Passive Restoration Potential of Riparian Areas Invaded by Giant Reed (*Arundo donax*) in Texas

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As complex environments that include terrestrial and aquatic ecosystems, riparian areas are the most threatened habitats in North America, suffering impacts from anthropogenic activities, such as extraction and regulation of water and pollution, as well as ecologically-driven changes due to climate change and invasion by non-native species (Poff et al. 2011). The current condition of the riparian corridor along the bi-national Rio Grande/Rio Bravo River, which forms much of the United States-Mexico border, is considered one of the world's prime examples of damage caused by overextraction and other human activities to riparian ecosystems in arid regions (Wong et al. 2007). A shared resource, the Rio Grande has been heavily managed to provide water to a robust agricultural economy and burgeoning urban areas on both sides of the border, and it is acutely contaminated by agricultural and industrial runoff. The Rio Grande basin has also been heavily impacted by non-native invasive plant species, including giant reed (*Arundo donax*), a rhizomatous woody non-native grass that has invaded at least 40,000 ha of the narrow riparian corridor along the river and its tributaries (Yang et al. 2011). Invasive non-native weeds often drive or accelerate riparian ecosystem decline by outcompeting native plant species (Mason et al. 2007). Giant reed has significantly reduced native biodiversity in riparian ecosystems across arid regions of North America, transforming riparian landscapes into thick, impenetrable monotypic stands (McGaugh et al. 2006; Yang et al. 2011). In addition, giant reed has negatively impacted water supply due to its great evapotranspirative capacity (Watts and Moore 2011), and it has decreased border security along the Rio Grande (Yang et al. 2011). These impacts have justified and informed a long-term integrated management plan for control of this weed. Current management of giant reed include a combination of mechanical control and chemical herbicides (Spencer et al. 2008), and more recently, classical biological control using natural enemies (Goolsby et al. 2009). Despite these control efforts, little is known about the successional response or potential for restoration after the removal or control of giant reed from riparian habitat. A succession of diverse native vegetation after a given treatment may signify a high potential for passive restoration (Prach et al. 2001), whereas re-invasion by the same or another non-native species may suggest a need for active restoration efforts (Zavaleta et al. 2001), such as intentional plantings or planned revegetation.

To explore the restoration potential of giant reed infested areas, we conducted a 27-month observational study of the diversity and abundance of emergent plant species after repeated above-ground removal of giant reed across 16–25 m^2 infested riparian plots near Laredo, Texas (27°31'28"N, 99°29'26"W). Careful attention for plot placement was given to slope, soil type, relative distance to the river, and proximity to patches of native vegetation so that plots could be considered environmentally similar across field sites. We placed each plot at least 5 m into a wide (30 m) stand of giant reed to avoid edge effects. Our first visit was in December 2007, when we removed all existing above ground biomass within each plot and cleared a 1-m buffer around the periphery of the plot to allow for minimal trampling within the plot. We cut all giant reed stems at the base using a set of loppers (Fiskars™, Madison, WI), and we measured the basal diameter of each removed stem (Fractional+©, General Tools International, New York, NY). At each subsequent visit, every 2–3 months, we removed any re-emegent giant reed stems > 1 m in length, simulating sustained biological control or repeated, selective mechanical control. We counted and identified all other plant species that were present in each plot at the time of sampling. We present information on post-treatment succession to reveal the potential for restoration of giant-reed infested areas and discuss these results in relation to giant reed management in the context of the available control options.

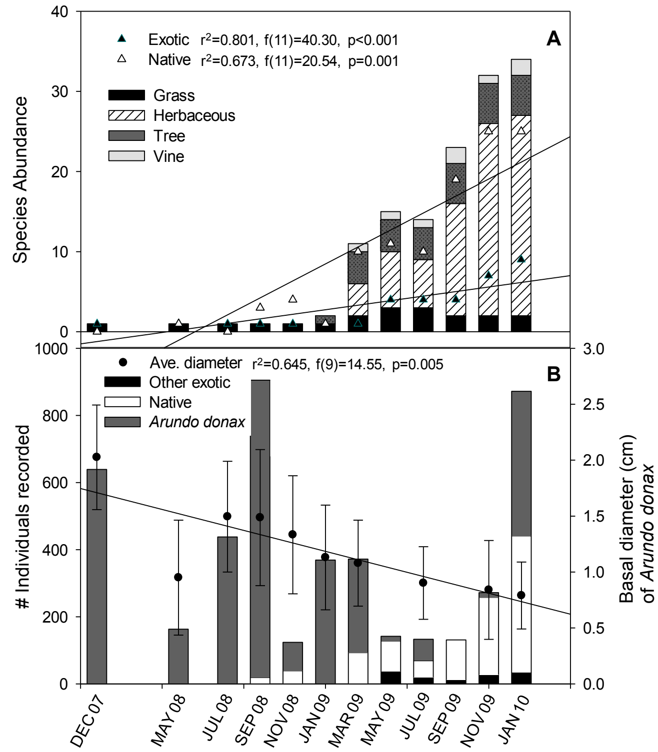
Of the 16 original plots, only 10 survived (a total area of 250 m^2) the entire observation period; the remaining 6 were either destroyed by unintentional fire, or access was rescinded by the landowner. We attempted to visit plots bi-monthly, but due to unforeseen circumstances, two observations periods were unintentionally skipped.

