The History, Biology and Future of Biological Control

Dan Bean, Colorado Department of Agriculture, Palisade Insectary
Palisade, CO

Biocontrol in Action Workshop
Phoenix, AZ
April 30, 2025

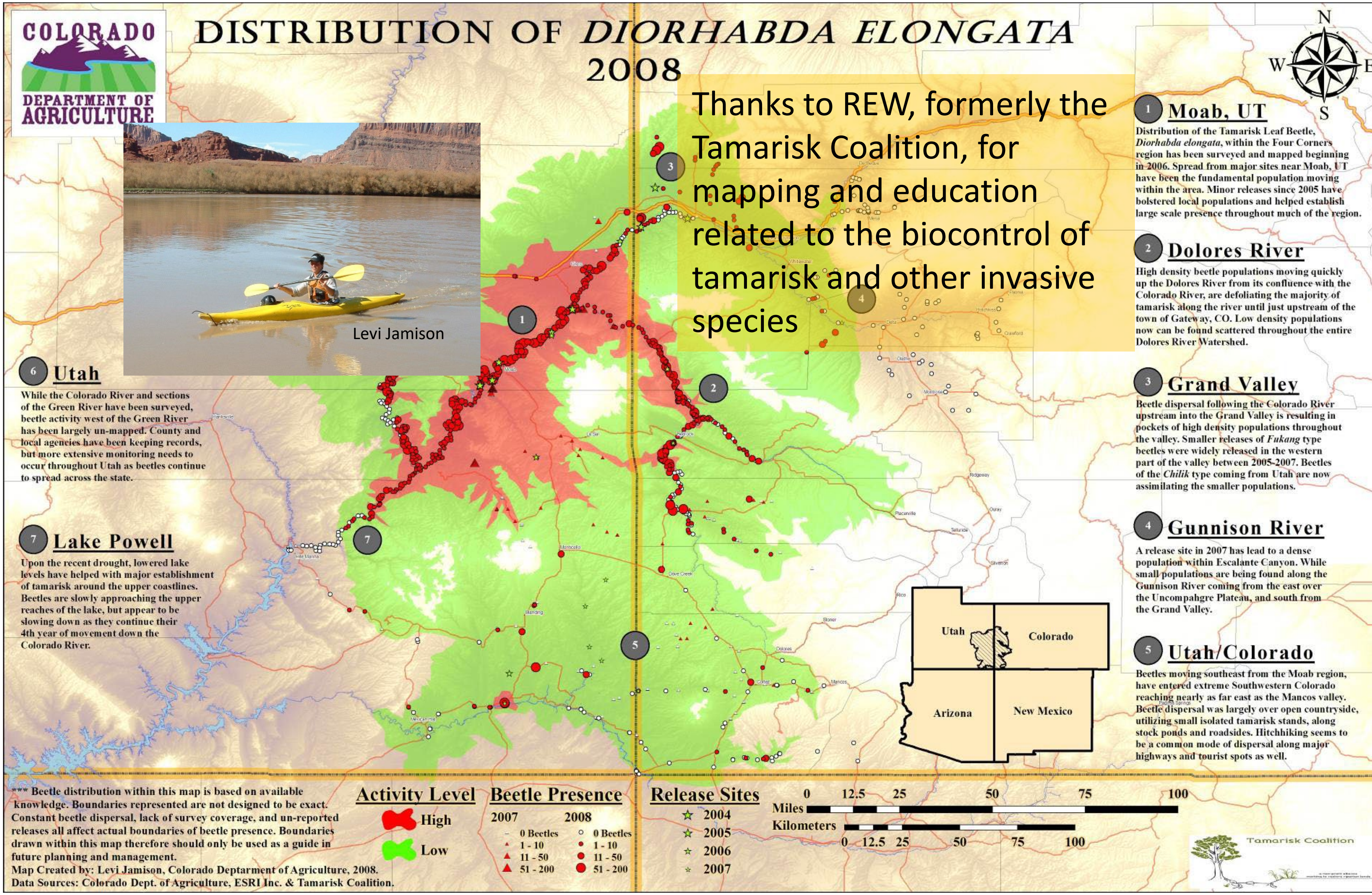
2007 (Nina Louden)

2010 (Sonya Daly)

Tamarisk Monitoring site on the Dolores River, CO

Diorhabda carinulata larvae

Thanks to REW, formerly the Tamarisk Coalition, for mapping and education related to the biocontrol of tamarisk and other invasive species



Levi Jamison

What is biological control?

1. Biological control (biocontrol) is the use of natural enemies to control pests, including insect pests and noxious weeds.

Field bindweed stunted by the mite *Aceria malherbae*

Macrocentrus ancylivorus stings host

Types of biocontrol

1. Augmentative
2. Conservation
3. Classical

Establishing host specific natural enemies from the native range of the weed or insect pest into the introduced range.

- Tamarisk originated in Eurasia
- About 300 natural enemies were discovered
- Beetles in the genus *Diorhabda* were selected as biocontrol agents

What is classical biological control?

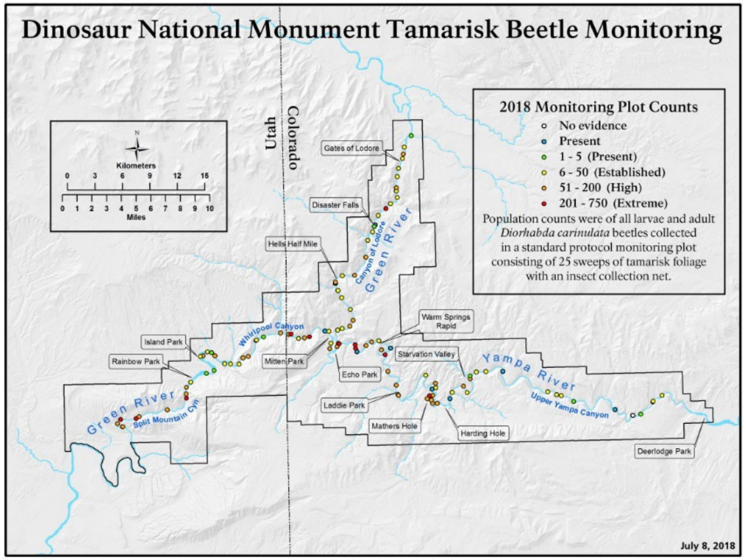
1. Biological control (biocontrol) is the use of natural enemies, including insects, mites and pathogens, to control pests, including insect pests and noxious weeds.
2. **Classical biocontrol** is a sustainable ecologically based pest control method. The goal is suppression of the weed or insect pest, not eradication. Often the desired results take years to achieve.

Field bindweed stunted by the mite *Aceria malherbae*

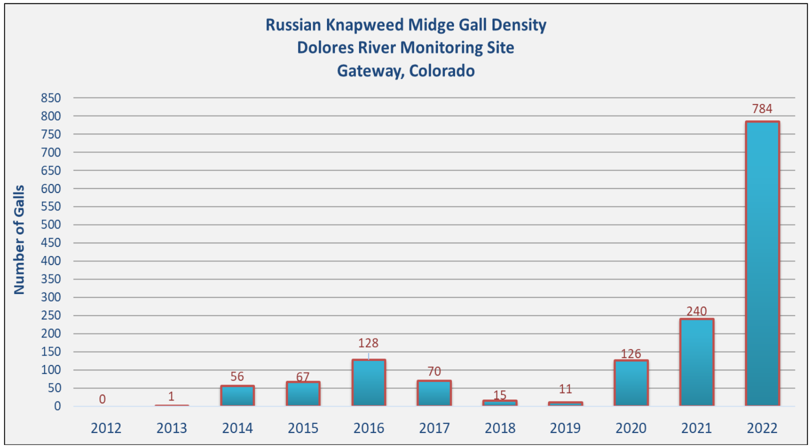
Leafy spurge herbivory by the red-headed borer, *Oberea*. Damage from feeding larvae (left) and feeding adult (right)

Results of classical biocontrol require years to achieve

Invasive plant biocontrol occurs in <u>ecological time</u>, requiring years and sometimes decades to reach equilibrium.



Dinosaur Natl Monument invasive species project since 2006



Russian knapweed, Dolores River, since 2012

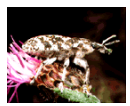
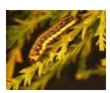
Poudre Invasive Species Partnership, Larimer County, since 2013

Is biocontrol safe?

Safety considerations centered on host specificity

1. Do agents feed on agriculturally important plants?
2. Do agents feed on native plants? (after 1970)

Generalists vs. Specialists:
What makes them specialists?

Insect		**Host Plant**
Leafy spurge flea beetles 	→	Leafy spurge 
Knapweed root weevil 	→	Diffuse and spotted knapweed
Russian knapweed gall fly 	→	Russian knapweed
Tamarisk beetle 	→	tamarisk

1. Long range volatile attractants (smells)
2. Feeding stimulants
3. Ability to detoxify plant compounds

Weed Biological Control is Safe

- **Only specialists are used**
- **It takes at least ten years for an agent to be approved**
- **There has never been a case in modern weed biocontrol where a biocontrol agent switched host plants**

Host Range Testing

Why do some non-native plants become invasive weeds?

1. Absence of natural enemies.
2. Unusual genetics, unique strains and hybrids
3. Better competitors in disturbed habitats
4. Some are drivers of ecosystem change

tamarisk
Tamarix ramosissima, chinensis, parviflora, etc

leafy spurge near Pine, CO
Euphorbia esula

Why do some non-native plants become invasive weeds?

Enemy release hypothesis

1. Absence of natural enemies.
2. Unusual genetics, unique strains and hybrids
3. Better competitors in disturbed habitats
4. Some are drivers of ecosystem change

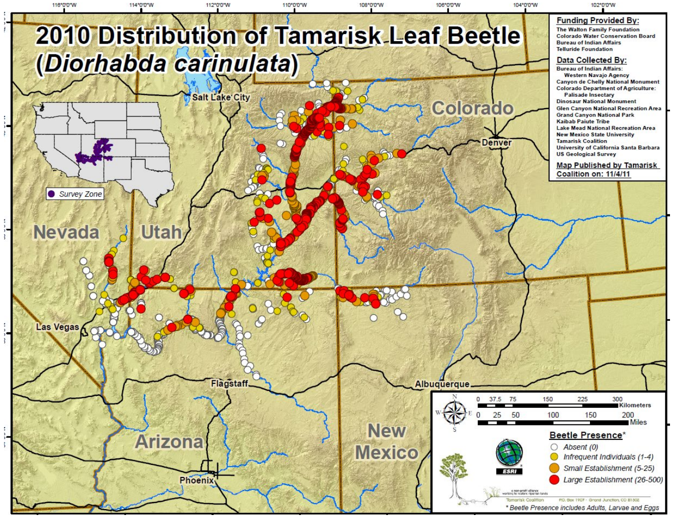
tamarisk
Tamarix ramosissima, chinensis, parviflora, etc

leafy spurge near Pine, CO
Euphorbia esula

Biocontrol is part of IPM

Colorado's biocontrol program promotes integrated management in which biocontrol is part of larger plans to diminish impact of invasive species

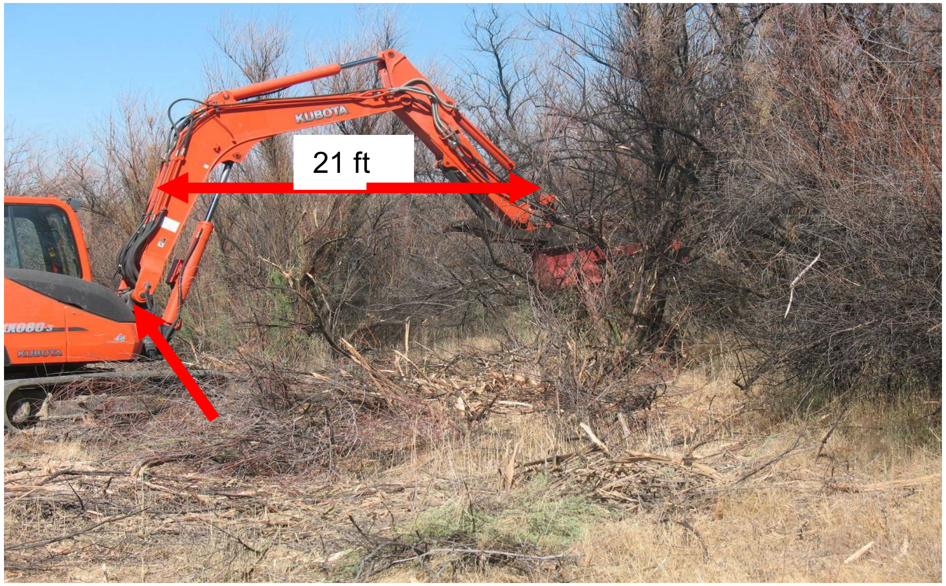
- Monitoring



Biocontrol is part of IPM

Colorado's biocontrol program promotes integrated management in which biocontrol is part of larger plans to diminish impact of invasive species

- Monitoring
- Mowing
- Grazing
- Herbicides

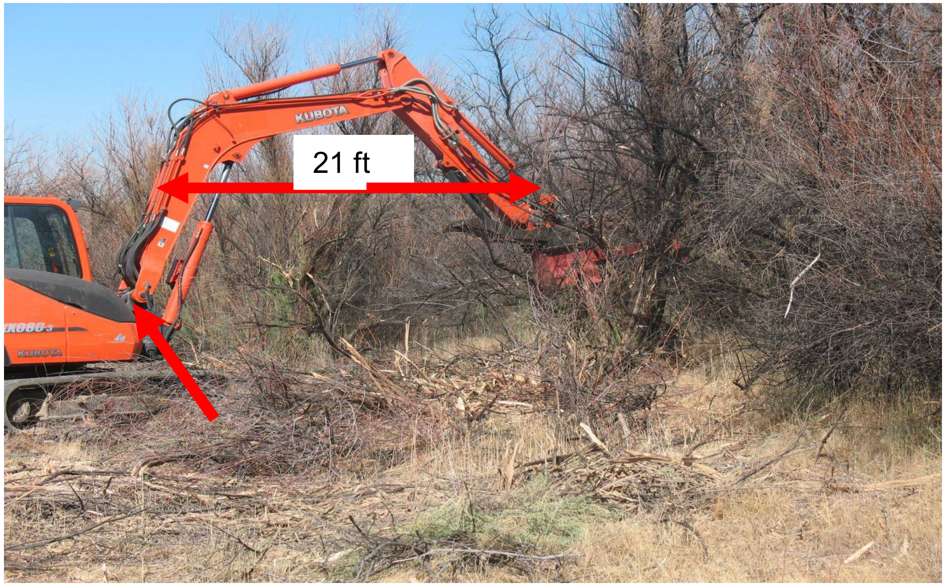


Physical removal of dead tamarisk

Biocontrol is part of IPM

Colorado's biocontrol program promotes integrated management in which biocontrol is part of larger plans to diminish impact of invasive species

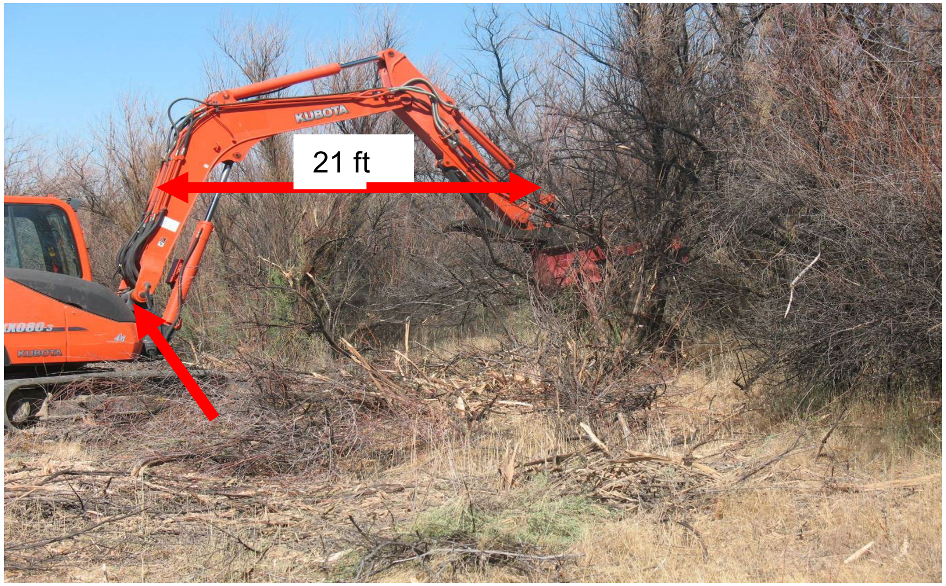
- Monitoring
- Mowing
- Grazing
- Herbicides
- Conservation
- Competition
- Restoration



