

## MODELING THE PHENOLOGY AND SPREAD OF *TAMARIX* BEETLE INFESTATION AND IMPACT ON WATER SAVINGS

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### ABSTRACT:

We summarize preliminary findings of our assessment of phenology and water use (sap flux and satellite-derived evapotranspiration (ET) rates) in two adjacent stands of beetle-infested saltcedar (*Tamarix* Spp.) stands on the Dolores River, Utah, USA. A 10 m tower was erected in each stand prior to 2008. Beetle damage was measured using canopy cover from images taken from tower-mounted visible and infrared cameras ("phenocams"). Time-lapse image sets from the cameras were compared with fine-scale estimates of water use using stem sap flow measurements conducted over three growing seasons (2007-2009). Fractional cover from tower phenocams was comparable to cover from MODIS Enhanced Vegetation Index (EVI). Also, EVI was combined with meteorological data to estimate evapotranspiration (ET) at 15 release sites throughout the western USA. ET was estimated at 16-day intervals from 2000-2009, encompassing pre- and post-release periods at each site. Ground data included leaf area index (LAI) data from an LAI-2000, canopy cover via camera, vegetation structure, composition, phenology, and litter traps. Preliminary results from the sap flux, phenocams and imagery show that both cover and plant transpiration fell dramatically during or shortly after the defoliated period, but recovered when new leaves were produced each year. Baseline ET rates were low, 2-6 mm d<sup>-1</sup> in summer (<0.5 potential ET). At 4 of 15 sites, estimated ET by MODIS decreased markedly after release. At other sites, no decrease in ET was detected. ET tended to recover to pre-release levels at affected sites. Potential water salvage was constrained to the period of defoliation.

## 1. INTRODUCTION

### 1.1 Background

*Tamarix* is an introduced shrub that is widespread in western U.S. riparian corridors. *Tamarix* arrived in the United States from Eurasia during the early 1800s, when eight species were imported to the East Coast for landscaping. The riparian shrub (or small tree) has spread extensively since being introduced near San Francisco area circa 1854. Tamarisk was for ornamental purposes and to control erosion on railroad beds and elsewhere. The hardy shrub naturalized by the late 1880s, spreading to dominate vegetation along the Colorado, Rio Grande, and Pecos Rivers and by 1900, it was already established in several western states. Today, invasive *Tamarix* covers more than one million acres of land in the Western United States, stretching from northern Mexico to Montana and from Kansas to California.

*Tamarix* species began to spread on western rivers at the same time as the major rivers were dammed and diverted for agricultural and municipal use. *Tamarix*

are drought- and salt-tolerant and are therefore better adapted than native trees to the conditions prevailing on these altered rivers. During the mid-to-late 1900s, they were commonly perceived as problem plants that used large amounts of water, out-competed native trees, and provided poor wildlife habitat. There is concern that it displaces native vegetation and consumes large amounts of water from riparian aquifers. Nonnative *Tamarix* shrubs have long been vilified in the American West and Southwest for guzzling water, outcompeting native vegetation, and destroying wildlife habitat. *Tamarix* has been the target of aggressive and costly eradication measures. Accordingly, local, state, and federal agencies have undertaken considerable efforts to eradicate tamarisk and restore riparian habitats to pre-invasion status. Consequently, the *Tamarix* leaf beetle (*Diorhabda carinulata*) has been introduced into the western US to control the spread of tamarisk.

*Tamarix* actually uses less water than many native plants, competes with native species mainly when river systems are disturbed, and provides habitat for native wildlife species, including threatened and

endangered birds (Stromberg et al., 2009; Nagler 2010a,b). Insights provided by *Tamarix* research may help managers understand how to better manage disturbed river systems.

### 1.2 Previous Related Research

Resource managers need accurate point estimates of agricultural and riparian evapotranspiration (ET) to construct water budgets for western rivers. Managers also need wide-area, landscape level estimates of plant water use to apportion water for human and ecosystem needs on arid zone rivers. On the Lower Colorado River, we combined ground measurements of ET from sap flux sensors and eddy covariance and Bowen ratio towers, and potential ET from meteorological stations, with satellite data such as Moderate Resolution Imaging Spectrometer (MODIS) Enhanced Vegetation Index (EVI) to scale ET over agricultural and riparian areas along river (Nagler et al., 2010; Murray et al., 2010). The Vegetation Index/Crop Coefficient Approach for Scaling ET by Remote Sensing is defined by Eqn. 1:

$$ET = 1.22 \times EVI * x ETo BC \quad [Eqn. 1]$$

In each irrigation district along the river, we used a sampling method for agricultural and riparian extents. We developed the first crop coefficients from remote sensing and ground data to provide new wide-area estimates of ET. We applied this method for estimating wide-area ET along the Dolores River. At a test site called "Rio Mesa" we are monitoring losses in ET due to the *Tamarix* leaf beetle using phenocams and sap flux sensors.