Initially, plots were entirely dominated by giant reed, but after more than one year of periodic treatment, a significant diversity of both native species and life forms started to emerge (Figure 1). After 27 months, more than half of the plants found in the observation plots were native (mostly herbaceous). Overall species abundance increased significantly over the observation period, during which we recorded a total of 44 non-giant reed species (6 of which were unidentified) (Table 1). We used a linear regression to test the increase in species abundance of both native and non-native species after periodic removal of giant reed. In each case, the model proved significant (Figure 1A), although the rate of increase in native species abundance (β=1.06, t(11)= 6.34, p<0.001) was greater than the rate of increase of non-native species (β=0.28, t(11)= 4.53,

Table 1. List of 39 emergent plant species found after periodic removal of giant reed (*Arundo* donax) over a 27-month period (December 2007–March 2010), Laredo TX (list does not include 6 unidentified species).

Common Name	Scientific Name	Family	Origin	Form
Huisache	*Acacia farnesiana*	Fabaceae	Native	Tree
Plains Lazy Daisy	*Aphanostephus ramosissimus*	Asteraceae	Native	Herbaceous
Spiny Pricklepoppy	*Argemone sanguinea*	Papaveraceae	Native	Herbaceous
Giant Reed; Carrizo	*Arundo donax*	Poaceae	Exotic	Grass
Prostrate Lawnflower	*Calyptocarpus vialis*	Asteraceae	Native	Herbaceous
Hackberry; Palo Blanco	*Celtis laevigata*	Ulmaceae	Native	Tree
Spiny Hackberry	*Celtis ehrenbergiana*	Ulmaceae	Native	Tree
Nettleleaf Goosefoot	*Chenopodium murale*	Chenopodiaceae	Exotic	Herbaceous
Chenopodium	*Chenopodium sp.*	Chenopodiaceae	?	Herbaceous
Ivy Treebine	*Cissus trifoliata*	Vitaceae	Native	Vine
Old Man's Beard	*Clematis drummondii*	Ranunculaceae	Native	Herbaceous
Jimsonweed	*Datura stramonium*	Solanaceae	Exotic	Herbaceous
Pinnate Tansy Mustard	*Descurainia pinnata*	Brassicaceae	Native	Herbaceous
White Margin Euphorbia	*Chamaesyce albomarginata*	Euphorbiaceae	Native	Herbaceous
Rio Grande Ash	*Fraxinus berlandieriana*	Oleaceae	Native	Tree
Pennsylvania Cudweed	*Gamochaeta pensylvanica*	Asteraceae	Native	Herbaceous
Small Flower Gaura	*Gaura mollis*	Onagraceae	Native	Herbaceous
Mock Vervain	*Glandularia quadrangulata*	Verbenaceae	Native	Herbaceous
Common Sunflower	*Helianthus annuus*	Asteraceae	Native	Herbaceous
Little Mallow	*Malva parviflora*	Malvaceae	Exotic	Herbaceous
Annual Sourclover	*Melilotus indicus*	Fabaceae	Exotic	Herbaceous
Tree Tobacco	*Nicotiana glauca*	Solanaceae	Exotic	Herbaceous
Retama	*Parkinsonia aculeata*	Fabaceae	Native	Tree
Buffelgrass	*Pennisetum ciliare*	Poaceae	Exotic	Grass
Ground Cherry	*Physalis cinerascens*	Solanaceae	Native	Herbaceous
Red Seed Plantain	*Plantago rhodosperma*	Plantaginaceae	Native	Herbaceous
Spearleaf Sida	*Rhynchosida physocalyx*	Malvaceae	Native	Herbaceous
Pigeon Berry	*Rivina humilis*	Phytolaccaceae	Native	Herbaceous
Plains Bristle Grass	*Setaria leucopila*	Poaceae	Native	Grass
London Rocket	*Sisymbrium irio*	Brassicaceae	Exotic	Herbaceous
American Nightshade	*Solanum ptycanthum*	Solanaceae	Native	Herbaceous
Texas Nightshade	*Solanum triquetrum*	Solanaceae	Native	Herbaceous
Prickly Sowthistle	*Sonchus asper*	Asteraceae	Exotic	Herbaceous
Annual Sowthistle	*Sonchus oleraceus*	Asteraceae	Exotic	Herbaceous
Narrow Leaf Globe Mallow	*Sphaeralcea angustifolia*	Malvaceae	Native	Herbaceous
American Germander	*Teucrium canadense*	Lamiaceae	Native	Herbaceous
Fanleaf Vervain	*Verbena plicata*	Verbenaceae	Native	Herbaceous
Deer Pea Vetch	*Vicia ludoviciana*	Fabaceae	Native	Vine
Lime Prickly-Ash	*Zanthoxylum fagara*	Rutaceae	Native	Tree