Biocontrol is part of IPM

Colorado's biocontrol program promotes integrated management in which biocontrol is part of larger plans to diminish impact of invasive species

- Sustainable
    i. Self propagation
    ii. Little or no resistance



Target choice for classical biocontrol

- A geographically widespread problem
- Difficult to control using conventional means
- Serious environmental and economic impacts
- Taxonomically distinct from native species

Tamarisk seen as a perfect target, **Saltcedar Consortium** formed for biocontrol development in the 1990s

Tamarisk

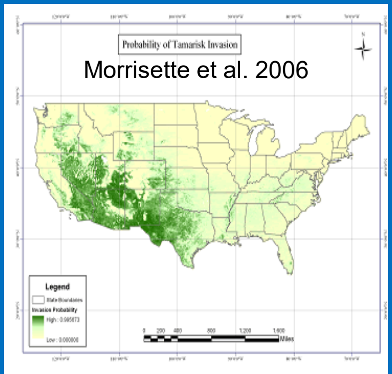
5 species of *Tamarix* and their hybrids

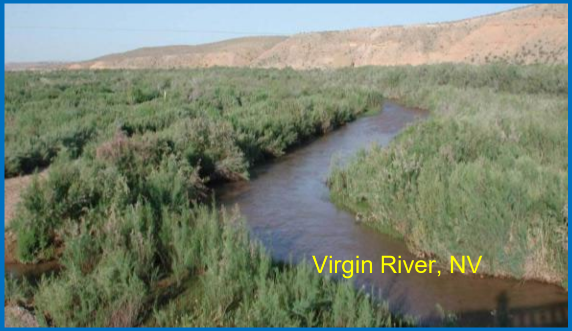
T. ramosissima, *T. chinensis* and their hybrids are the most common (J. Gaskin and colleagues) with *T. parviflora* common in the coast range of CA

A N/S genetic gradient with *T. ramosissima m*ore prevalent in the north and *T. chinensis* with a higher genetic representation in the south. (Williams et al 2014)

Tamarisk is a dominant shrub in the west

- *Tamarix* spp. (aka tamarisk or saltcedar) occupy > 500,000 hectares in No. America
- *Tamarix* is the 3rd most common woody plant in Western riparian areas (Friedman et al. 2005)





Colorado River

Tamarisk is a driver of ecosystem change

1. Tamarisk in dense stands **increases evapotranspiration (ET) and lowers water tables**, which may help it to out compete native vegetation (Nagler et al 2014 Remote Sensing of Environment 140 206-219)

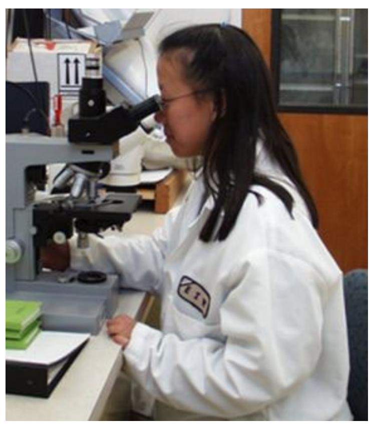
2. Tamarisk is fire adapted and with its fine structured leaves and branches **carries fire in riparian ecosystems** (Drus 2013 in "*Tamarix*: a case study of ecological change in the American West").

3. Tamarisk **alters soil chemistry** leading to unfavorable conditions for mycorrhizae associated with native vegetation, particularly cottonwoods (Meinhardt, KA and Gehring, CA 2012 Ecol App 22:532-49)

Cottonwood death following tamarisk-carried fire, San Pedro River, AZ

Diorhabda elongata was selected for use against tamarisk by the **Saltcedar Consortium**, a group of stakeholders and biocontrol scientists

In the 1990s Jack DeLoach (right) headed up a program for tamarisk biocontrol development

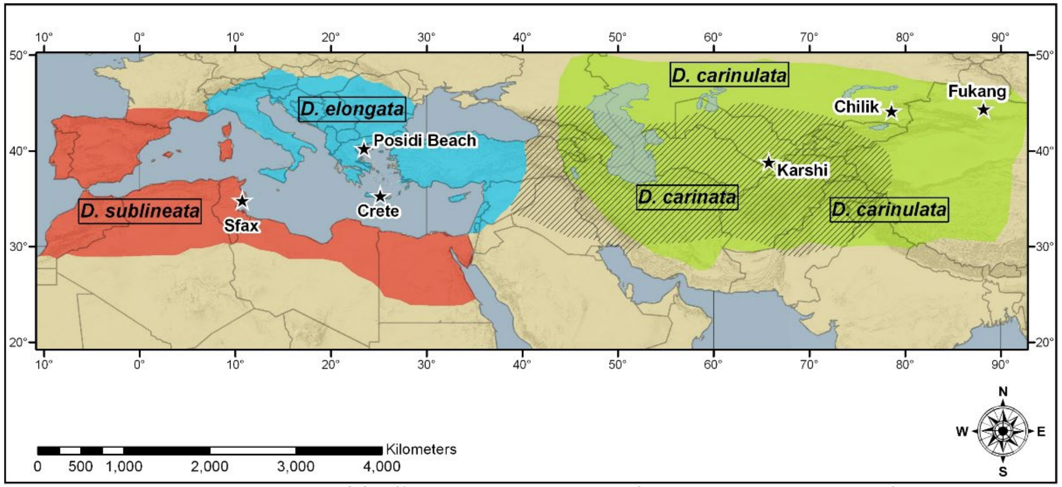


Host range testing as well as research on life cycle and behavior conducted at the USDA ARS facilities in Albany, CA (Ray Carruthers) and Temple, TX, (Jack DeLoach) show beetles in the genus *Diorhabda* to be promising as host specific control agents.

adult

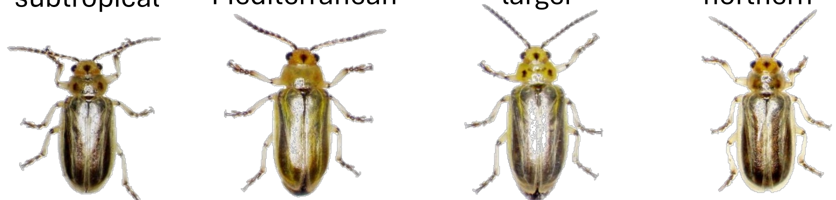
feeding larvae

Diorhabda elongata



Four members of the *Diorhabda* species complex were introduced from Eurasia into North America for control of exotic *Tamarix*, **beginning in 2001**

subtropical Mediterranean larger northern

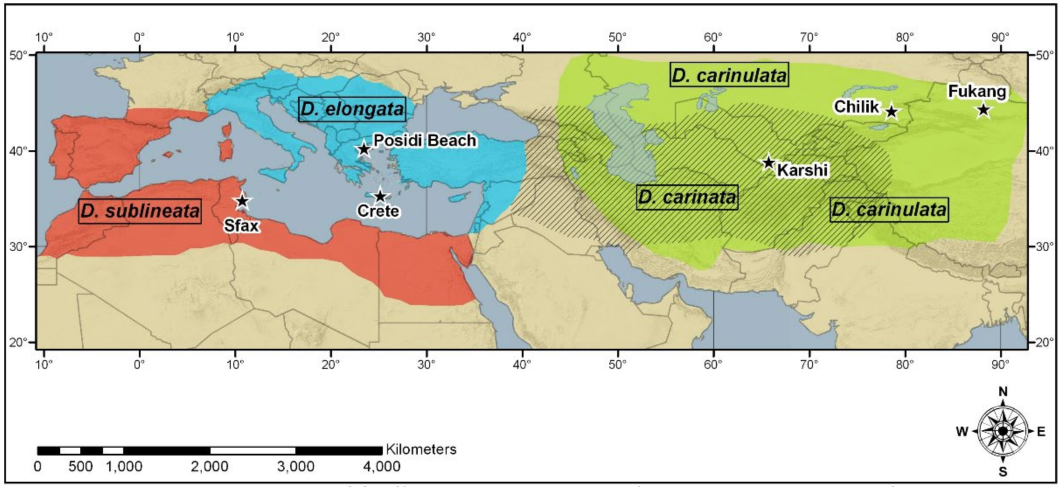


D. sublineata *D. elongata* *D. carinata* *D. carinulata*

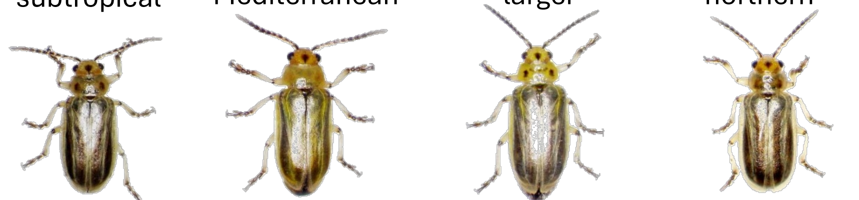
Tracy and Robbins 2009 Zootaxa **2101**: 1-152

Widespread defoliation of *Tamarix* and range expansion of *Diorhabda* followed introduction

Four members of the *Diorhabda* species complex were introduced from Eurasia into North America for control of exotic *Tamarix*, **beginning in 2001**



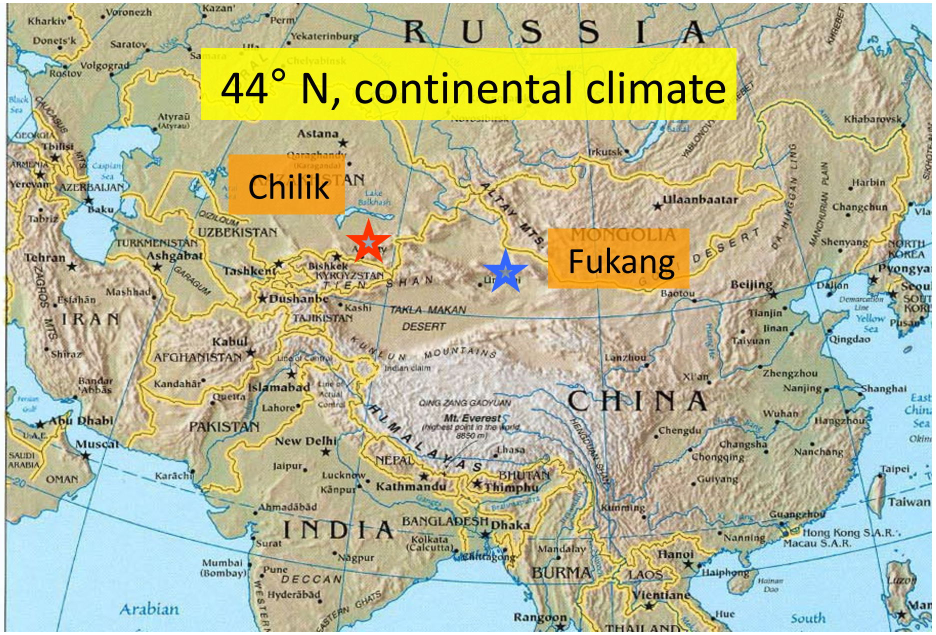
subtropical | Mediterranean | larger | northern



D. sublineata 2008 | *D. elongata* 2003 | *D. carinata* 2006 | *D. carinulata* 2001

Tracy and Robbins 2009 Zootaxa **2101**: 1-152

Widespread defoliation of *Tamarix* and range expansion of *Diorhabda* followed introduction



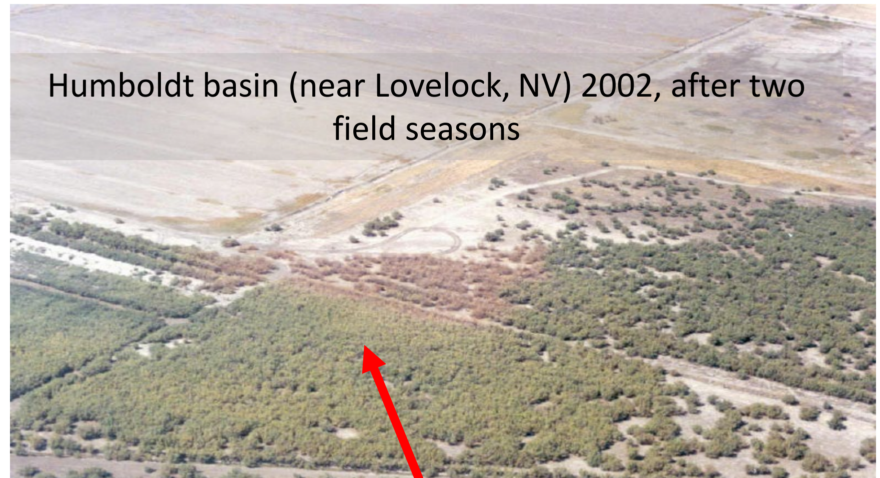
The first biocontrol agent for tamarisk was *Diorhabda carinulata*, **northern tamarisk beetle** originated from two sites in the interior of central Asia.