### 1.3 Location of Study

Traditional eradication methods for *Tamarix*, including herbicide treatments, are now considered undesirable because they are costly and have unintended impacts on native species. In recent years, several specialist herbivore species (beetles) in the genus *Diorhabda* have been field released in western U.S. river systems to achieve biological control of *Tamarix*. These beetles can cause substantial defoliation and may eventually cause mortality of *Tamarix*, paving the way for changes to plant community composition and structure, with consequent effects on wildlife populations and ecosystem processes (such as wildfire, hydrological dynamics, and sediment dynamics). The beetle is spreading rapidly in the Upper Colorado River watershed, is well established in parts of Texas, New Mexico, Wyoming, Utah, and Nevada, and is expected to colonize the Lower Colorado River system in the future. A rapid loss of *Tamarix* will cause cascading effects on riparian communities, the severity of which will depend on the type of plant successions and the speed with which such plants colonize post-beetle habitats.

Release of the beetle was not accompanied by a coordinated monitoring program to document its spread and effectiveness. Current knowledge is incomplete and is based on individual, short-term research projects. The beetle has spread much more rapidly than was originally predicted. There is concern about how rapidly it has spread, how it affects wildlife habitat, and where it will go next. Therefore, development of a scientifically sound, interdisciplinary set of research and monitoring activities focused on determining the effects of *Tamarix* beetles on riparian ecosystems is critical to help inform managers in the region about conservation of wildlife species and habitat, as well as management alternatives such as restoration and rehabilitation. Restoration, or returning a disturbed ecosystem to some previous state—in this case, repopulating native riparian zones with cottonwood and willow trees—may not be a realistic goal on many altered rivers due to changes in flow regimes and salinization of the aquifers and soils. Increasing the vegetation cover and productivity of a disturbed ecosystem so that it may still provide wildlife habitat, erosion control, or recreational services through rehabilitation is often a more realistic goal, even though the riparian system is not returned to its original state. Because simply replacing *Tamarix* with native species following defoliation might not be the most feasible course of action at a given site, managers are seeking a scientific basis to guide their choices for ensuring functional wildlife and ecosystem habitats as the *Tamarix* – *Diorhabda* interactions proceed on western rivers. The release of the tamarisk leaf beetle (*Diorhabda elongata*) in 2004 near the Entrada Field Station provides an ideal opportunity to fill the monitoring gap between management activity & scientific research on the consequences of tamarisk defoliation spread and other impacts on the Colorado Plateau. There are currently no public or private programs to monitor (i) the movement of the beetle from the release points or (ii) whether its presence ultimately leads to tamarisk mortality, changes in watershed hydrology and plant community structure. We summarize preliminary findings of our assessment of phenology and water use (sap flux and satellite-derived evapotranspiration (ET) rates) in two adjacent stands of beetle-infested saltcedar (*Tamarix* Spp.) stands on the Dolores River, Utah, USA. MODIS EVI data was combined with meteorological data from Moab, Utah, the city closest to the field site, to estimate ET. This methodology is described in detail in Dennison et al., 2009 and Nagler et al., 2009. It was further used to evaluate ET changes over the last ten years at 15 beetle release sites throughout the western USA.