p=0.001). For example, of the 34 plant species we identified in the final month of our observations, 74% were native species (25/34). We also found a wide diversity of plant life forms at the end of the study, including many herbaceous plant species (25 spp.), vines (2 spp.), and 5 species of native tree saplings (sweet acacia (*Vachellia farnesiana* var. *farnesiana*), lime pricklyash (*Zanthoxylum fagara*), Mexican ash (*Fraxinus berlandieriana*), spiny hackberry (*Celtis pallida*), and sugar hackberry (*Celtis laevigata*) that are considered ecologically important trees in riparian ecosystems of south Texas. Over the last 5 observation periods, we recorded the presence of plains bristle grass (*Setaria leucopila*), a native grass which, though not rare, is uncommon in south Texas riparian areas due to pressures from non-native exotic grasses (J.H. Everitt, personal communication). Although the mechanism for the resurgence and succession of native species was not the focus of this project, repeated cutting led to a decrease in basal diameters of reemerging giant reed ramets (β = -17.22, t(10) = -3.81, p = 0.005; Figure 1B), signaling a significant physiological stress on the plant caused by cutting. Combined with a decrease in the overall spatial dominance of giant reed, this stress may allow for establishment of native plants from the surprisingly diverse and persistent seed bank found in giant reed-invaded riparian areas (A. Rubio, unpublished data). In riparian areas where there is natural recruitment through seed dispersal, enhanced moisture, and the formation of deep seed banks, the potential for passive restoration may be high. However, as this report demonstrates, an effort towards passive restoration of giant reed-infested areas requires sustained and persistent control of giant reed. Selective hand removal, such as that conducted in this effort, is an option which can allow for passive regeneration of native vegetation, but it is labor- intensive and most practical at a stand scale. Repeated mechanical control using a mower might be best for larger areas but should not be employed for more than 1 yr to minimize collateral damage to other regenerating species. A well-timed combination of mowing and selective removal may be an efficient, mechanical way to allow for passive restoration of giant reed infested areas along the Rio Grande. Alternatively, the selective, host –specific nature and long-term implications of biological control suggest that this strategy may also allow for the passive natural regeneration of a diversity of riparian vegetation, if natural enemies can effectively reduce the competitive advantage of giant reed. However, successful biological control is often regarded as a long-term, broad-scale goal, especially with robust woody weeds as seen with the management of the Australian paperbark tree (*Melaleuca quinquenervia*) in South Florida (Rayamajhi et al. 2011). The tradeoffs across temporal and spatial scales must be considered as land managers assess the ecological and social implications for giant reed management. This research can help inform land managers that have the restoration of giant-reed infested riparian areas as a goal.



(A) Species abundance of various life forms (grass, herbaceous plant, tree, or vine) over more than two years of periodic removal of giant reed. Lines indicate regression model of species abundance of native (white triangles) and non-native species (black triangles) in relation to time since initial removal. (B) Number of individuals (giant reed, native species, and other non-native plants) recorded at every sampling event. All stems of giant reed (Arundo donax) (<1 m height) were counted, measured (basal diameter), and removed. Non-giant reed species were left undisturbed. Line indicates regression model of giant reed stem diameter over time.

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