Northern Adapted Physiology and Phenology

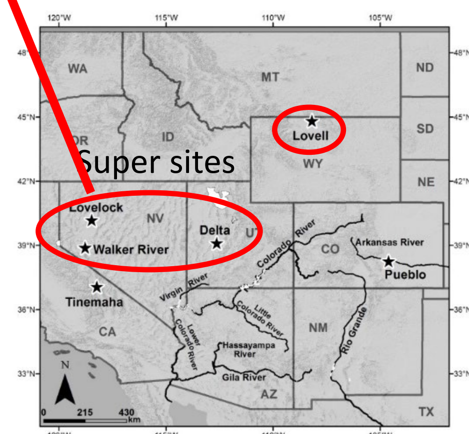
- Timing of entry and exit from diapause (dormancy)
- Diapause intensity
- Cold tolerance

Well adapted or **Maladapted** depended on where the beetle was released in the western US

Beetles thrived at northern sites (Lovelock, Lovell, Delta)

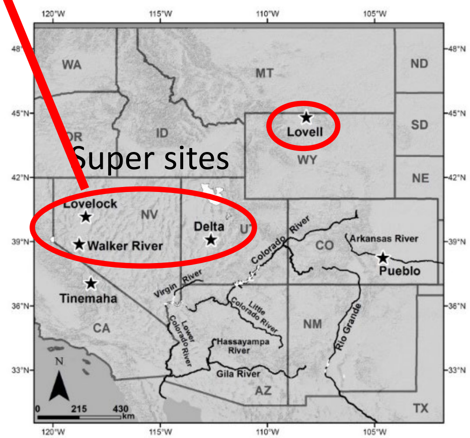


- Cycles of defoliation and refoliation
- Decrease in flowering
- Die back of branches, decrease of plant biomass
- Mortality (about 30%, 70% at release site)

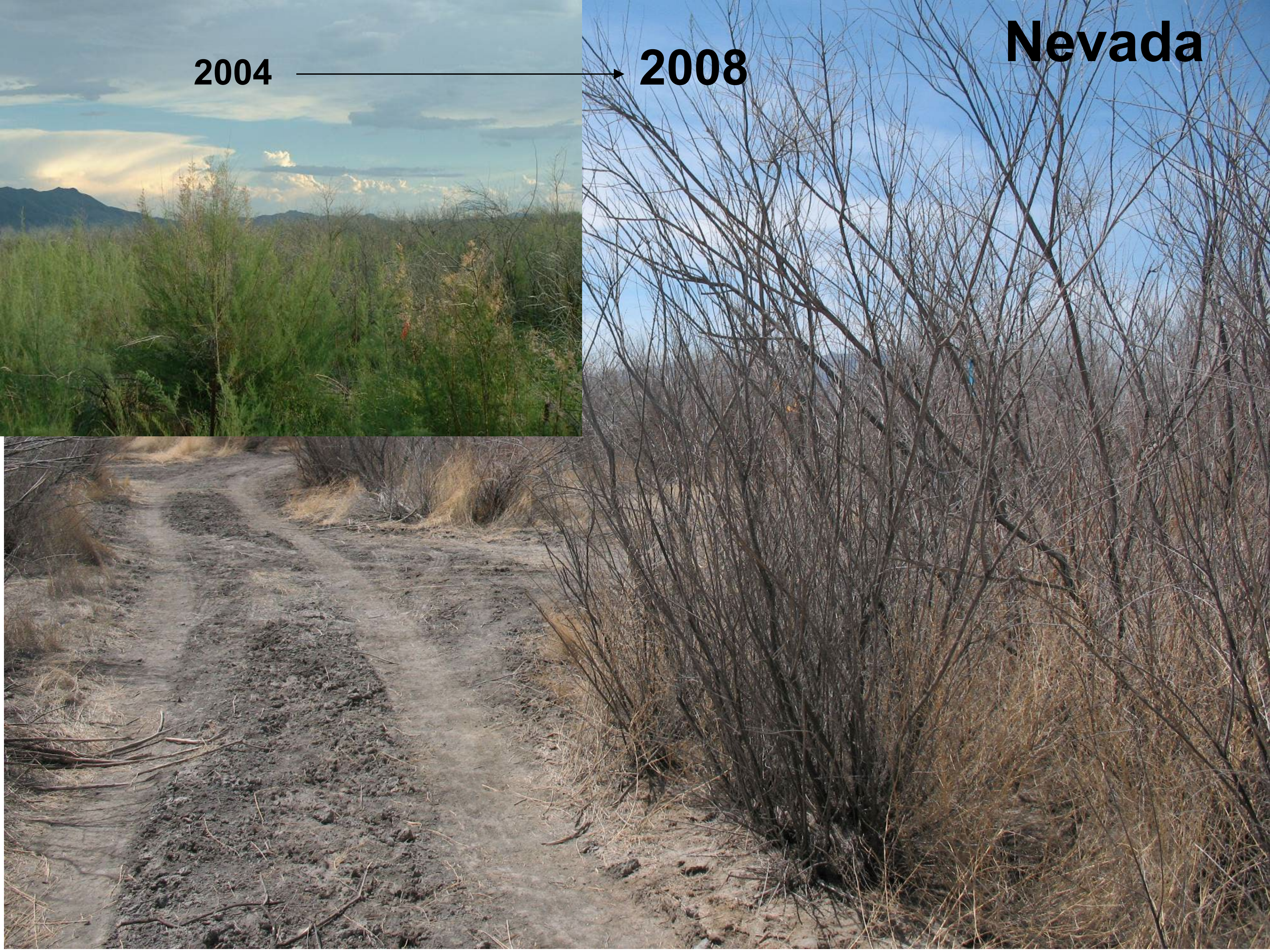


Beetles thrived at northern sites (Lovelock, Lovell, Delta)

- Cycles of defoliation and refoliation
- Decrease in flowering
- Die back of branches, decrease of plant biomass
- Mortality (about 30%, 70% at release site)

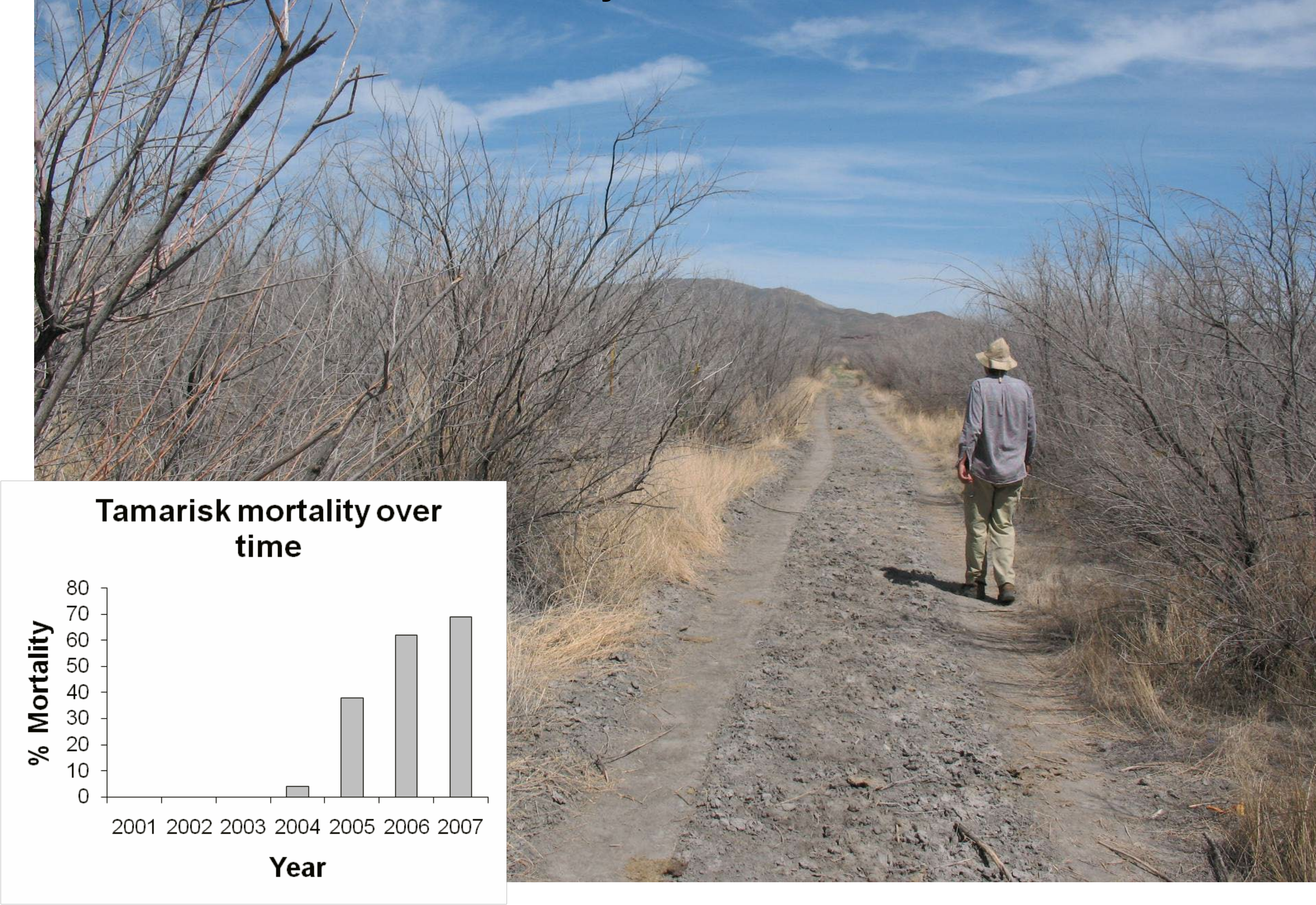


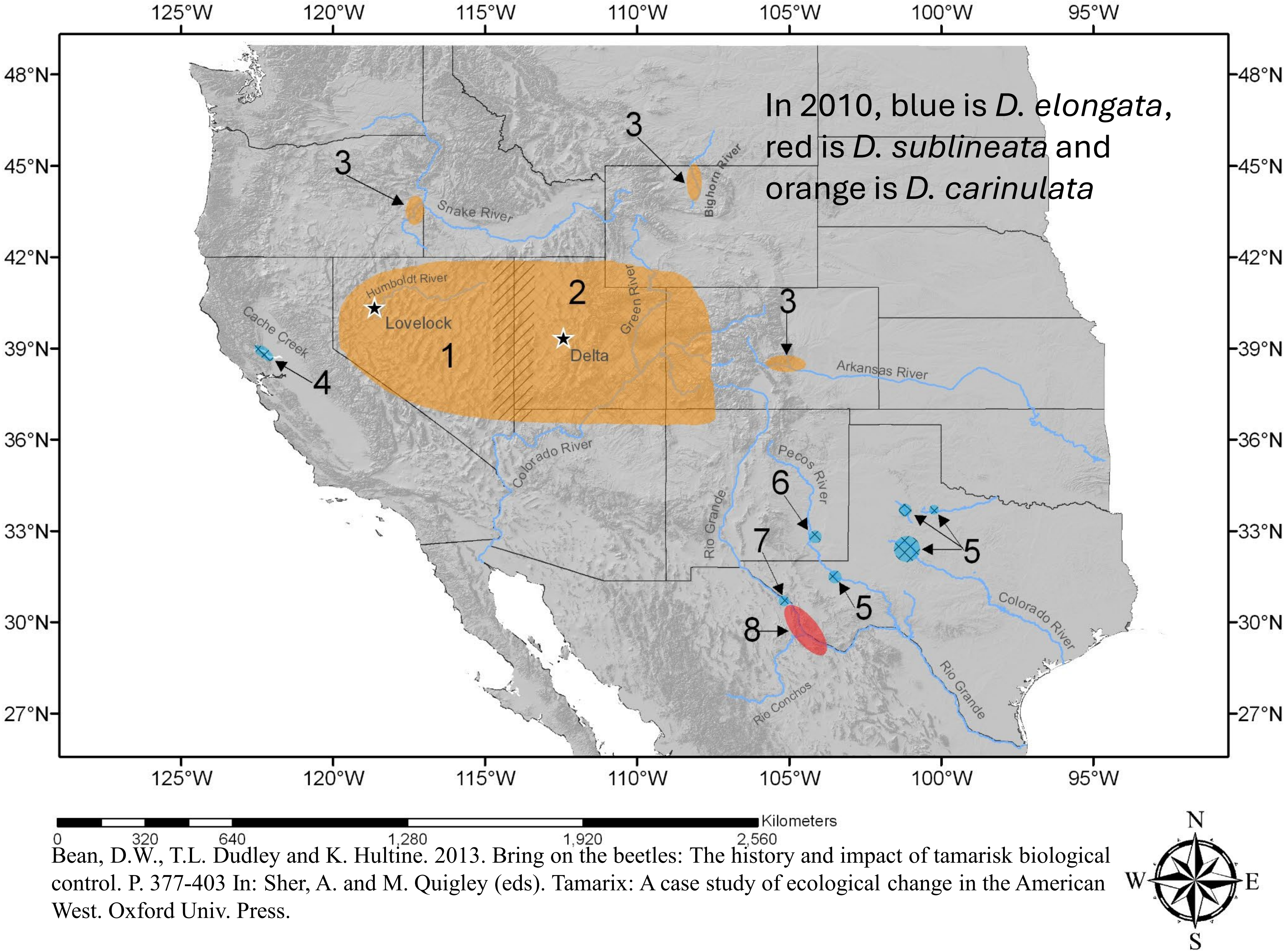
Saltcedar at Lovelock, NV, after two years of defoliation. Photos were taken in May, 2004, after foliage on uninfested plants had fully leafed out.



