Biological Control 101 (2016) 114–122

Contents lists available at ScienceDirect

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

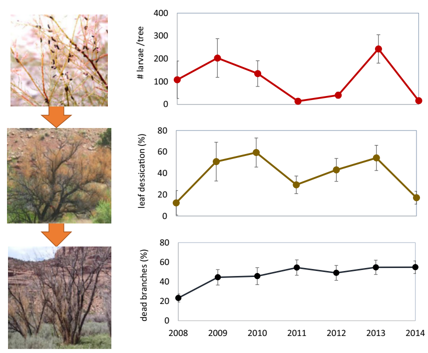
Deborah Kennard [a,*], Nina Louden [b], Darren Gemoets [a,1], Sonya Ortega [b], Eduardo González [c,d], Dan Bean [b], Phil Cunningham [a,2], Travis Johnson [a], Karen Rosen [b], Amanda Stahlke [a,3]

[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

H I G H L I G H T S

- *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.

G R A P H I C A L A B S T R A C T



A R T I C L E I N F O

Article history:
Received 18 January 2016
Revised 4 July 2016
Accepted 6 July 2016
Available online 6 July 2016

Keywords:
Diorhabda carinulata
Tamarix spp.
Riparian ecosystems
Southwestern United States

A B S T R A C T

The northern tamarisk beetle (*Diorhabda carinulata*) was released in 2001 as a biocontrol agent for *Tamarix* spp., an invasive tree that dominates riparian ecosystems throughout the southwestern United States. The factors that influence its effectiveness at controlling *Tamarix*, and the effects of control on plant communities, are not well known. Here we report patterns of *Tamarix* dieback, mortality, and vegetation composition at ten of the early *D. carinulata* release sites in western Colorado. Across the ten release sites, 265 permanently marked *Tamarix* trees were measured over a six year period (2008–2014). Vegetation composition and woody debris adjacent to each of these trees were measured annually for four years (2011–2014). We examined relationships between site factors (soil properties, hydrology, and land use history), *Tamarix* dieback, and vegetation composition. *Tamarix* mortality was observed at seven of ten sites, where it ranged from 15% to 56% after six years. Overall, *Tamarix* crown cover decreased by more than half (54%) while crown volume decreased by 63% in the first two years of the study. Neither total plant cover nor fallen woody debris increased under *Tamarix* trees over the last four years of the study. Combined cover of classified noxious weeds and other non-native species was greater than native plant cover at eight of ten sites. *D. carinulata* proved to be effective in controlling the *Tamarix*

* Corresponding author.
E-mail addresses: dkennard@coloradomesa.edu (D. Kennard), nina.louden@state.co.us (N. Louden), dgemoets@gmail.com (D. Gemoets), sonya.ortega@state.co.us (S. Ortega), edusargas@hotmail.com (E. González), dan.bean@state.co.us (D. Bean), pcunningham@rubycanyoneng.com (P. Cunningham), travingj@gmail.com (T. Johnson), karen.rosen@state.co.us (K. Rosen), amandastahlke@gmail.com (A. Stahlke).
[1] Current address: Department of Mathematics and Computer Science, West Virginia Wesleyan College, 59 College Ave, Buckhannon, WV 26201, USA.
[2] Current address: Ruby Canyon Engineering, 743 Horizon Ct., Grand Junction, CO 81506, USA.
[3] Current address: University of Idaho, 709 S Deakin St, Moscow, ID 83844, USA.

http://dx.doi.org/10.1016/j.biocontrol.2016.07.004

invasion locally. However, the high cover of noxious weeds will continue to be a management problem, with or without *Tamarix* control by the northern tamarisk beetle.

1. Introduction

Since their introduction to the western United States from Asia over a century ago, members of the genus *Tamarix* (tamarisk, salt cedar) have become the third most common woody species along rivers in the southwestern US and the second-most dominant in cover (Friedman et al., 2005). *Tamarix* gained this dominance in part by taking advantage of human alterations in riparian systems, such as altered flood regimes brought about by dams (Stromberg et al., 2007). Once established, *Tamarix* can be a powerful ecosystem engineer, leading some researchers to describe it as both a passenger and a driver of ecosystem change (e.g., Johnson, 2013). The presence of *Tamarix* in western North America has been cited for reducing water availability (Brotherson and Field, 1987), reducing biodiversity (Bailey et al., 2001), displacing native vegetation (particularly cottonwood and willow tree species) (Di Tomaso, 1998) and reducing wildlife habitat quality (Hink and Ohmart, 1984). However, recent studies have shown that although native riparian vegetation is preferable, *Tamarix* may contribute some ecosystem services, particularly as wildlife habitat, and it is not as profligate in water use as once was thought (Shafroth et al., 2005; Stromberg et al., 2009; Bateman et al., 2013; Nagler and Glenn, 2013; Cleverly, 2013).