### 1.4 Methods

A 10 m tower was erected in each *Tamarix* stand along the Dolores River field site at the Rio Mesa Center prior to 2008. Beetle damage was measured using canopy cover from images taken from tower-

mounted visible and infrared cameras (“phenocams”). Time-lapse image sets from the cameras were compared with fine-scale estimates of water use using stem sap flow measurements conducted over three growing seasons (2007-2009). Fractional cover from tower phenocams was comparable to cover from MODIS EVI. Also, EVI was combined with meteorological data to estimate ET at 15 release sites throughout the western USA. ET was estimated at 16-day intervals from 2000-2009, encompassing pre- and post-release periods at each site. Ground data included leaf area index (LAI) data from an LAI-2000, canopy cover via camera, vegetation structure, composition, phenology, and litter traps. Preliminary results from the sap flux, phenocams and imagery show that both cover and plant transpiration fell dramatically during or shortly after the defoliated period, but recovered when new leaves were produced each year. Baseline ET rates were low, 2-6 mm d<sup>-1</sup> in summer (<0.5 potential ET). At 4 of 15 sites, estimated ET by MODIS decreased markedly after release. At other sites, no decrease in ET was detected. ET tended to recover to pre-release levels at affected sites. At each location, the results support our past 3 years of findings for the ET seasonally and annually time-series curves as the beetle came into the area and defoliated saltcedar. Potential water salvage was constrained to the relatively brief period of defoliation.

### 1.5 Results

EVI was combined with meteorological data to estimate ET at 15 release sites throughout the western USA. ET was estimated at 16-day intervals from 2000-2009, encompassing pre- and post-release periods at each site. Results from the sap flux, phenocams and imagery show that both cover and plant transpiration fell dramatically during or shortly after the defoliated period, but recovered when new leaves were produced each year. Baseline ET rates were low, 2-6 mm d<sup>-1</sup> in summer (<0.5 potential ET). At 4 of 15 sites, estimated ET by MODIS decreased markedly after release. At other sites, no decrease in ET was detected. ET tended to recover to pre-release levels at affected sites. Potential water salvage was constrained to the period of defoliation and determined to be <15% of the river water’s savings.



Figure 1. Tamarisk stand on the Dolores River, near Moab, UT, (a) before and (b) after defoliation by the saltcedar leaf beetle (*Diorhabda elongata*).

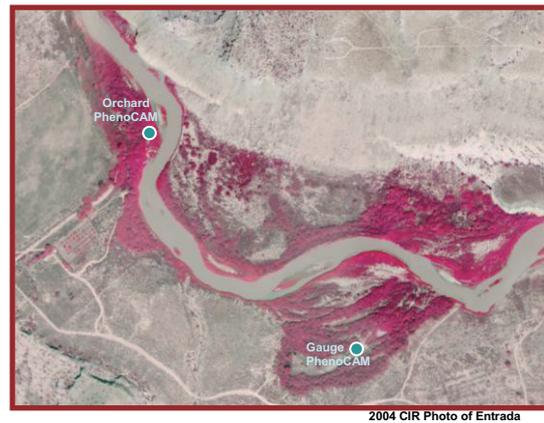


Figure 2. We set up infrastructure for long-term monitoring of ET using point measurements from sap flux sensors, percent cover from “PhenoCAMS” and scaling ET to the river reach / landscape scale using imagery (ASTER and MODIS).

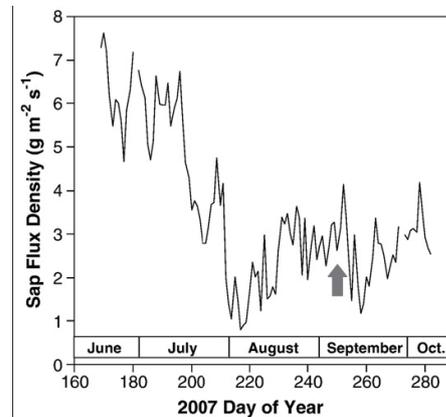


Figure 3. We measured daily sap flux density on *tamarisk* and saw a steep decline ~ day 195 (July 14), which is when the beetle starts munching, after being dormant in Winter.

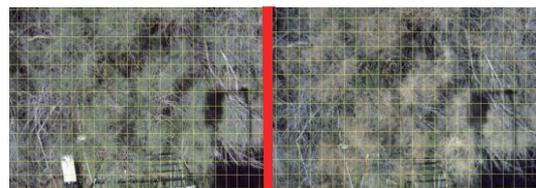


Figure 4. Entrada’s Gauge Station PhenoCam, before (June 9, 2008) and after (July 2, 2008) images at a beetle-infested site on the Dolores River. Left image depicts 13.7% Green Leaf Cover. Right image depicts only 1.1% Green Leaf Cover. Note brown leaves.