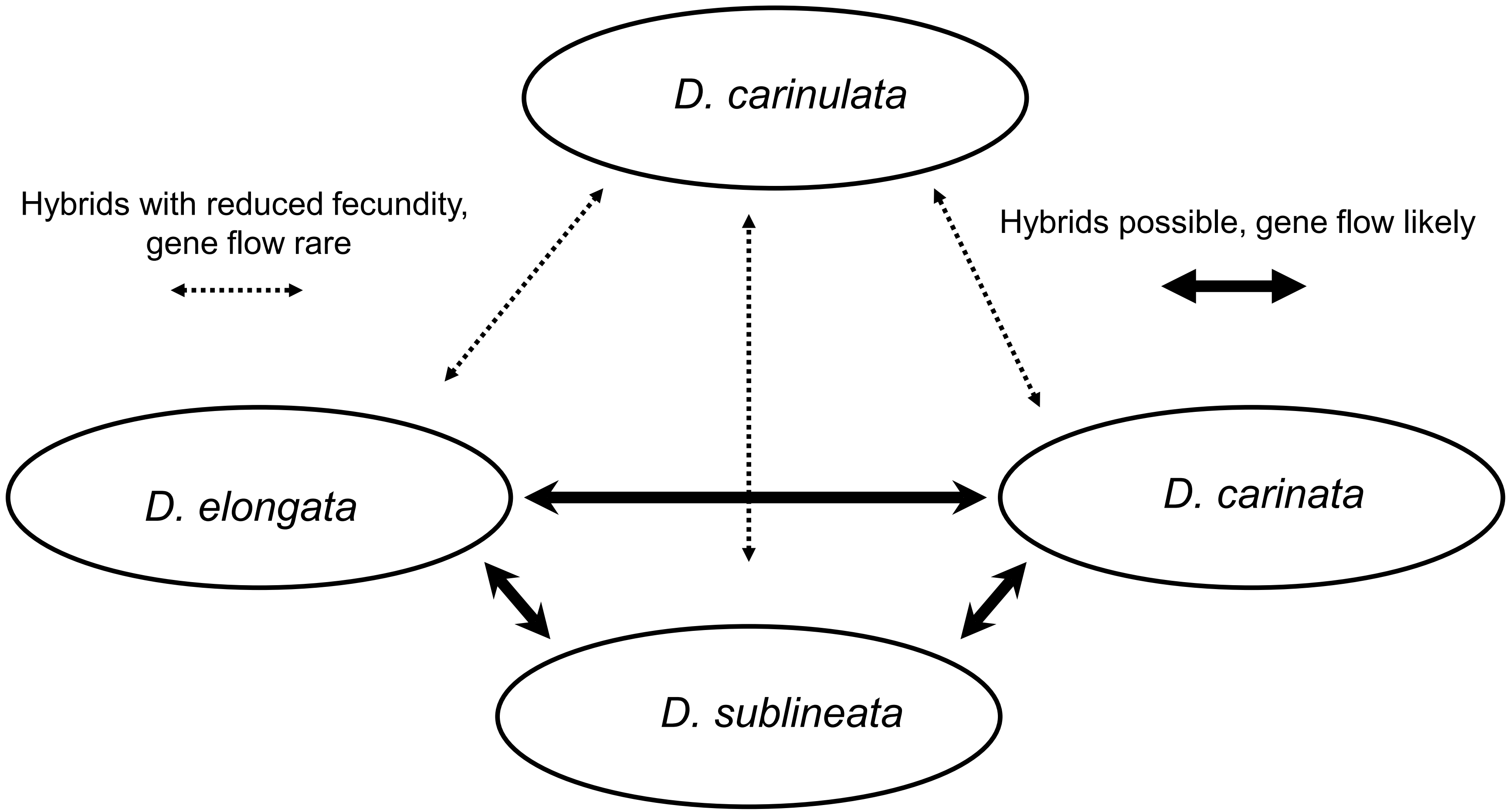
Nevada
2004
2008

70% kill in 4 years, at the release site



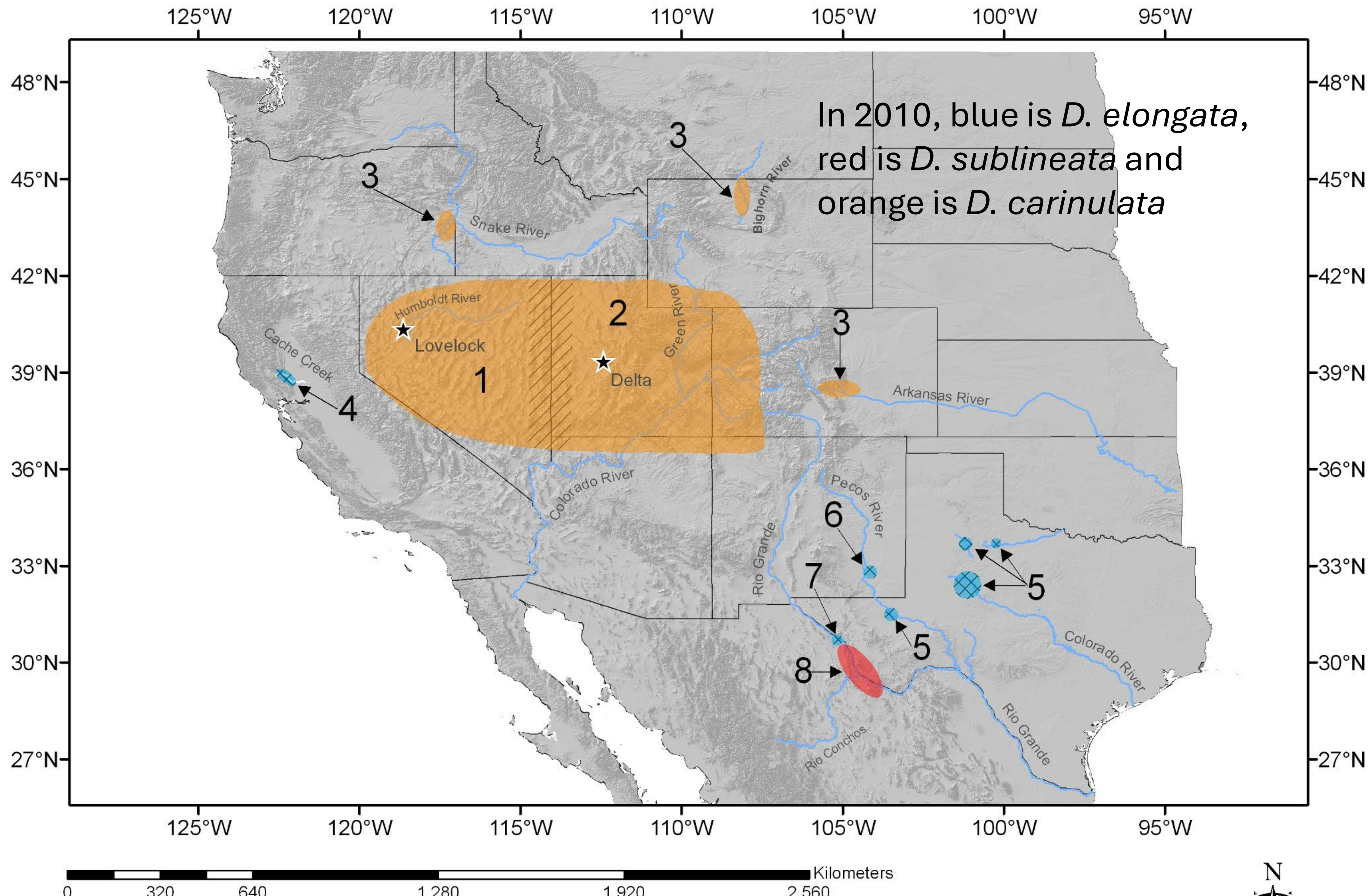


Bean, D.W., T.L. Dudley and K. Hultine. 2013. Bring on the beetles: The history and impact of tamarisk biological control. P. 377-403 In: Sher, A. and M. Quigley (eds). Tamarix: A case study of ecological change in the American West. Oxford Univ. Press.

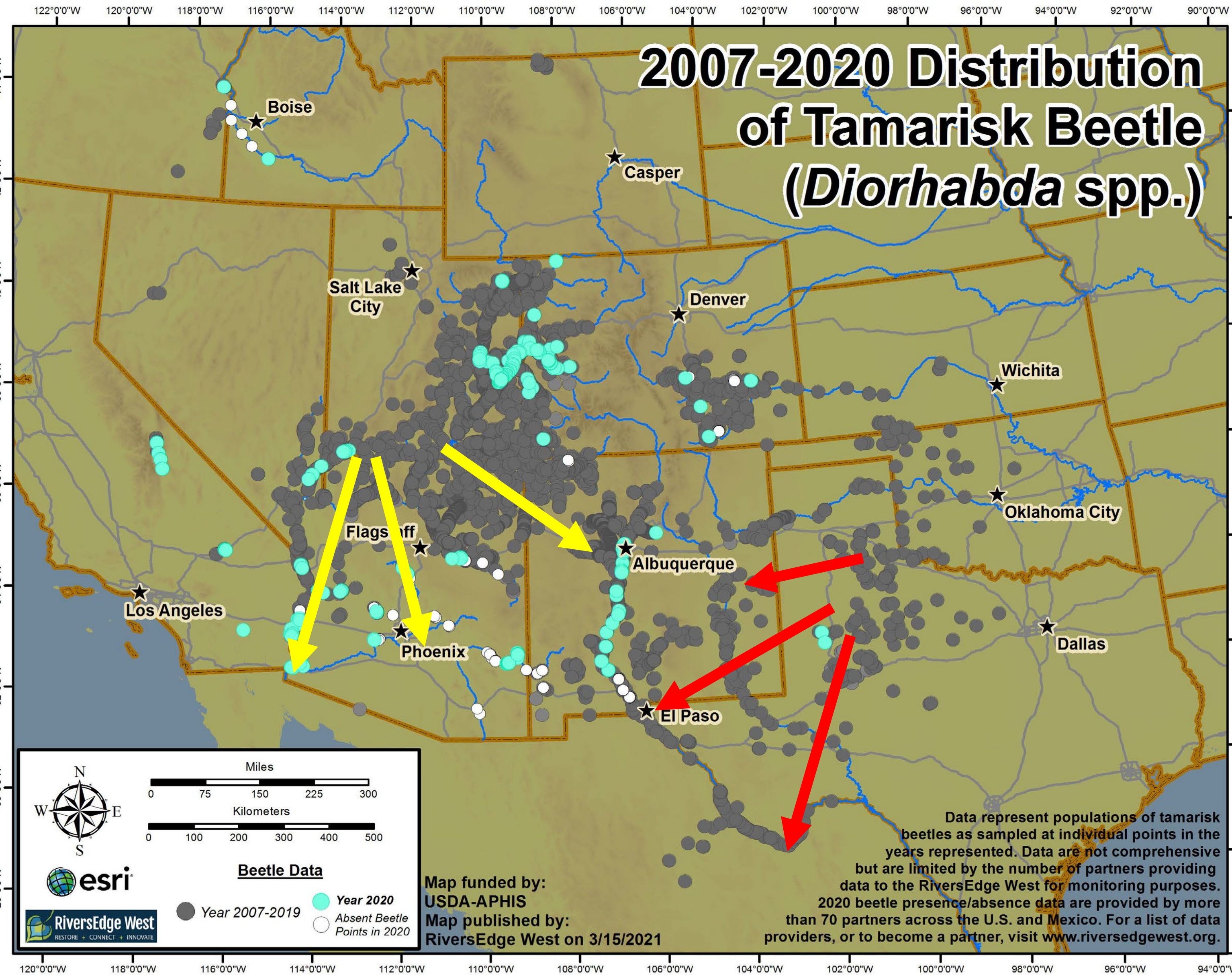


Bean et al (2013) Invasive Plant Science and Management 6:1-15

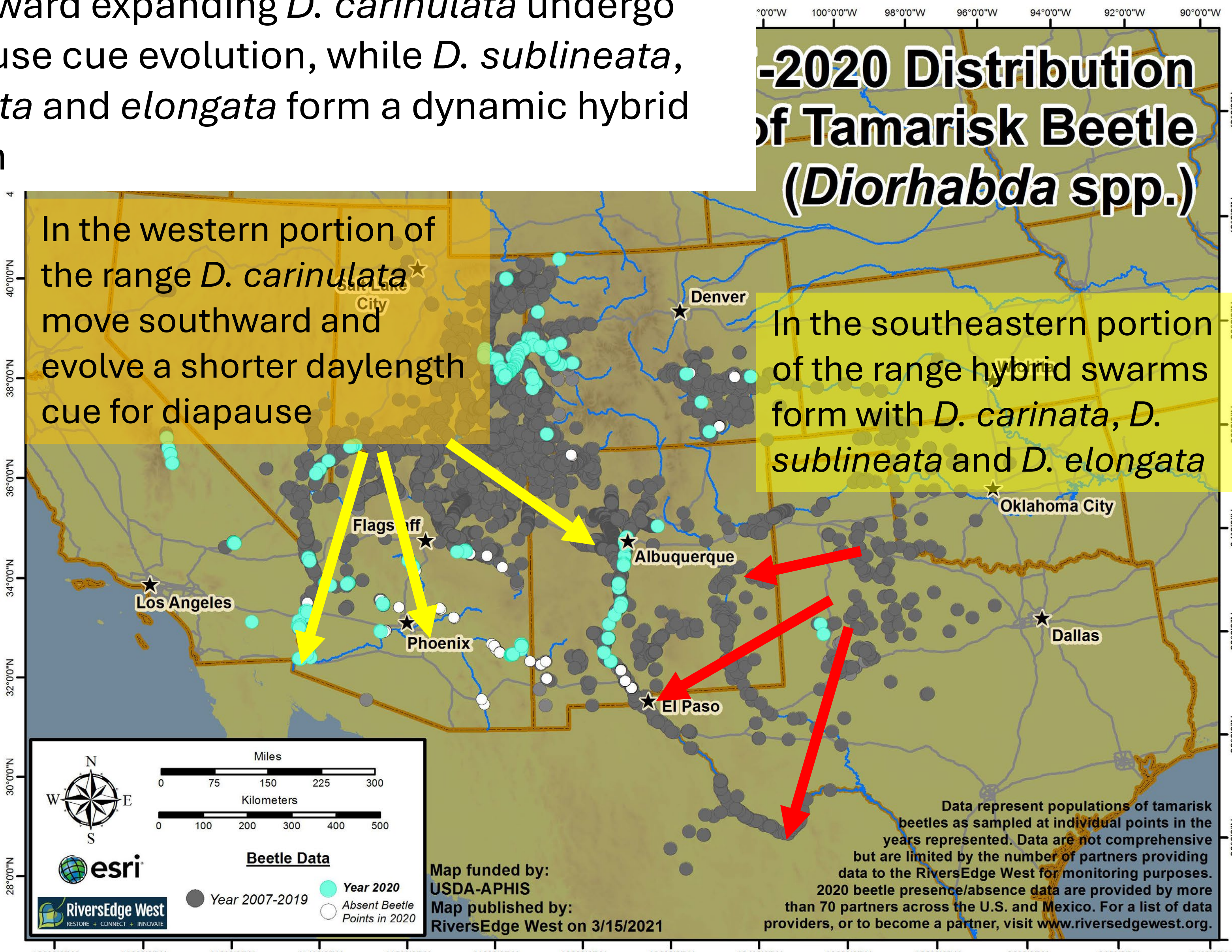
1. D*. carinata* establishes at a site where a cage had washed away
2. Hybrids form between *D. elongata, D. carinata* and *D. sublineata*
3. D. *carinulata* adapts, through evolution, to southern conditions



Bean, D.W., T.L. Dudley and K. Hultine. 2013. Bring on the beetles: The history and impact of tamarisk biological control. P. 377-403 In: Sher, A. and M. Quigley (eds). Tamarix: A case study of ecological change in the American West. Oxford Univ. Press.


2007-2020 Distribution of Tamarisk Beetle (Diorhabda spp.)
Boise
Casper
Salt Lake City
Denver
Wichita
Oklahoma City
Flagstaff
Albuquerque
Los Angeles
Phoenix
Dallas
El Paso
Miles
0 75 150 225 300
Kilometers
0 100 200 300 400 500
esri
RiversEdge West
RESTORE + CONNECT + INNOVATE
Beetle Data
Year 2007-2019
Year 2020
Absent Beetle Points in 2020
Map funded by: USDA-APHIS
Map published by: RiversEdge West on 3/15/2021
Data represent populations of tamarisk beetles as sampled at individual points in the years represented. Data are not comprehensive but are limited by the number of partners providing data to the RiversEdge West for monitoring purposes. 2020 beetle presence/absence data are provided by more than 70 partners across the U.S. and Mexico. For a list of data providers, or to become a partner, visit www.riversedgewest.org.

Southward expanding *D. carinulata* undergo diapause cue evolution, while *D. sublineata*, *carinata* and *elongata* form a dynamic hybrid swarm

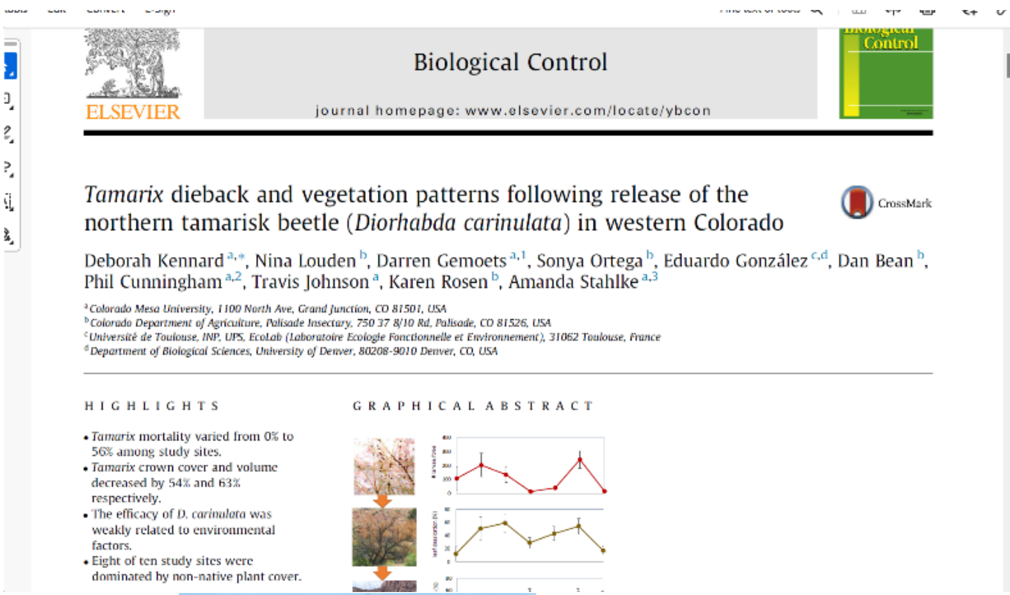


The effective biocontrol of tamarisk

Diorhabda sublineata *Diorhabda carinulata*

- Found in much of the arid west
- Saves 20,000+ acre-ft/yr in the upper CO basin
- Waves of defoliation/ refoliation

Tamarisk Monitoring and Restoration following Biocontrol



Biological Control

journal homepage: www.elsevier.com/locate/ybcon

Tamarix dieback and vegetation patterns following release of the northern tamarisk beetle (*Diorhabda carinulata*) in western Colorado

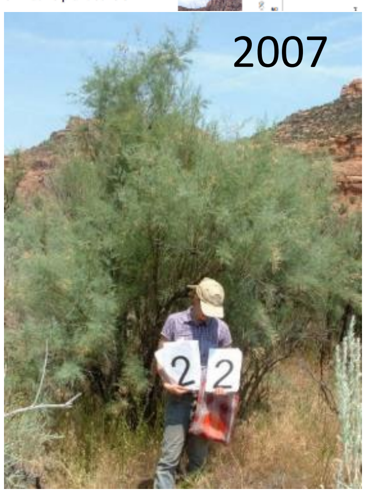
Deborah Kennard[a,*], Nina Louden[b], Darren Gemoets[a,1], Sonya Ortega[b], Eduardo González[c,d], Dan Bean[b], Phil Cunningham[a,2], Travis Johnson[a], Karen Rosen[b], Amanda Stahlke[a,3]

[a] Colorado Mesa University, 1100 North Ave, Grand Junction, CO 81501, USA
[b] Colorado Department of Agriculture, Palisade Insectary, 750 37 8/10 Rd, Palisade, CO 81526, USA
[c] Université de Toulouse, INP, UPS, EcoLab (Laboratoire Ecologie Fonctionnelle et Environnement), 31062 Toulouse, France
[d] Department of Biological Sciences, University of Denver, 80208-9010 Denver, CO, USA

HIGHLIGHTS

- *Tamarix* mortality varied from 0% to 56% among study sites.
- *Tamarix* crown cover and volume decreased by 54% and 63% respectively.
- The efficacy of *D. carinulata* was weakly related to environmental factors.
- Eight of ten study sites were dominated by non-native plant cover.