Tamarix control has been a major priority of private and public land management for decades (Douglass et al., 2013). Traditional control strategies such as mechanical removal, fire, and herbicidal treatments are very costly (Tamarisk Coalition, 2008), particularly considering the enormous scale of the landscape requiring treatment. In 1996, the United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) approved the saltcedar leaf beetle (*Diorhabda elongata* Brulle) from Central Asia for use as a *Tamarix* biocontrol agent (DeLoach et al., 2003; Bean et al., 2013). Although originally identified as *D. elongata*, the beetles used in this study have been reclassified as *D. carinulata* Desbrochers, the northern tamarisk beetle (Tracy and Robbins, 2009). In 2001, *D. carinulata* was released in multiple locations across the Western U.S. where it has spread much faster than originally predicted, at least in some locations (Nagler et al., 2014). By 2015, it could be found along river corridors in Utah, Colorado, Nevada, Arizona, New Mexico, Texas, Oklahoma, Kansas, Mexico, Wyoming, Idaho and Oregon (Tamarisk Coalition, 2015).

Diorhabda carinulata feeds exclusively on *Tamarix* foliage resulting in foliage desiccation and subsequent leaf drop (i.e. defoliation) that lasts several weeks (Dudley and Kazmer, 2005). Repeated defoliation either within one season or over several consecutive growing seasons results in carbon starvation that reduces foliated production and growth, in some cases killing the tree (Hultine et al., 2015). Early studies of *D. carinulata* show that stand level mortality rates of up to 80% are possible after five years (Pattison et al., 2011), but mortality varies considerably among stands (0–100%; Hultine et al., 2015). Why some *Tamarix* stands experience mortality faster than others is still an open question, but mortality is likely influenced by several factors including, the timing of defoliation, soil conditions, plant access to resources (Hultine et al., 2015), stand age, tree growth rate (Hultine et al., 2013), the number of defoliation events (but see Hultine et al., 2015) and population genetics (Williams et al., 2014).

The widespread distribution of *D. carinulata* will likely reduce the competitive ability of *Tamarix* populations by lowering water resource use (Pattison et al., 2011; Sueki et al., 2015) and shifting water, nutrient, and carbon cycling processes (reviewed in Hultine et al., 2009). If resource monopolization by *Tamarix* has inhibited the growth of other plants, dieback of *Tamarix* canopies or outright mortality could release associated plants from competition. Where *Tamarix* dieback and mortality is extensive, the resulting effects on plant communities could be large-scale. Since defoliation is a relatively recent process, few studies are available on changes in vegetation communities as *Tamarix* canopies decline (Sher 2013; Hultine et al., 2009). While replacement vegetation is critical for bank stabilization and erosion control, wildlife habitat enhancement, and other ecosystem services, of equal concern is the colonization of non-native plants in areas released from competition due to *Tamarix* defoliation (Hultine et al., 2009). The flux of woody litter from dead *Tamarix* crowns to the ground is not well studied but is also important since it could alter microsite conditions for plants as well as microbial communities involved in decomposition and nutrient cycling.

From 2005 to 2007 *D. carinulata* beetles were released at ten riparian study sites in the upper Colorado River watershed in western Colorado. The ten sites span a range of hydrologic conditions from ephemeral canyon drainages to banks of the Colorado River. In this paper, we describe the patterns of beetle-induced defoliation, crown dieback, and mortality of *Tamarix* trees, and changes in vegetation composition and woody debris near affected *Tamarix* trees. We also explore how the observed patterns relate to site conditions, including soil properties, hydrology, and land use history.

2. Material and methods

2.1. Study sites

Ten long-term monitoring sites were selected in Mesa County, Colorado, USA (Fig. 1) where the Colorado Department of Agriculture, Palisade Insectary had released northern tamarisk beetles from 2005 to 2007 (Table 1). All sites were located in *Tamarix* stands, but the ten sites represented a variety of riparian and hydrologic conditions ranging from sites adjacent to the Colorado River to sites along ephemeral streams. The Colorado, Gunnison, and Dolores Rivers all have dams upriver from the field sites yet still experienced episodic flooding. The perennial creeks and ephemeral streams are unregulated and experienced flooding associated with heavy rains and snowmelt.

Eight of the sites are managed by the Bureau of Land Management and the remaining two sites are located on private property that is used primarily as range for grazing cattle. Two of the sites were burned by wildfires in 2007, one accidentally (Knowles) and the other intentionally (SYBurned). At one site (Salt Creek 2), *Tamarix* trees were mulched by hydroax in 2010 (Torrent EX40 mulching head mounted on a lightweight minimum impact Kubota excavator). *Tamarix* trees resprouted after both the fires and mulching treatment so these sites were kept in the present study, although no measurements were made in the mulched site in the year it was mulched.

Between 5000 and 15,000 *D. carinulata* adults were released at each site, with most sites requiring more than one release over two to four years to establish adequate beetle populations (Table 1). At each site, beetles were released onto the same *Tamarix* tree, located at the center of the site, called the release tree.