alone (extrapolated to 0% herbivory using logit function)} \]
\[ P_B P_F = \text{product of } P_B \text{ and } P_F \]

Figure 5: a) Observed vs. predicted *Tamarix* mortality rates as a function of *Diorhabda* defoliation. Probabilities were determined using polynomial regression, and the logit function was added to graph the curves. Predicted mortality rates were determined using the multiplicative model. Observed mortality rates were determined directly from observed probabilities of mortality.
Fire & herbivory have interactive effects

Are fire and herbivory synergistic?

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

- Additive theory of probability:
  \[ P(A \text{ and } B) = P(A) + P(B) - P(AB) \]

- 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

**Figure 5:** a) Observed vs. predicted *Tamarix* mortality rates as a function of *Diorhabda* defoliation. Probabilities were determined using polynomial regression, and the logit function was used to graph the curves. Predicted mortality rates were determined using the multiplicative model. Observed herbage starch was predicted from observed probabilities of mortality.

\[ P = \frac{1}{1 + e^{-(a+bx)}} \]

\( M_{BF} \) = 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 < 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*
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**

- **Tamarix invasion**
- Can the system return to this point?
  - Lower intensity fires
  - Higher intensity fires

**Community composition**

Hydrologic modification

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

*Tamarix* fire cycle

- *Tamarix* invasion
- Lower intensity fires
  - *Tamarix* mortality, some native recovery
- Higher intensity fires

Community composition

Time

Hydrologic modification

100
Can the *Tamarix* fire cycle be altered to allow the coexistence of natives?

- Time
- Community composition
- Hydrologic modification
- Lower intensity fires
- *Tamarix* invasion
- *Tamarix* mortality, some native recovery

*Tamarix* fire cycle
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

**Community composition**

- Hydrologic modification

**Time**
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

= % Fire Canopy Removal Index x (% Tamarisk Fire Mortality Index + % Willow Mortality Index + % 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.
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!