GRAPHICAL ABSTRACT



- Biomass reduction - 60%
- Mortality- 30%
- Significant decrease in flowering

Work with Dr. Deb Kennard, Colorado Mesa University

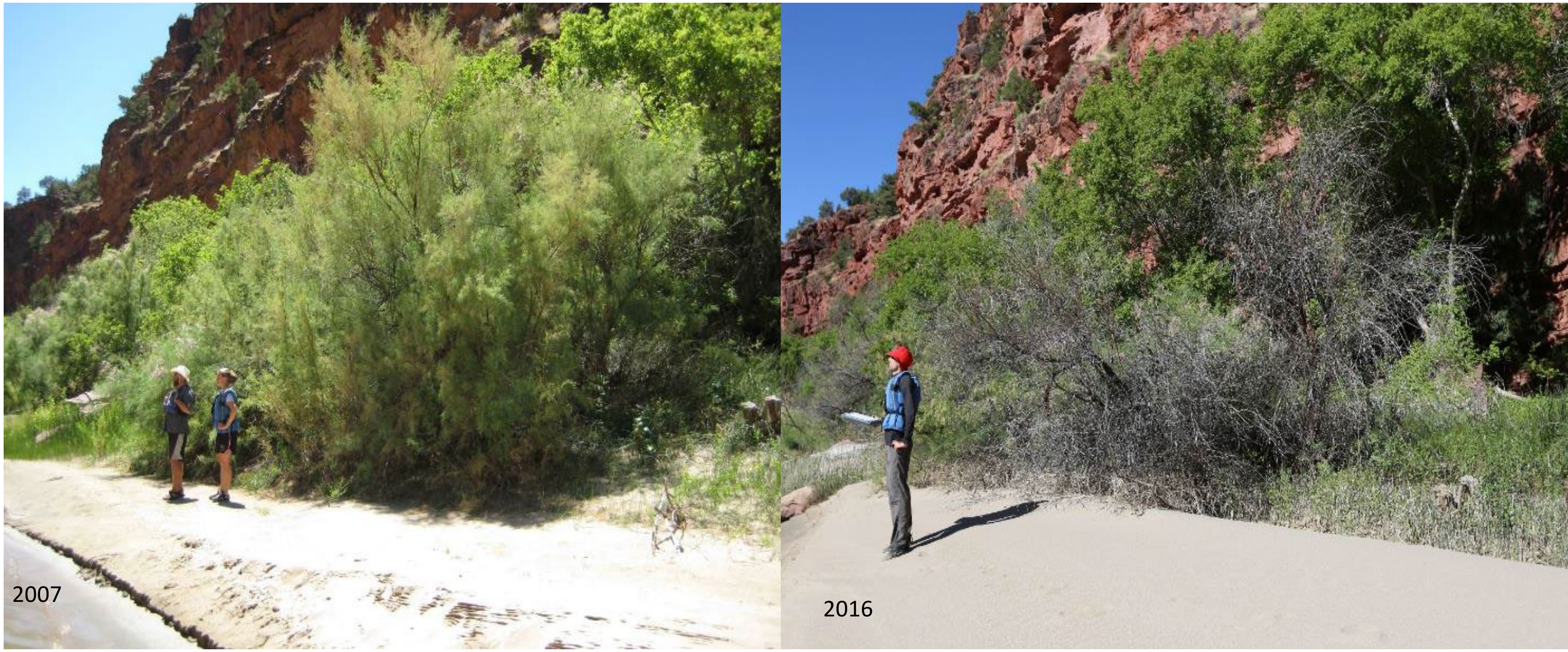


Photo point showing dieback of tamarisk on the Green River, Dinosaur National Monument, seen in 2016 as gray dead branches. Photos were taken near Disaster Rapid, where John Wesley Powell lost one of his boats in 1869.

The biology of *Diorhabda*

- Dispersal, aggregation, defoliation and the chemical cues that control them
- Seasonal timing of life cycle events and synchrony with host plant phenology
- Hybridization and genetics

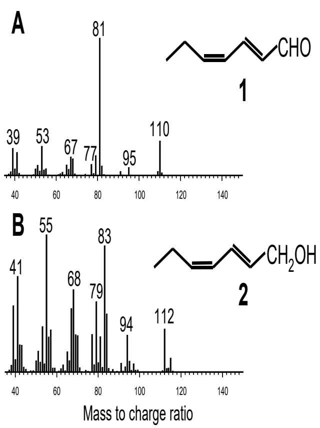
June 8, 2019
Cibola NWR

June 18, 2019

Swarming adults/ defoliating larvae

Insect Attractants: practical uses in weed biological control

In collaboration with Bob Bartelt and Allard Cossé of USDA ARS NCAUR, Peoria



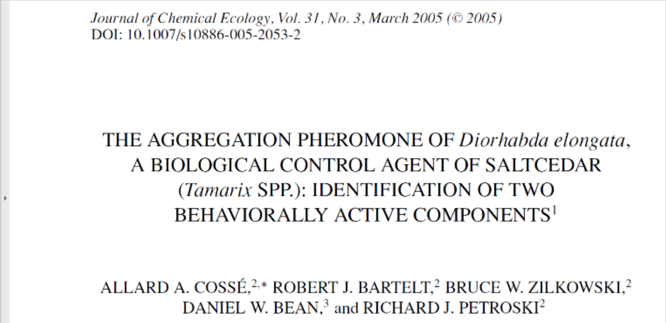
1. Male produced pheromone blend

2. Plant volatiles from *Tamarix* (mostly 'green leaf' volatiles)

Allard Cossé monitors trap baited with plant volatiles, spring 2004, Lovelock, NV

Pheromone blend attracts adults that are reproductively active

The tamarisk beetle, *Diorhabda carinulata*, forms aggregations of reproductive males and females in response to a male-produced pheromone blend

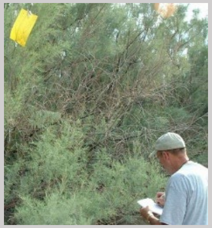

Journal of Chemical Ecology, Vol. 31, No. 3, March 2005 (© 2005)
DOI: 10.1007/s10886-005-2053-2

THE AGGREGATION PHEROMONE OF *Diorhabda elongata*, A BIOLOGICAL CONTROL AGENT OF SALTCEDAR (*Tamarix* SPP.): IDENTIFICATION OF TWO BEHAVIORALLY ACTIVE COMPONENTS[1]

ALLARD A. COSSÉ,[2,*] ROBERT J. BARTELT,[2] BRUCE W. ZILKOWSKI,[2] DANIEL W. BEAN,[3] and RICHARD J. PETROSKI[2]

- Discovered by Allard Cossé and Bob Bartelt of the USDA ARS
- Calls in swarms of reproductive beetles that can cause tamarisk defoliation

Allard



Bob

swarming reproductive males and females

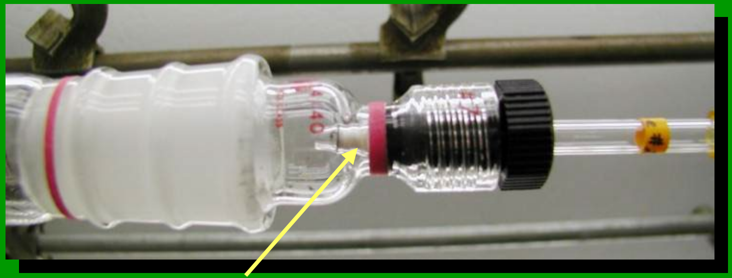
after aggregation they form mating pairs

Near Lovelock, NV, 2003

First step: Collection of volatiles from feeding beetles

Collector tube with foliage and beetles

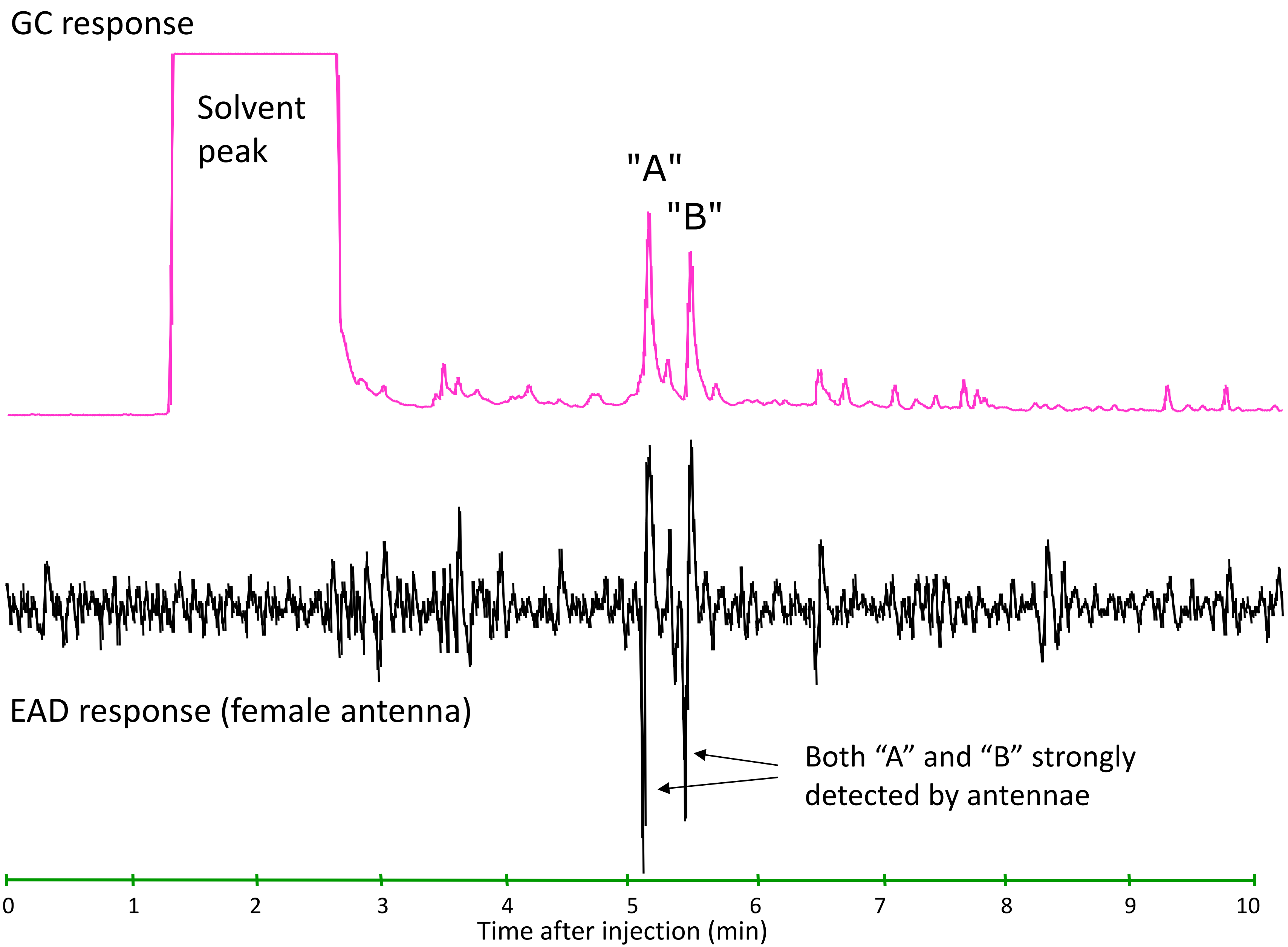
Beetles on foliage



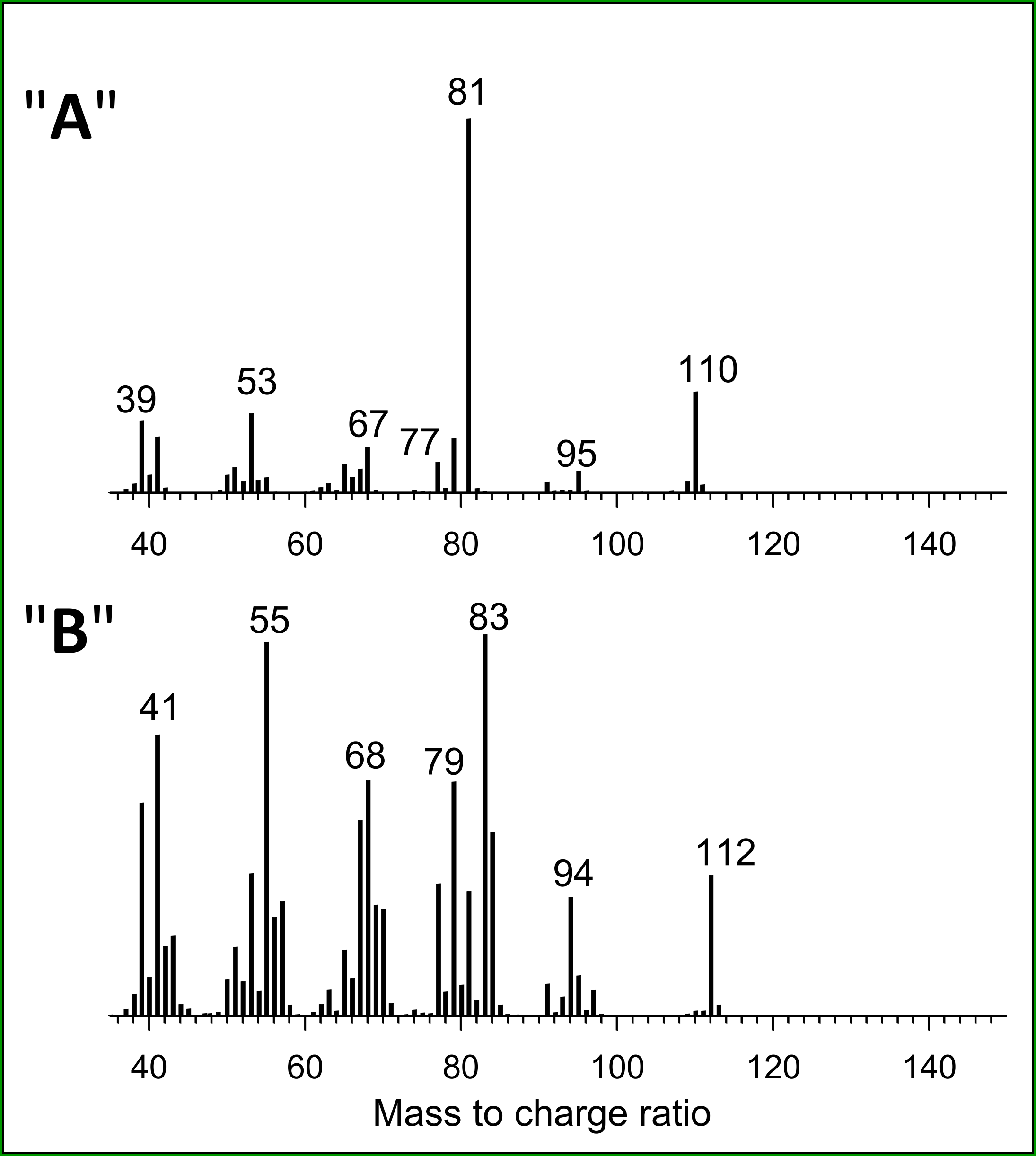
Close up of Super-Q filter

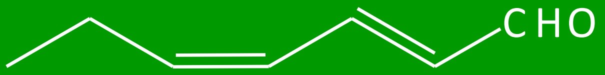
- Draw volatiles emitted from feeding beetles into filter of porous polymer ("Super-Q") with gentle vacuum; later on, rinse filter with solvent.
- On the plus side: Beetles + food is a "natural" situation; good chance of pheromone emission.
- On the minus side: plant compounds will also be collected.