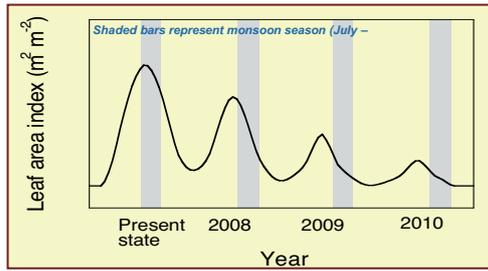


Figure 5. During the 2004 beetle release, we hypothesized this change in leaf area index (LAI) in response to tamarisk defoliation by the saltcedar leaf beetle. Multiple defoliation events reduce carbohydrates and stored carbon pools, resulting in a progressive reduction in leaf production. The system will either crash after 2010, resulting in tamarisk mortality or stabilize with little or no mortality.

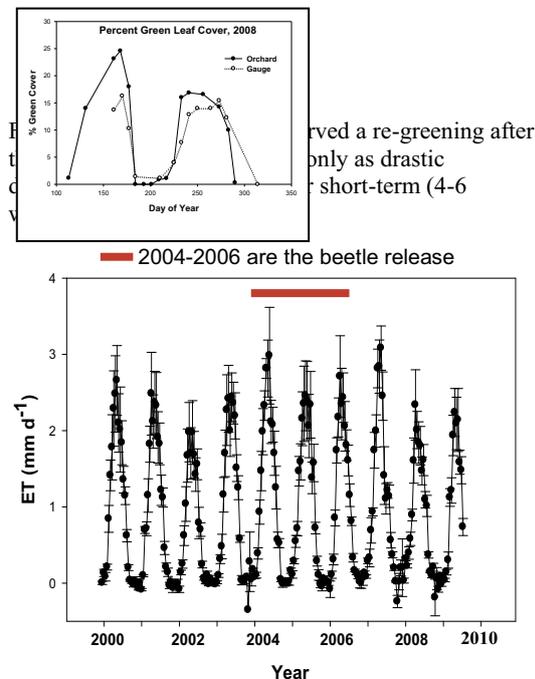


Figure 7. We observed minimal decline at the landscape level as well. Post-beetle ET or water use has not changed significantly at this scale.

Annual ET estimated by MODIS EVI for individual pixels (six at 250m res.) and the average of the six pixels at the Entrada site, before major beetle infestation was noted (2000 – 2006) and after infestation was noted (2007– 2009). Before and after differences were non-significant in all cases ( $P > 0.05$ ).

### 1.5 Key Questions for Future Research

Many scientists have come together to assess what is needed to evaluate the *Tamarix* landscape problem (Hultine et al., 2009). Numerous information gaps on

the ecosystem effects of *Tamarix* biological control exist; some central questions include:

- 1) Beetle distribution, movement, and effects. What is the current distribution of the different species of *Tamarix* biocontrol beetles across the West? What are the underlying mechanisms producing the pattern (directionality, extent) and rate of spread? What is the fraction of canopy cover defoliated in each annual cycle? And do defoliated plants eventually recover? And, how many years does it take to cause *Tamarix* mortality? How does phenology, defoliation and mortality of *Tamarix* vary regionally over western North America?
- 2) Defoliation, rehabilitation, restoration, and wildlife responses. How does beetle defoliation influence *Tamarix* litter quality and quantity, soil organic matter, and soil chemistry? And how will nutrient cycling be altered, given input of insect frass and bodies, altered soil moisture, increased *Tamarix* litter and invasion of exotic weeds? What vegetation will occupy sites following biological control of *Tamarix*? What site factors and processes influence natural recovery vs. secondary weed invasion? What are the most effective strategies for providing habitat for priority wildlife species or recreational activities? How are various animal communities and key species (such as insects, birds, small mammals, reptiles and amphibians, fish, and aquatic insects) affected by defoliation, rehabilitated and/or restored reaches? Will changes in wildlife composition and/or activity affect ecosystem processes and vegetation changes? How will certain groups of animals directly and/or indirectly facilitate or hinder beetle defoliation? Will defoliating beetles affect wildlife populations and/or communities directly (increased resources) or indirectly (altered habitat structure)?
- 3) Ecosystem processes. In the years after initial beetle release at known sites, how do key physical and ecosystem processes change? For example, how do changes in canopy foliage and structure change light interception, fraction of absorbed light (PAR), litter, and soil reflectance? And are there landscape-scale effects on surface radiation/energy balance? How do these effects influence water quality and use by riparian species, canopy temperature and humidity (important for not only water use, but also avian habitat), and riparian soil fertility and stability? How do these canopy changes and ecosystem processes affect riparian obligate avian species (e.g., avian populations and productivity, food base, and migratory routes)? And how are these ecosystem changes affecting endangered or threatened species? Are these sites more susceptible to sediment erosion and channel entrenchment, as has been the case on rivers

where *Tamarix* was killed with herbicides? What opportunities are there for restoration or rehabilitation of riparian areas following beetle infestations?

