Ecological Engineering 111 (2018) 167–175

Contents lists available at ScienceDirect

Ecological Engineering

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

Native species recovery after reduction of an invasive tree by biological control with and without active removal

Anna A. Sher[a,*], Hisham El Waer[a], Eduardo González[a,b], Robert Anderson[a], Annie L. Henry[a], Robert Biedron[a], PengPeng Yue[a]

[a] University of Denver, Department of Biological Sciences, Denver, CO USA
[b] Colorado State University, Department of Biology, Fort Collins, CO USA

ARTICLE INFO

Keywords:
Biological control
Riparian restoration
Tamarix
Diorhabda
Invasive tree removal
Plant community response
Ecological restoration
Integrated pest management
BACI design
RDA multivariate analysis
Field of dreams hypothesis
Disturbance ecology

ABSTRACT

Removal of invasive species is often an important, if not central, component of many riparian restoration projects, however little is known about the response of plant communities following this practice. In particular, active control of the exotic, dominant tree *Tamarix* spp is often a focus of riparian restoration, much of which occurring against a backdrop of biological control by a folivore beetle. Our research employed controls in both time and space to investigate the impact of active *Tamarix* removal methods in sites subjected to biological control in 40 sites sampled three times over a period of five years. We found that reduction in *Tamarix* cover was much greater over time with active means of removal, however the native understory increased both with and without active removal. Importantly, change in the relative cover of understory native species was significantly negatively correlated with change in *Tamarix* cover, with those sites that received a combination of low-disturbance-mechanical, chemical and bio-control showing greater increases in native understory dominance than those sites with biological control alone or high-disturbance mechanical control. Sites with only biocontrol still contained 10% live *Tamarix* cover > 7 yr since the beetle was released there. Taken together, these results suggest that the reduction of this exotic tree, even by biological control that leaves some canopy intact, can facilitate recovery of the native plant community. As such, this study supports the *Field of Dreams* hypothesis that states that once niches are restored, native plants should be able to recolonize.

1. Introduction

Invasive trees can have substantial negative impacts both economically and ecologically on the systems in which they occur (Richardson and Rejmánek, 2011), thus restoration of degraded ecosystems often involves extensive noxious species removal efforts (González et al., 2015). Ecological restoration theory has suggested that plant communities may recolonize ecosystems once their ecological niches have been restored (*Field of Dreams Hypothesis*; Palmer et al., 1997). However, experience in the field has shown that the ecological impact of removal efforts can be both negative and positive (Mason and French, 2007; Gooden et al., 2009; Loo et al., 2009). This is due to several factors, including the extent to which control of the target is successful and the degree and type of disturbance incurred on an ecosystem by the removal method. Human-caused disturbances have long been associated with plant invasions, due to changes in both physical and chemical flux (Sher and Hyatt, 1999). Because of this, the removal of one invasive species can stimulate the establishment of other invasive species, referred to as secondary invasion (Pearson et al., 2016). Pearson et al. (2016) suggested that the space vacated by the first alien was the most important factor explaining the responses of secondary invaders, but specific case studies also showed that the type and intensity of management disturbance can promote the establishment of certain weeds. Invasive plant removal techniques can determine the responses of natives as well (Flory and Clay, 2009). Successful restoration is often defined by the recovery of native or otherwise desirable vegetation, however such species may or may not respond positively to the removal of the invasive target, due to the combined and interacting influence of remnant target individuals, the removal method, and secondary invasions.

Available techniques for removal of invasives are numerous. However, their effectiveness is usually compared in mesocosms or at small scales in experimental fields, and not in real large-scale restoration projects (Flory, 2010). While there is a great need for restoration practitioners to rigorotusly test he effects of exotic plant control methods (Clewer and Rieger, 1997; Byers et al., 2002), the truth is that

* Corresponding author.
E-mail address: anna.sher@du.edu (A.A. Sher).

https://doi.org/10.1016/j.ecoleng.2017.11.018
Received 19 June 2017; Received in revised form 1 November 2017; Accepted 18 November 2017

most restoration projects are not even evaluated, as they are not designed to conduct scientific research but rather to meet management goals (Bernhardt et al., 2007). Projects combining removal techniques of different types and intensity of disturbance could help us better understand key ecological processes, such as assembly rules in plant communities (Trowbridge, 2007). However a limitation of existing studies is the confounding effects of target reduction and disturbance; in most cases it is not possible to determine whether the response of the plant community to the removal method is due to decreased competition or some unrelated feature of disturbance by the removal method itself.

Furthermore, studies that do exist to assess the ecological impact of noxious species removal in actual restoration projects tend to be at a small geographic scale and without much replication over time or space (e.g., Mason et al., 2007; Sher et al., 2008; Loo et al., 2009; Flory, 2010). Because of the potentially great influence of both geographic location and inter-year variability, understanding of these systems benefits greatly from a BACI design; that is, with comparisons of the same sites Before versus After (B vs. A) as well as between different treatments (Control vs. Impact) at the same point in time (Stewart-Oaten et al., 1986). However funding and other limitations make such monitoring very unusual (Bernhardt et al., 2005; González et al., 2015).