GC-EAD Response to Volatiles Collected from Feeding Male *D. elongata*

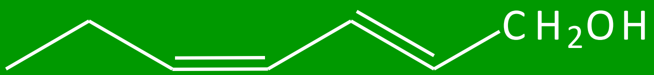


Mass spectra of male-specific compounds and ID's, based on MS library and analytical comparison with standards





(2*E*,4*Z*)-2,4-heptadienal
= "2*E*,4*Z*-7:Ald"

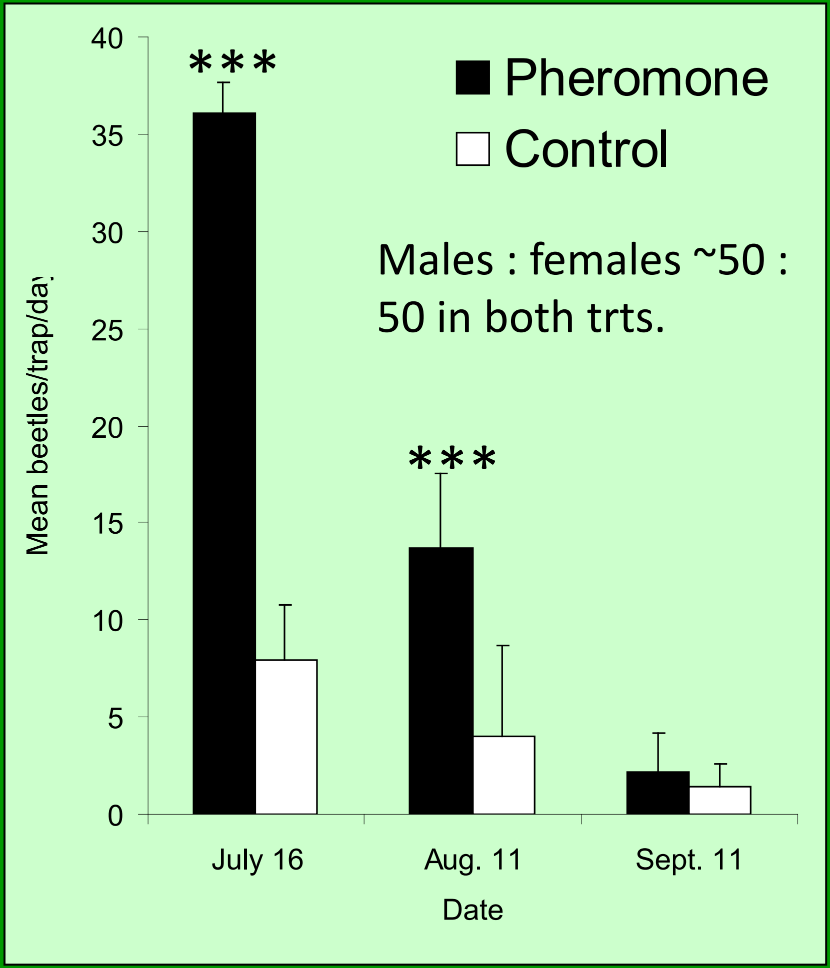


(2*E*,4*Z*)-2,4-heptadien-1-ol
= "2*E*,4*Z*-7:OH"

Cossé et al., 2005, J. Chem. Ecol.

Trapping results at Lovelock, Nevada, during 2003

Close up of sticky trap with pheromone dispensers in place.



Pheromone treatment significantly more attractive than control ($P<0.001$)

Reproductive tamarisk beetles were observed to avoid areas where larvae were abundant. Gaffke et al discovered a compound emitted by damaged foliage that is repellent to adult tamarisk beetles and could be the signal to indicate high densities of feeding larvae.

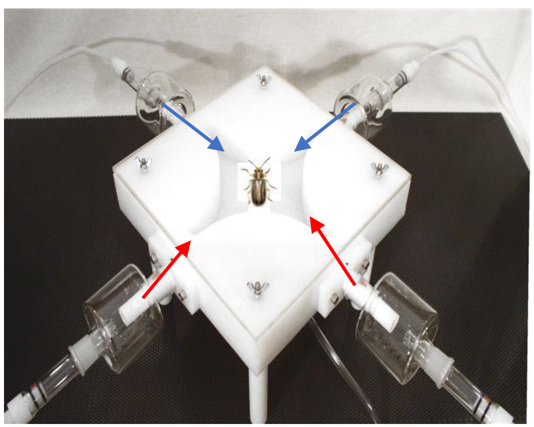
Environmental Entomology, XX(XX), 2020, 1–8
doi: 10.1093/ee/nvaa079
Research
OXFORD

Chemical Ecology

An Herbivore-Induced Plant Volatile From Saltcedar (*Tamarix* spp.) Is Repellent to *Diorhabda carinulata* (Coleoptera: Chrysomelidae)

Alexander M. Gaffke,[1,2,7] Sharlene E. Sing,[3] Jocelyn G. Millar,[4] Tom L. Dudley,[5] Daniel W. Bean,[6] Robert K. D. Peterson,[1] and David K. Weaver[1]

[1]Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT 59717, [2]Agricultural Research Service, Department of Agriculture, Center for Medical, Agricultural, and Veterinary Entomology, Gainesville, FL 32608, [3]USDA Forest Service, Rocky Mountain Research Station, Bozeman, MT 59717, [4]Department of Entomology, University of California, Riverside, CA 92521, [5]Marine Science Institute, University of California, Santa Barbara, CA 93106, [6]Colorado Department of Agriculture, Palisade Insectary, Palisade, CO 81526, and [7]Corresponding author, e-mail: alexander.gaffke@usda.gov



Behavioral assays show that a volatile compound (4-oxo-(*E*)-2-hexenal) is repellent to adult beetles. Beetle responses to air streams containing the compound (red arrows) are compared with responses to those without the compound (blue arrows).

- Adult reproductive beetles avoid tamarisk with a dense population of feeding larvae
- Foliage damaged by feeding tamarisk beetles emits a volatile compound repellent to tamarisk beetles

Feeding *Diorhabda* larvae

Field trials conducted by Alex Gaffke, Sharlene Sing and David Weaver at Montana State University, show that semiochemicals can be used to manipulate of tamarisk beetle populations, resulting in defoliation of targeted plants.

SCIENTIFIC REPORTS
natureresearch

OPEN

Field demonstration of a semiochemical treatment that enhances *Diorhabda carinulata* biological control of *Tamarix* spp.

Received: 2 July 2018
Accepted: 19 August 2019
Published online: 10 September 2019

Alexander M. Gaffke[1,2], Sharlene E. Sing[3], Tom L. Dudley[4], Daniel W. Bean[5], Justin A. Russak[6], Agenor Mafra-Neto[7], Robert K. D. Peterson[1] & David K. Weaver[1]

Alex Gaffke

Pheromone treated plants are defoliated

insects MDPI

Review

Using Chemical Ecology to Enhance Weed Biological Control

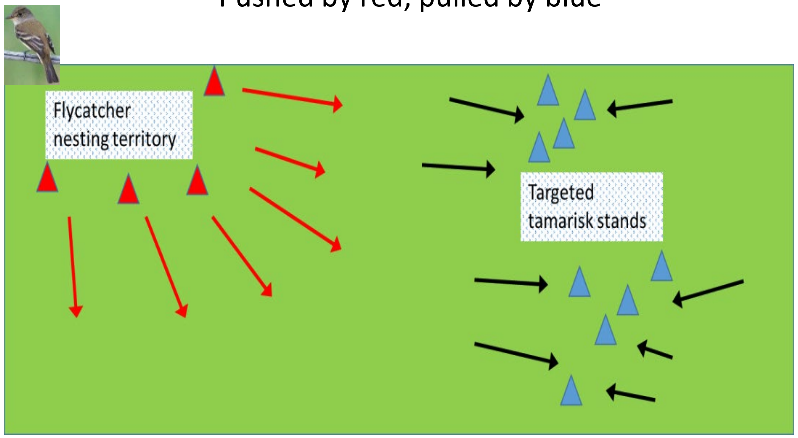
Alexander M. Gaffke [1,2], Hans T. Alborn [1], Tom L. Dudley [3] and Dan W. Bean [4,*]

1. Center for Medical, Agricultural, and Veterinary Entomology, Agricultural Research Service, United States Department of Agriculture, Gainesville, FL 32608, USA; agaffke@agcenter.lsu.edu (A.M.G.); hans.alborn@usda.gov (H.T.A.)
2. Department of Entomology, Louisiana State University Agricultural Center, Baton Rouge, LA 70803, USA
3. Marine Science Institute, University of California, Santa Barbara, CA 93106, USA; tdudley@msi.ucsb.edu
4. Colorado Department of Agriculture, 750 37.8 Rd, Palisade, CO 81526, USA

* Correspondence: dan.bean@state.co.us; Tel.: +1-970-464-7916

Simple Summary: Signaling chemicals produced by one organism that bring about a behavioral response in a recipient organism are known as semiochemicals, with pheromones being a well-known example. Semiochemicals have been widely used to monitor and control insect pests in agricultural and forestry settings, but they have not been widely used in weed biological control. Here, we list

A Push/Pull strategy preserves tamarisk used for nesting
Pushed by red, pulled by blue



- As shown by Gaffke et al, beetles can be attracted to tamarisk stands and will defoliate them
- The southwestern willow flycatcher, a T&E species, sometimes nests in tamarisk so pushing beetles away from nesting territories may enhance ecosystem services
- Pulling beetles to targeted tamarisk with GLVs and pheromones, while pushing them away from possible nesting habitat with the repellent, is a strategy for selective suppression of tamarisk

Tamarisk Control on Ute Mountain Ute Tribal Lands with Herbicides and Biological Control

Cynthia S. Brown, PhD[1], Hannah Ertl[2], Dan Bean, PhD[3], Zeynep Özsoy, PhD[4], Farley Ketchum Sr.[5], and Emily Swartz[6]

(1) CSU Department of Agricultural Biology; Graduate Degree Program in Ecology; (2) Trees, Water & People Indigenous Lands Program; (3) Colorado Department of Agriculture Palisade Insectary; (4) Colorado Mesa University Department of Biological Sciences; (5) Ute Mountain Ute Tribe Environmental Programs Department; and (6) CSU Department of Forest and Rangeland Stewardship.

A PILOT STUDY

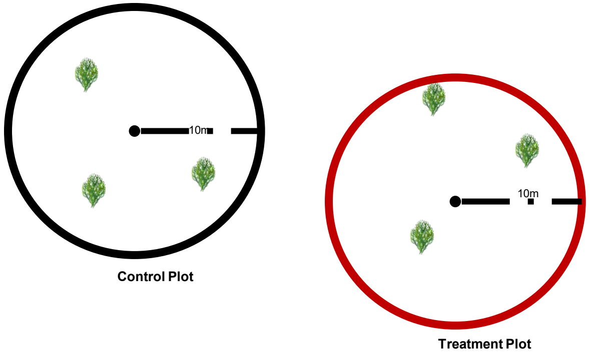
Introduction

We tested the presence of tamarisk beetle (*Diorhabda carniculata*) GLV and pheromone lures in reducing re-sprout vigor of tamarisk following initial tamarisk treatment.

Methods

We used a paired plot design, where control and treatment plots had very similar characteristics. There were 4 plot pairs, or 8 plots total.

Paired Plot Design:



- We hung 10 Green Leaf Volatile (GLV) lures in treatment plots during spring leaf-out. GLV alert beetles that growing tamarisk is present.

- We hung 3 Pheromone (PHE) lures in treatment plots 3 times, every 3 weeks through the end of July. PHE are naturally produced by male beetles and stimulate beetle aggregation.

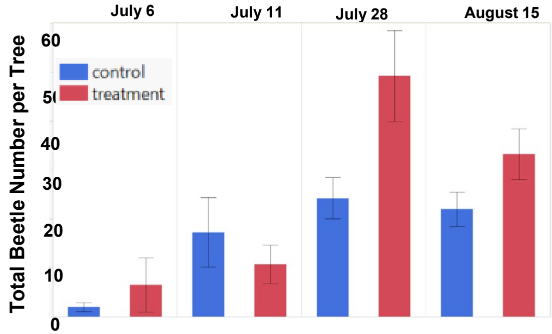
Mastication plot

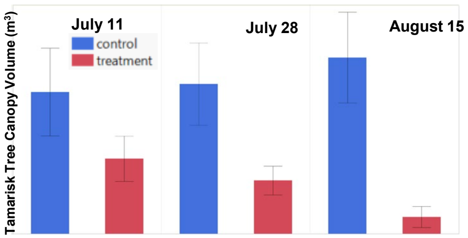
Modified cut stump plot

We conducted sweep net surveys and monitored the response of tamarisk beetles in control and treatment plots.

We monitored defoliation and canopy volume in three target trees per plot.

Results





- Trees with pheromone lures appeared to have more beetles later in the growing season than controls, but this effect was not statistically significant.
- Tamarisk canopies with pheromone lures appeared to be smaller than controls without lures and to decrease in size over time.

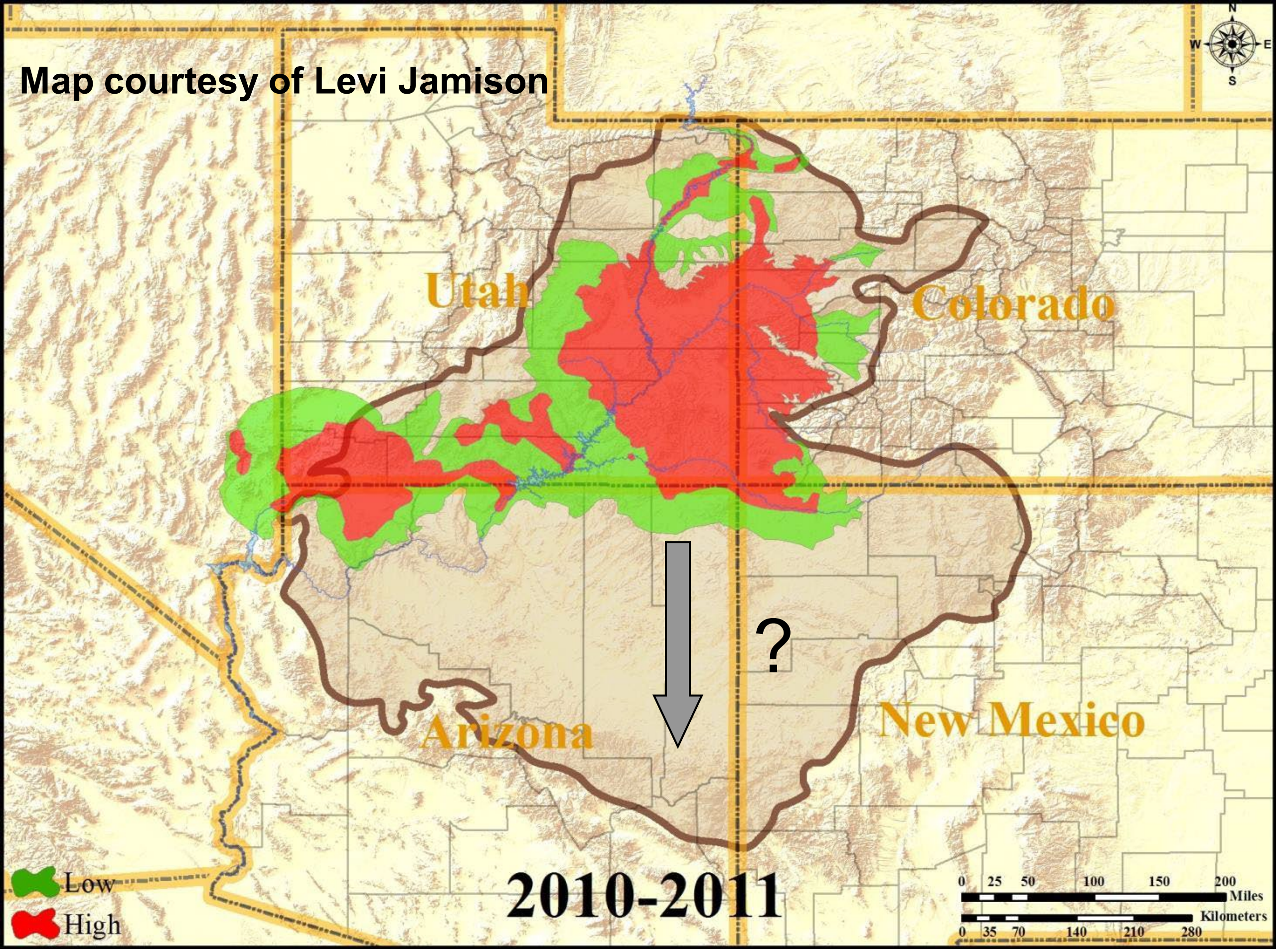
Next Steps

Pheromone Treatment Scale-up

- 20 acres of tamarisk treatment in summer/fall 2023.
- SCALE UP Pheromone Study after herbicide treatment, beginning spring 2024.