## 2. CONCLUSIONS

These preliminary findings support both satellite and phenological observations showing that beetle damage is transient and spotty and localized at most sites, and reduction in ET is confined mainly to July when beetles are actively feeding. Because defoliation by the beetle is new to the ecosystem (~ 5 years), relative to the presence of tamarisk (>100 years), the long-term effect of the defoliation on water salvage is unknown. Prospects for water salvage over large areas of river so far appear to be limited as beetle – tamarisk interactions have not yet stabilized on western rivers.

## 3. REFERENCES

- Hultine, Kevin R., Jayne Belnap, Phillip E. Dennison, James R Ehleringer, Martha E. Lee, Pamela L. Nagler, Keirith A. Snyder, Shauna M. Uselman, Charles van Riper III, Jason B. West. 2009. Tamarisk biocontrol in the western United States: ecological and societal implications. *Frontiers in Ecology and the Environment* (In press, August 2009) doi:10.1890/090031.
- Nagler, Pamela L., Edward P. Glenn, and Kamel Didan. 2009. Remote Sensing Methods for Monitoring Wetland and Riparian Ecosystems in the Delta of the Colorado River, Mexico. Special Issue of *Remote Sensing of Environment* (RSE) focused on Monitoring Parks and Protected Areas 113: 1473-1485.
- Nagler, Pamela L., Morino, Kiyomi, Murray, Scott, Osterberg, John, Glenn, Edward P. 2010. An Empirical Algorithm for Estimating Agricultural and Riparian Evapotranspiration Using MODIS Enhanced Vegetation Index and Ground Measurements of ET. I. Description of Method. Part I. Description of method. *Remote Sensing: Special Issue: Global Croplands*. 1273-1297.
- R. Scott Murray, Pamela L. Nagler and Edward P. Glenn. 2010. An Empirical Algorithm for Estimating Agricultural and Riparian Evapotranspiration Using MODIS Enhanced Vegetation Index and Ground Measurements of ET. I. Description of Method. Part II. Application to the Lower Colorado River, U.S. *Remote Sensing: Special Issue: Global Croplands* 1125-1138.
- Nagler, P.L., E.P. Glenn, C.S. Jarnevich, and P.B. Shafroth. 2010. In Press. Chapter 2: Distribution and abundance of saltcedar and Russian olive in the western United States. Pages 7-32 in P.B. Shafroth, C.A. Brown, and D.M. Merritt, editors, Saltcedar and Russian olive Control and Demonstration Act science assessment. U.S. Geological Survey, Scientific Investigations Report 2009-5247.
- Nagler, P.L., P.B. Shafroth, J.W. LaBaugh, K.A. Snyder, R.L. Scott, D.M. Merritt, and J. Osterberg. 2010. In Press. Chapter 3: The potential for water savings through the control of saltcedar and Russian olive. Pages 33-48 in P.B. Shafroth, C.A. Brown, and D.M. Merritt, editors, Saltcedar and Russian olive Control and Demonstration Act science assessment. U.S. Geological Survey, Scientific Investigations Report 2009-5247.
- Stromberg, J. C., M. K. Chew, P. L. Nagler, E. P. Glenn. 2009. Changing Perceptions of Change: The Role of Scientists in *Tamarix* and River Management. *Restoration Ecology* 17 (2): 177-186.
- Dennison, P. E., P. L. Nagler, K. R. Hultine, E. P. Glenn, J. Ehleringer. 2009. Remote Monitoring of Tamarisk Defoliation and Evapotranspiration Following Saltcedar Leaf Beetle Attack. Special Issue of *Remote Sensing of Environment* (RSE) focused on Monitoring Parks and Protected Areas 113: 1462-1472.