Monitoring the impact of restoration of river systems can especially benefit from comparisons in both time and space, due to the very strong effects of each on biotic systems associated with rivers (González et al., 2015), and because treatments are rarely if ever randomly assigned. In the American Southwest, removal of invasive *Tamarix* spp. (saltcedar, tamarisk) and other weedy trees is often a central feature of restoration of riparian habitat, with the goal of increasing native species cover (Taylor and McDaniel, 1998; Sher, 2013). *Tamarix* invasion is highly associated with the damming and channelization of rivers in this region, and it has been argued that recovery of the native flora is unlikely to occur after removal of invasives if the underlying hydrological issues are not also addressed (González et al., 2017a). Here, we use a well-replicated BACI design to consider the response of a riparian plant community both without ("control") versus with ("impact") active removal of an invasive tree at 40 sites both before and after that active removal by two methods in sites with no concurrent hydrological improvements.

The restoration of *Tamarix* infested communities is also particularly interesting because it takes place in the context of the release of a biological control insect, the folivore *Diorhabda* sp. (Hultine et al., 2010). When using an insect or pathogen, living biomass of the invader can be reduced with minimal if any disturbance to the soil or other vegetation (Primack and Sher, 2016). This low-disturbance method of decreasing the cover of the target species therefore provides a unique opportunity to isolate the impact of reducing competition for light and other resources, decoupled from the soil-disturbing impacts of active methods. Studies comparing biological control alone versus in combination with active removal in the field are nearly non-existent in the literature (but see González et al., 2017a,b) and have yet been investigated specifically as such. Because all of our study sites were subjected to beetle defoliation at the initiation of the study, it is important to clarify that we will not be testing the impact of biological control relative to no impact at all. Rather, we will investigate the plant community response to degree of canopy reduction by the beetle alone versus canopy reduction by additional means that also involve mechanical and chemical disturbance of the soil. In this way, we hope to measure the impacts of those active means beyond that of reducing competition by the target.

The largest study to date on ecological impact of restoration of river/riparian systems took advantage of data from a variety of studies conducted at different times and by different methods (González et al., 2017a,b). The conclusions of that study were that high disturbance *Tamarix* removal methods were associated with increases in other weeds ("secondary invasion") and both high and moderate disturbance methods were associated with only modest increases in native species cover. However, because this study depended on pre-existing data, comparisons could not be made between before versus after these active removal methods. More importantly, it was not possible to determine whether plant community response was due to changes in cover of the target invader or because of other disturbance caused by the removal method.

Our research measured the response of a riparian plant community before and after to two methods of active removal of an invasive tree with comparisons over both time and space. We are also able to investigate changes in the plant community as a function of the reduction in the target without the disturbance of active removal, because of the backdrop of biological control. In this way, we were able to assess the impact of the disturbance of active removal on the assembly of plant communities, including the recovery of natives and secondary invasions, both as a function of the control of the target tree and as a consequence of the removal method itself. As such, we are testing the *Field of Dreams* hypothesis at a large scale representative of actual restoration projects usually neglected in restoration evaluations.

2. Methods

2.1. Study system

The Dolores River watershed is approximately 388 km long and runs through both Colorado and Utah. The Bureau of Land Management, as a part of the Dolores River Restoration Partnership (DRRP), have engaged in intensive efforts to control exotic *Tamarix* spp trees with the goal of restoring riparian habitat (Parternship, 2010). *Tamarix* in this area are likely to be a hybrid swarm between *T. ramosissima* and *T. chinensis* (Gaskin and Schaal, 2002; Gaskin, 2013). *Tamarix* is a poor competitor in every sense as a seedling (Sher et al., 2000, 2002; Sher and Marshall, 2003; Dewine and Cooper, 2008), but as a mature tree *Tamarix* is a strong effect competitor *sensu* (Goldberg, 1990) by shading neighbors (Sher, 2012; Taylor and McDaniel, 1998), elevating soil salinity (Ohrtman et al., 2012), and using water (Smith et al., 1998; Glenn and Nagler, 2005; Cleverly, 2013). It also promotes and withstands wildfire better than native riparian trees (Drus et al., 2013). Therefore, we expect that lowering the cover of *Tamarix* will correspond with an increase in the cover of desirable understory plants.

2.2. Research sites and treatments

Forty monitoring sites were established in 2010 along the Dolores River, where removal of *Tamarix* was an eventual goal but in nearly all cases had yet to be done (Fig. 1). The Dolores is a river regulated by the McPhee Dam, upstream from all of the sites in this study. Studies have shown that although the dam has reduced the flood frequency and magnitude (Wilcox and Merritt, 2005), flows are still sufficient to support the establishment of some native species of Salicaceae (Coble et al., 2013; Dott et al., 2016). The biological control agent was introduced to this area 2005–2007 and was active throughout the sampling period throughout the region to varying degrees. Approximately half (21/40) of the sites were selected as "impact" sites to have active removal of *Tamarix* above ground biomass in addition to the ongoing biological control, while the remainder would serve as "control" sites in which biological control was the only means by which *Tamarix* cover was reduced. Over the following years, some sites were lost and others added to maintain a sample size of 39–40 each year (Appendix A). Selection of sites, method and timing of removal were determined by the DRRP. Selection was non-random and driven by management objectives as well as practical and logistical constraints.

Active removal was conducted by one of two methods: CHEM ("cut stump" method that involves chainsaw cutting with immediate application of herbicide to the cut surface, 7 sites), and MECH (above ground biomass is removed through either mastication with heavy machinery