TREES, WATER & PEOPLE
Helping people and the planet

COLORADO
Department of Agriculture



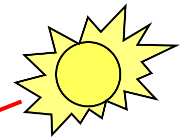
D. carinulata is the **northern** tamarisk beetle

← 37° N

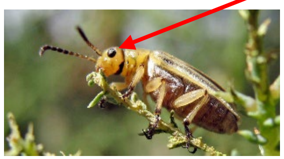
How far and how fast populations of *D. carinulata* moved southward in the basin was a function of diapause timing

The environmental cues for diapause induction have evolved from being **northern adapted** to **southern adapted**.

Diapausing beetles (photo: Nina Louden)



Daylength cues diapause or reproduction. 50% mix occurs at the critical daylength (CDL)



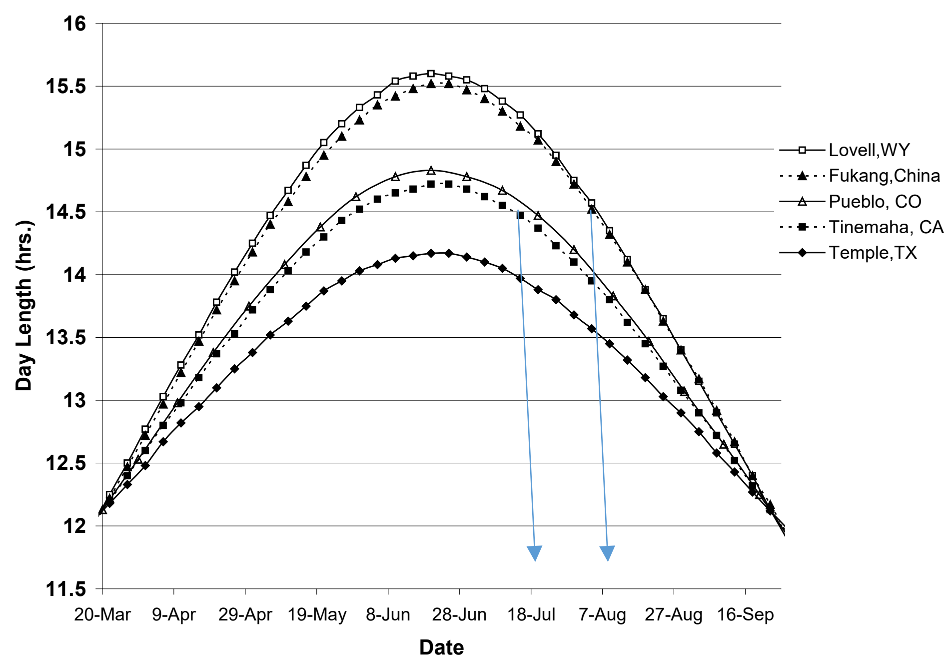
shorter ← **14hr 30min** → longer

female system

diapause

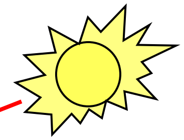
reproductive

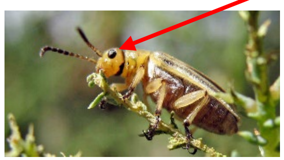
in original populations



The environmental cues for diapause induction have evolved from being **northern adapted** to **southern adapted**.

Diapausing beetles (photo: Nina Louden)





Daylength cues diapause or reproduction. 50% mix occurs at the critical daylength (CDL)

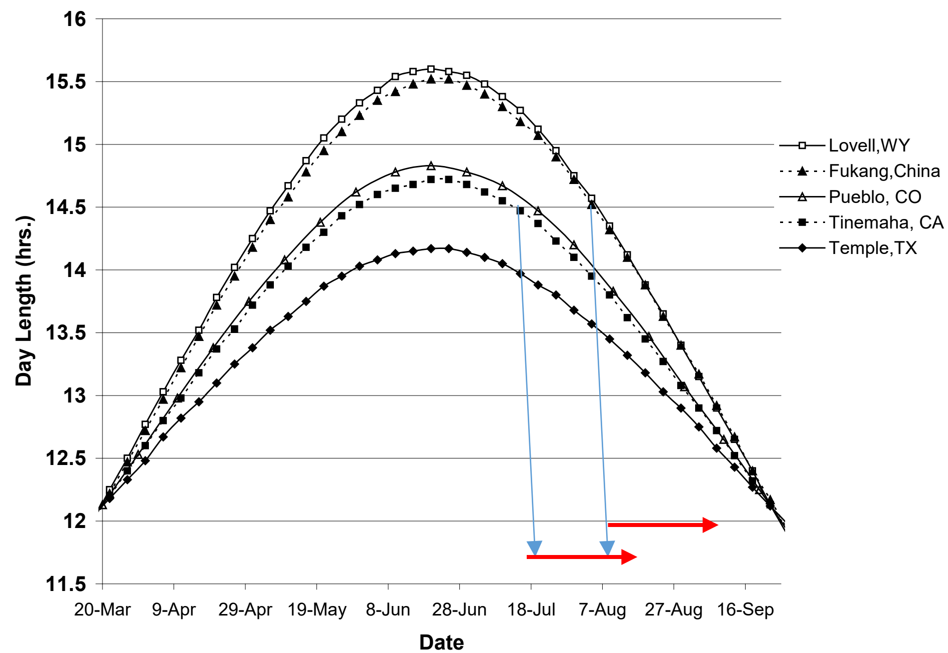
shorter ⟵ **14hr 30min** ⟶ longer

diapause

female system

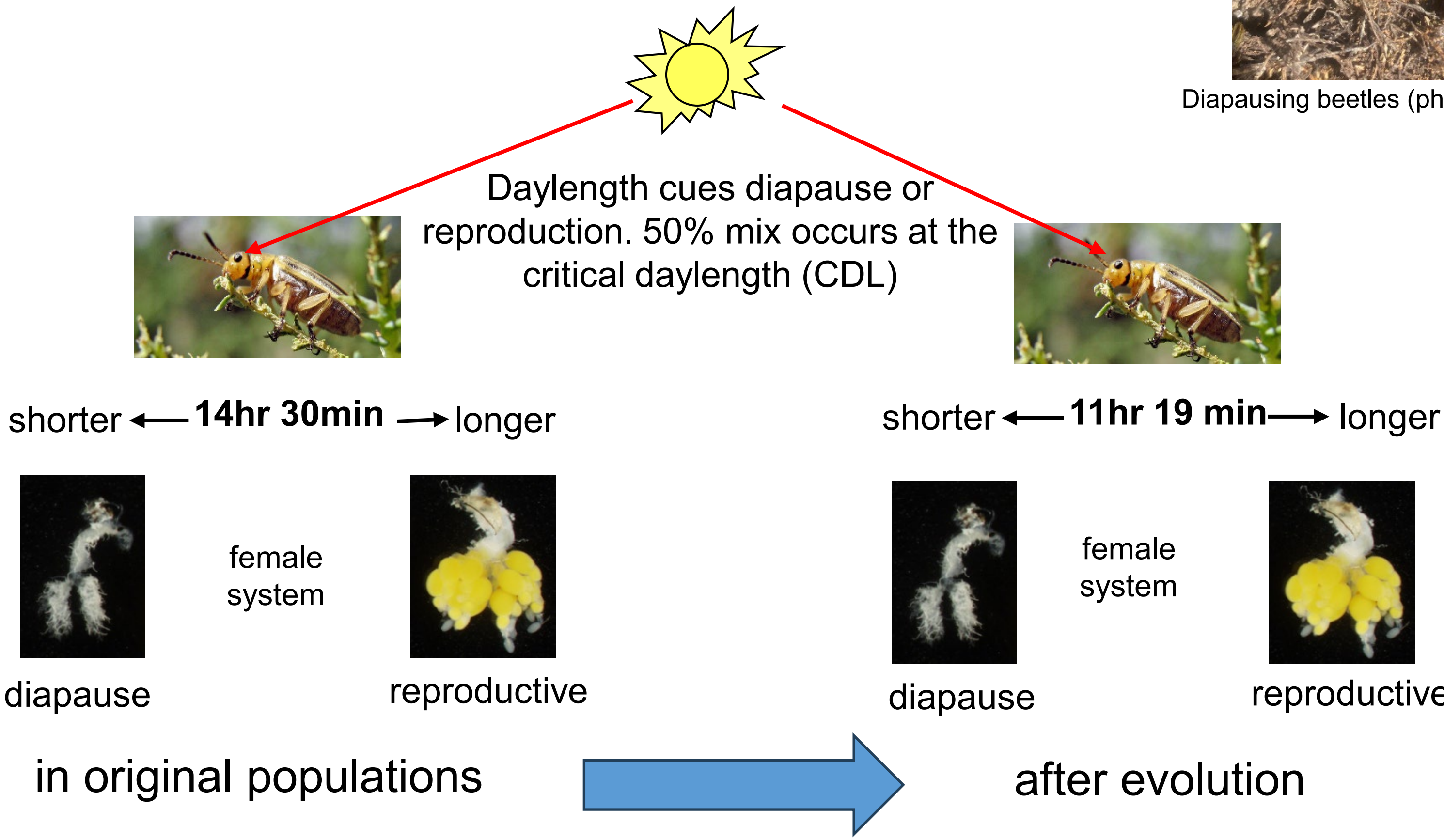
reproductive

in original populations

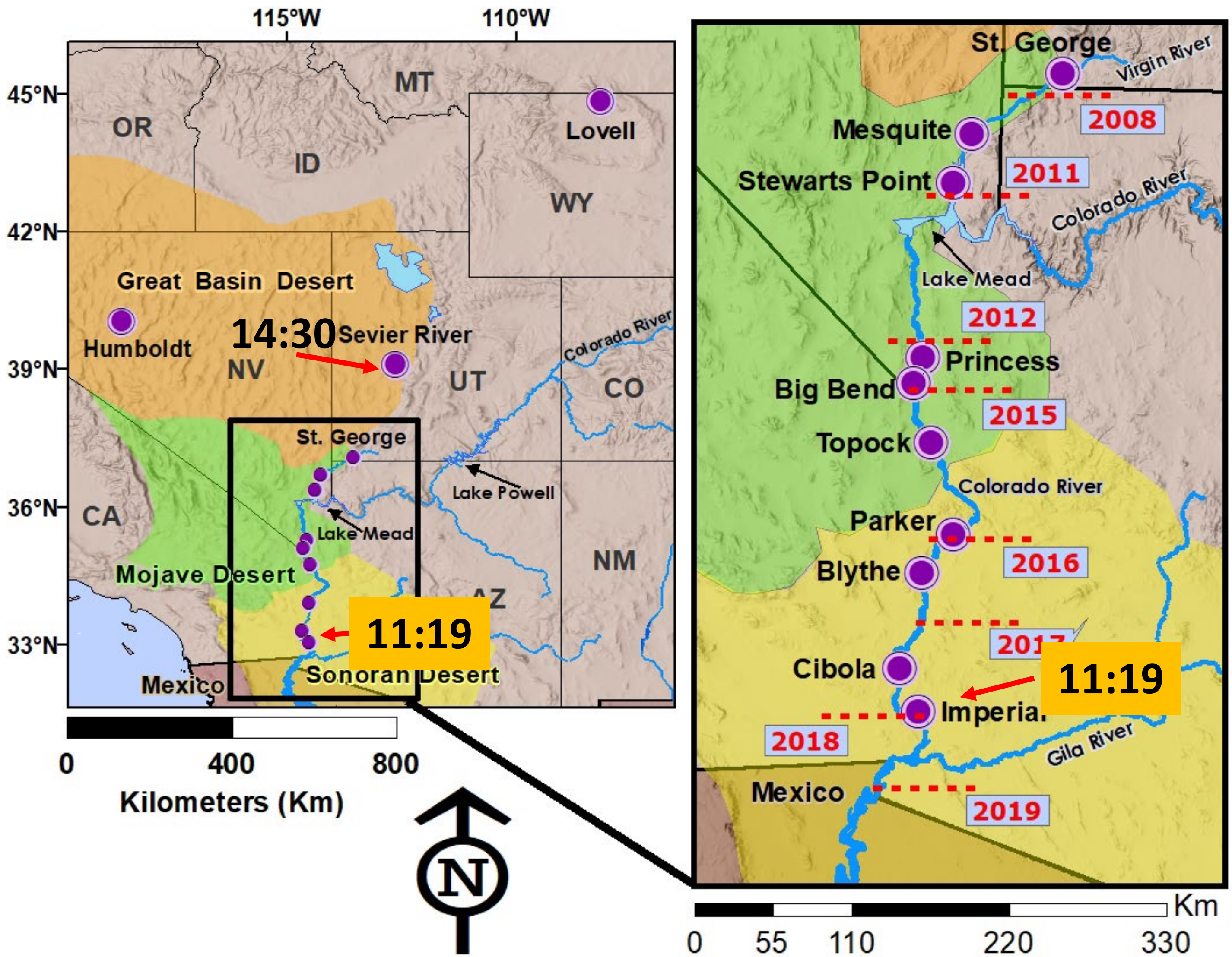


The environmental cues for diapause induction have evolved from being **northern adapted** to **southern adapted**.

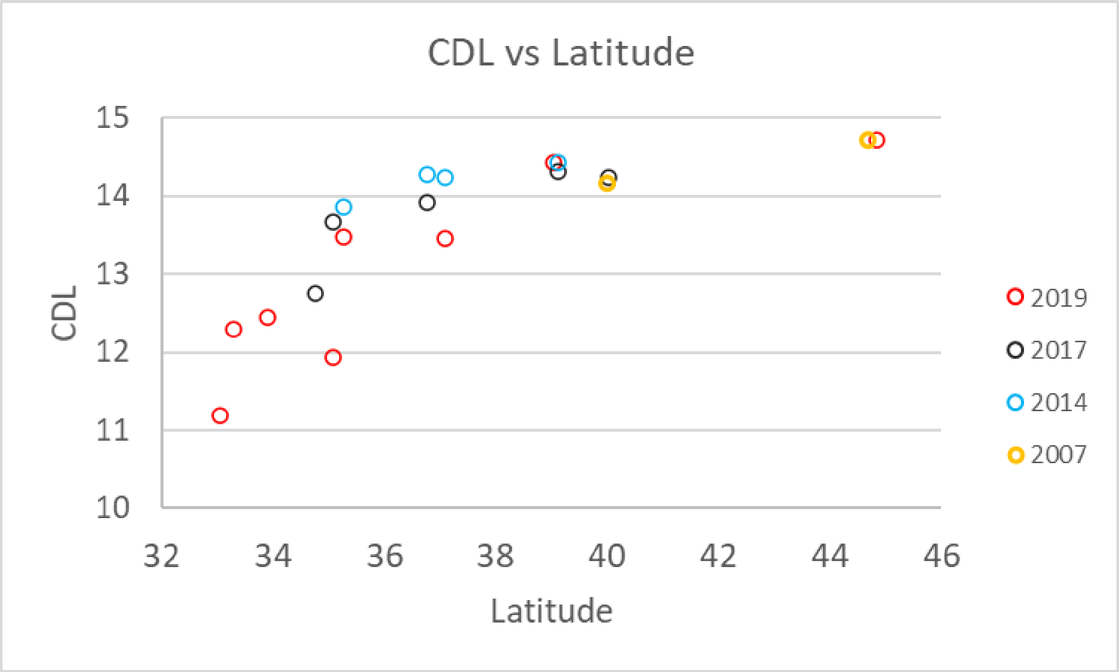
Diapausing beetles (photo: Nina Louden)



CDL has evolved in southward expanding populations



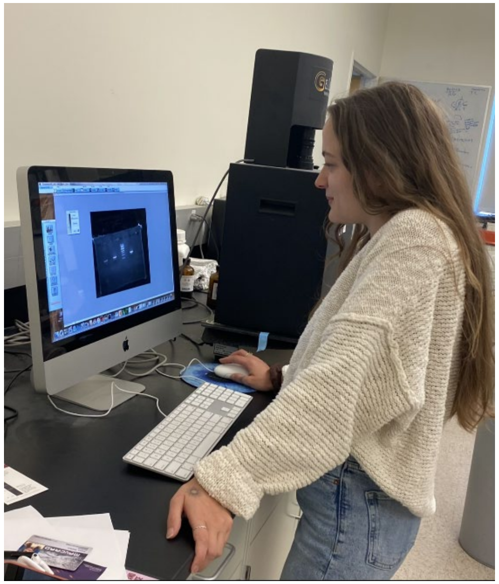
Tom Dudley inspects a dead tamarisk shrub near Blythe, CA, 2019



CDL measurements, over a 12-year period from 2007-2019, made under a thermoperiod of 35° day/ 15° night. Field collections were made at or near the leading front of range expansion in the intermountain west on each of the dates listed. The three sites north of the 38° N were original release sites (releases made in 2001).

Zeynep Özsoy mentored Amanda and Emma as undergrads and beyond

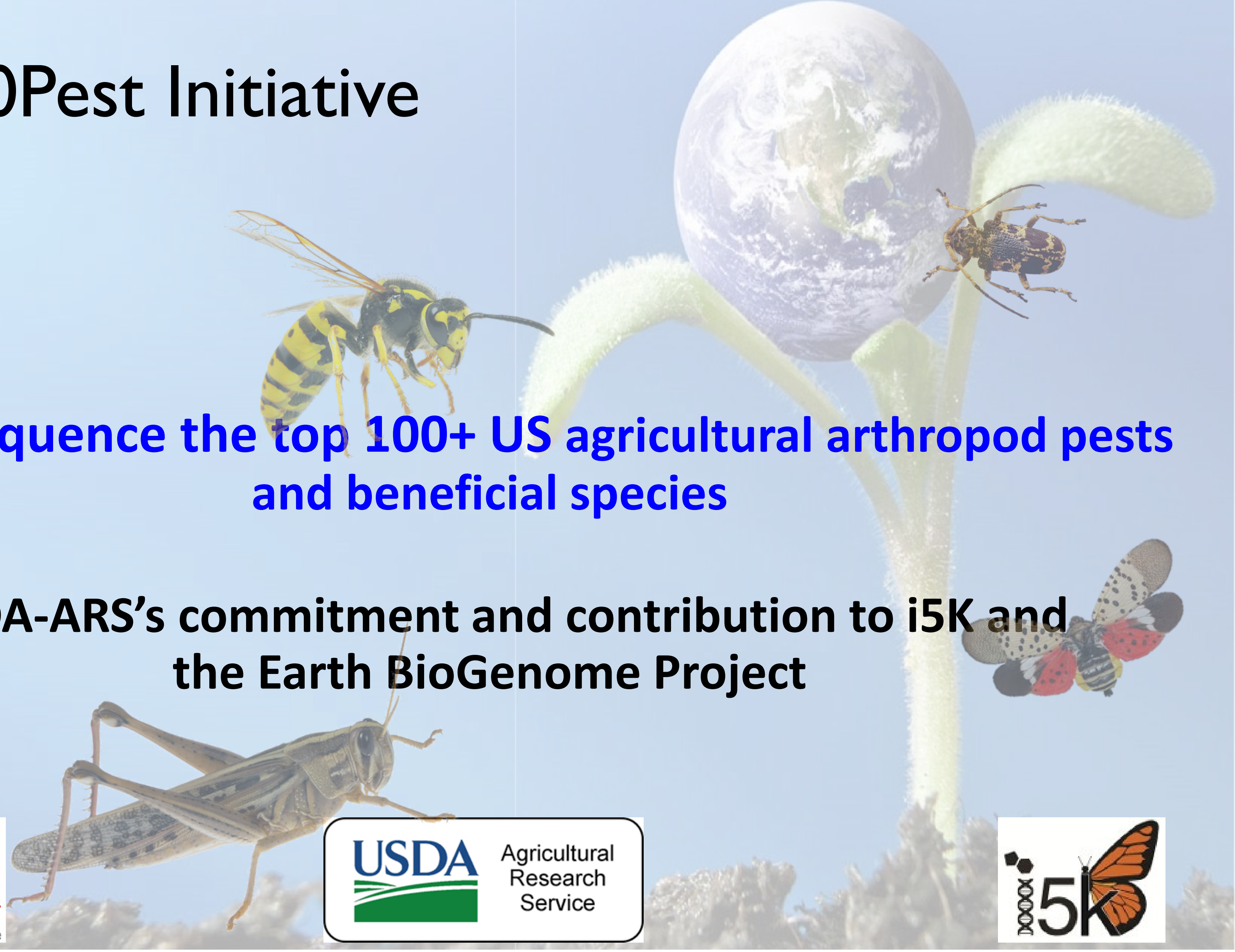
Amanda Stahlke brought bioinformatics to Biological Sciences at CMU



Emma Shelton and others are working to identify specific genes

The genome team, working with scientists from the USDA in Hawaii, sequenced the genomes of the four *Diorhabda* species used in biocontrol.

Ag100Pest Initiative



Goal: Sequence the top 100+ US agricultural arthropod pests and beneficial species

USDA-ARS's commitment and contribution to i5K and the Earth BioGenome Project

EARTH BIOGENOME PROJECT
sequencing life for the future of life

USDA Agricultural Research Service

i5K

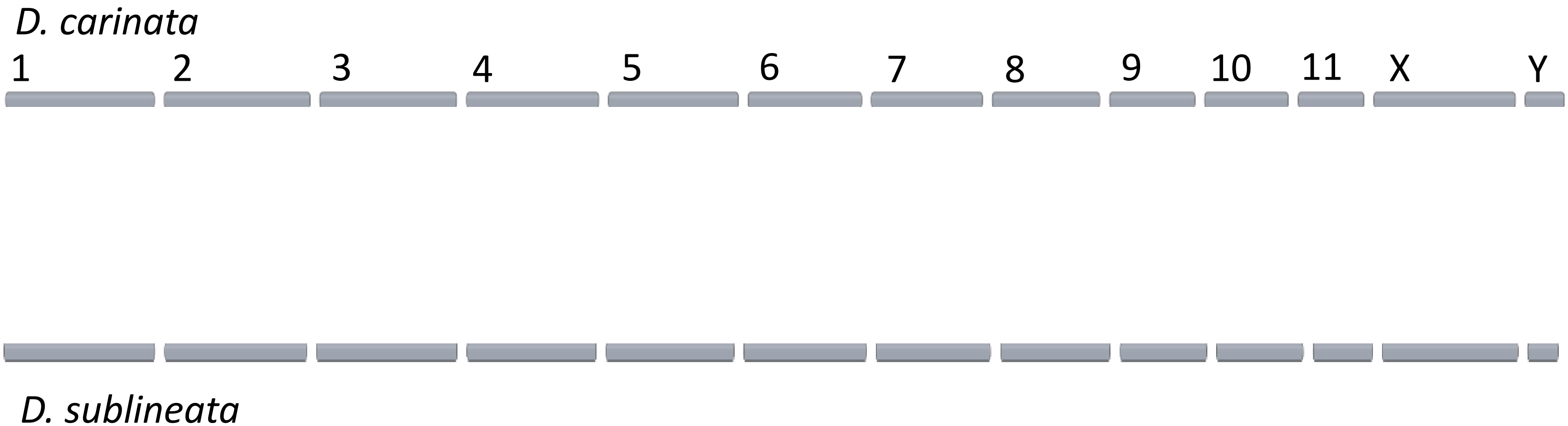
Ag100Pest Initiative

We found that new sequencing technology makes assembly somewhat routine

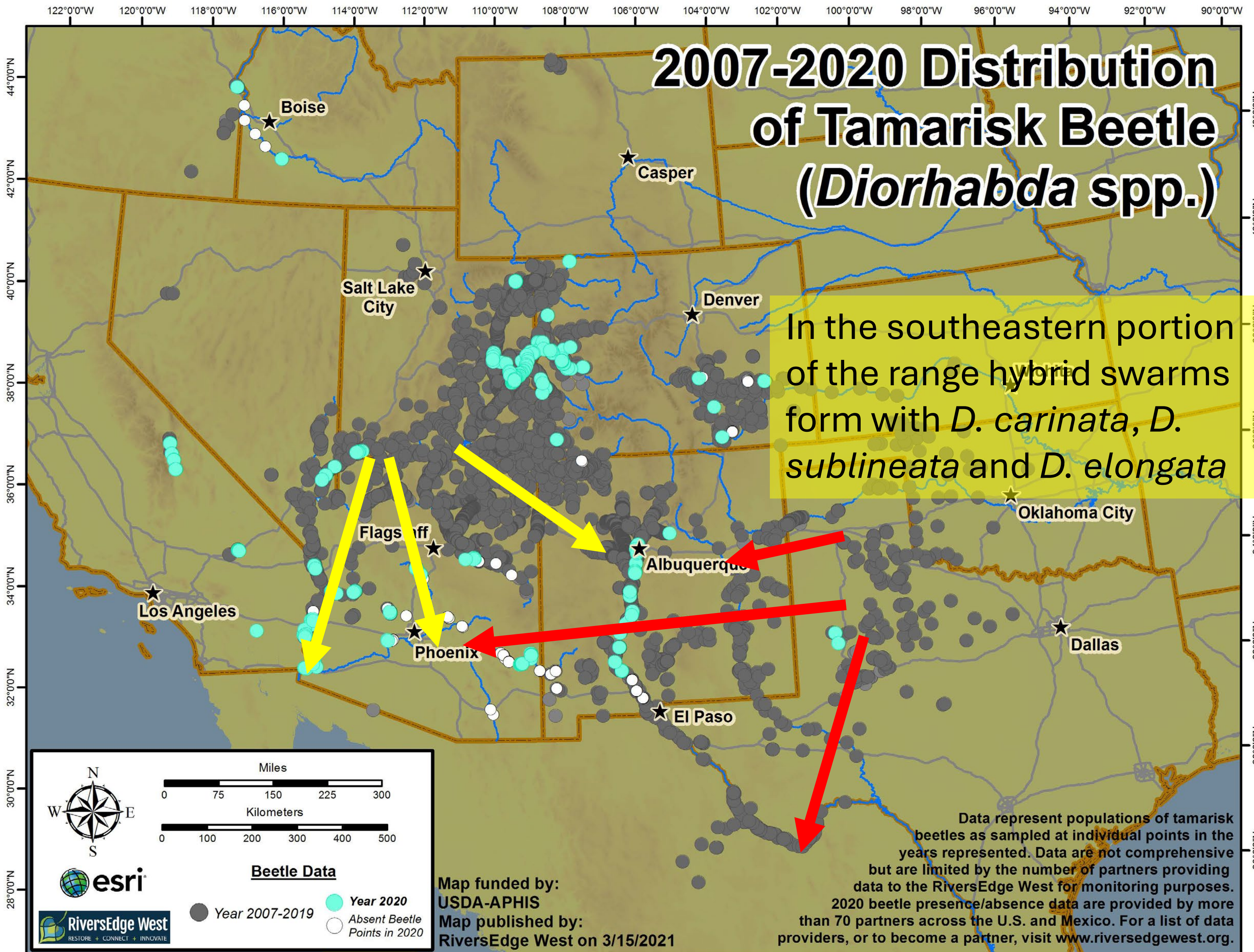
Got a handful of biocontrol agents done too!

Diorhabda* spp. and *Aphthona nigriscutis

Compare chromosome structure between the three species that readily hybridize and to *D. carinulata*: Maintenance of boundaries, explained by genome architecture



Diorhabda sister species have 11 autosomes plus an XY. *D. sublineata* and *D. carinata* are similar at the chromosome level



In the southeastern portion of the range hybrid swarms form with *D. carinata*, *D. sublineata* and *D. elongata*

Coniatus splendidulus

A new tamarisk feeder enters the system
2007

Coniatus damage
Bill Williams River, AZ

Coniatus enter Colorado in 2011 and are now widespread

Coniatus larva on tamarisk, highly cryptic

Woven basket where *Coniatus* pupates
This offers protection from predators found in the leaf litter.

Coniatus begin feeding earlier in the spring and remain active later in the summer/fall than *Diorhabda*

Tamarisk branch collected September 28, 2013. *Diorhabda* have been in diapause for about 30 days, *Coniatus* populations have exploded on the regrowth. Adults abundant, baskets abundant on branches with regrowth.

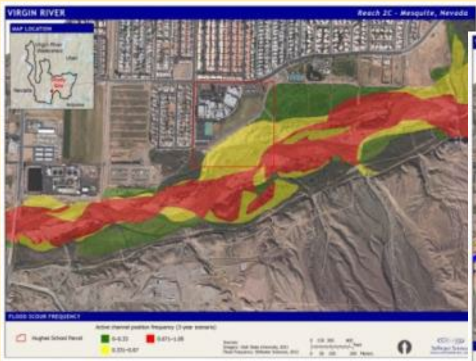
Riparian restoration is the final step to biocontrol success

Tom Dudley, Marine Science Institute, University of California, Santa Barbara

Bruce Orr, Stillwater Sciences

EcoHydrological Approach to Restoration

Stillwater Sciences

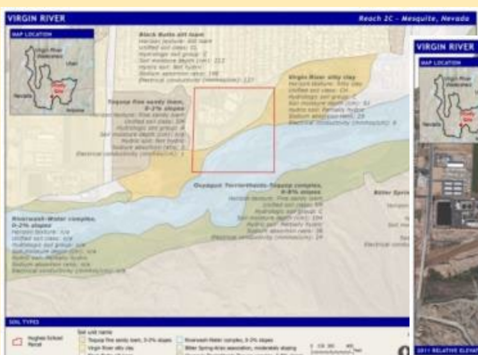


Flood Reset Zone
(>33% frequency)

Vegetation Types
(% native vs tamarisk)

Potential
Restoration Areas

Phase 1: Identify Potential Restoration Areas



Soils
(texture & salinity)

Depth to
Groundwater
(Relative Elevation)

Vegetation Structure
(canopy height)

+

SWFL Habitat

Phase 2: Refinement Using Reach- and Site-scale Data

Future Projects

- Russian knapweed gall formers
- Hoary cress mites
- Russian olive mites
- Cheat grass agents (insects and mites)

Galled Russian knapweed

Thanks to:
The Palisade Insectary, especially Nina Louden, Sonya Ortega, Jess McKenney, Karen Rosen, John Kaltenbach, Mike Racette, Kristi Gladem and Joel Price
The many members of team tamarisk, especially Jack DeLoach, James Tracy, Tom Dudley, Kevin Hultine, John Gaskin, Alex Gaffke, Anna Sher and Levi Jamison
The Colorado Department of Agriculture