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Choked out: Battling invasive giant cane along the Rio Grande/ Bravo Borderlands

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Abstract

Along the U.S.-Mexico border, an aggressive non-native grass, giant cane (*Arundo donax*), grows in dense, nearly impenetrable stands along hundreds of kilometers of the Rio Grande/Bravo (RGB). Between 2008 and 2018, a diverse, multisector binational-team repeatedly treated giant cane with prescribed fire and herbicide along 90 km of this binational river to restore aquatic and riparian habitat and native plant community composition. The large geographic scale, binational management response, treatment methods used, and development of a long-term monitoring program to quantify treatment impacts on the RGB's riparian plant community underscore the unique aspects of this effort. Results of this decade-long management experiment indicate that (i) the combination of a primary treatment of giant cane (using prescribed fire followed 4–6 weeks later by herbicide treatment of regrowth) and a secondary treatment (spot treatment of regrowth one or more years following primary treatment) was effective in reducing the extent and distribution of giant cane at relatively low cost, (ii) giant cane re-establishment following treatment is often not rapid, nor dramatic; and (iii) as revealed by analysis of riparian vegetation monitoring data, eradication of dense stands of giant cane have fostered significant and long-term reduction in giant cane cover and recovery of native woody riparian plant taxa. Important caveats to the long-term viability of managing giant cane hinge on better understanding the consequences of herbicide use, securing funding to cover the cost of re-treatment, and continuing river flow management focused on promoting the recovery of native riparian obligate plants over non-natives.

KEYWORDS

invasive grasses, invasive species management, Rio Bravo, Rio Grande, riparian restoration

1 | INTRODUCTION

Giant cane (*A. donax* L.) is a perennial, clump-forming hydrophyte that has transformed the structure and function of many subtropical and semiarid riparian zones worldwide. Giant cane, along with saltcedar (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia* L.), comprise the top three "most-wanted" floodplain exotic invasive plants in the western U.S. and northern Mexico, with millions of dollars spent annually on their control (Lovell, Stone, & Fernandez, 2006; Pimentel, Zuniga, & Morrison, 2005). Giant cane is native to eastern Asia (Polunin & Huxley, 1987) and the Mediterranean (Dudley, Lambert, & Kirk, 2008), but it was first introduced to the New World in the early 1800s via plantings along irrigation ditches (Bell, 1997) and as living fences around thermal or saline springs (Papazoglou, 2007). Its rapid growth and establishment in dense, nearly monospecific stands has displaced native riparian vegetation (Coffman, 2007; Herrera & Dudley, 2003; Johnson, Olden & Vander Zanden, 2008; Lambert, Dudley, & Saltonstall, 2010) and negatively impacted arthropod diversity and abundance (Herrera & Dudley, 2003; Kisner, 2004). In North America, giant cane is now a dominant riparian plant along waterways, from Maryland to California, but this species has invaded most aggressively along with riparian areas in southern California and the Rio Grande/Bravo (RGB) in Texas and Mexico (Bell, 1997; Dudley, 2000; Dudley & Collins, 1995).

The Rio Grande/Bravo (RGB) Basin – called the Rio Grande in the U.S. and the Rio Bravo in Mexico- covers over 870,000 km^2 (336,000 mi^2) of the southwestern U.S. and northern Mexico. The river forms a natural boundary between the U.S. and Mexico, and provides freshwater resources for millions of people and a habitat for myriad riparian species (Ward & Pulido-Velazquez, 2008). The RGB has experienced a variety of human interferences, including the construction of numerous large dams that restrict annual flow (Schmidt, Everitt, & Richard, 2003) which impedes the movement of water, sediment, and nutrients, with cascading impacts on channel morphology, aquatic and riparian habitat, and native fauna and flora (Brandt, 2000; Hart & Poff, 2002; Poff & Zimmerman, 2010 and Rosenberg, McCully & Pringle, 2000).

The geographic focus of this paper is the portion of the international reach of the RGB that passes through the Big Bend region (Figure 1). The RGB channel through Big Bend passes through alternating wide alluvial valleys and narrow canyons. The region is remote, rugged, and beautiful (Figure 2). Along this international river reach, declines in mean and peak streamflow as a result of upstream river impoundment and diversion along the Rio Conchos in Mexico and within the northern stem of the Rio Grande in New Mexico, U.S. and a relatively unchanged sediment supply has produced a situation of sediment surplus where more sediment enters the system than exits (Dean & Schmidt, 2011; Dean, Topping, Schmidt, Griffiths, & Sabol, 2015). Increased sediment storage is the result and the RGB channel narrowed by as much as 50% between 1940 and 1980 (Dean & Schmidt, 2013). The establishment of dense, nearly impenetrable fields of giant cane along much of the RGB within the Big Bend by the early 2000s exacerbates channel-narrowing processes by increasing sediment deposition during high flows and anchoring

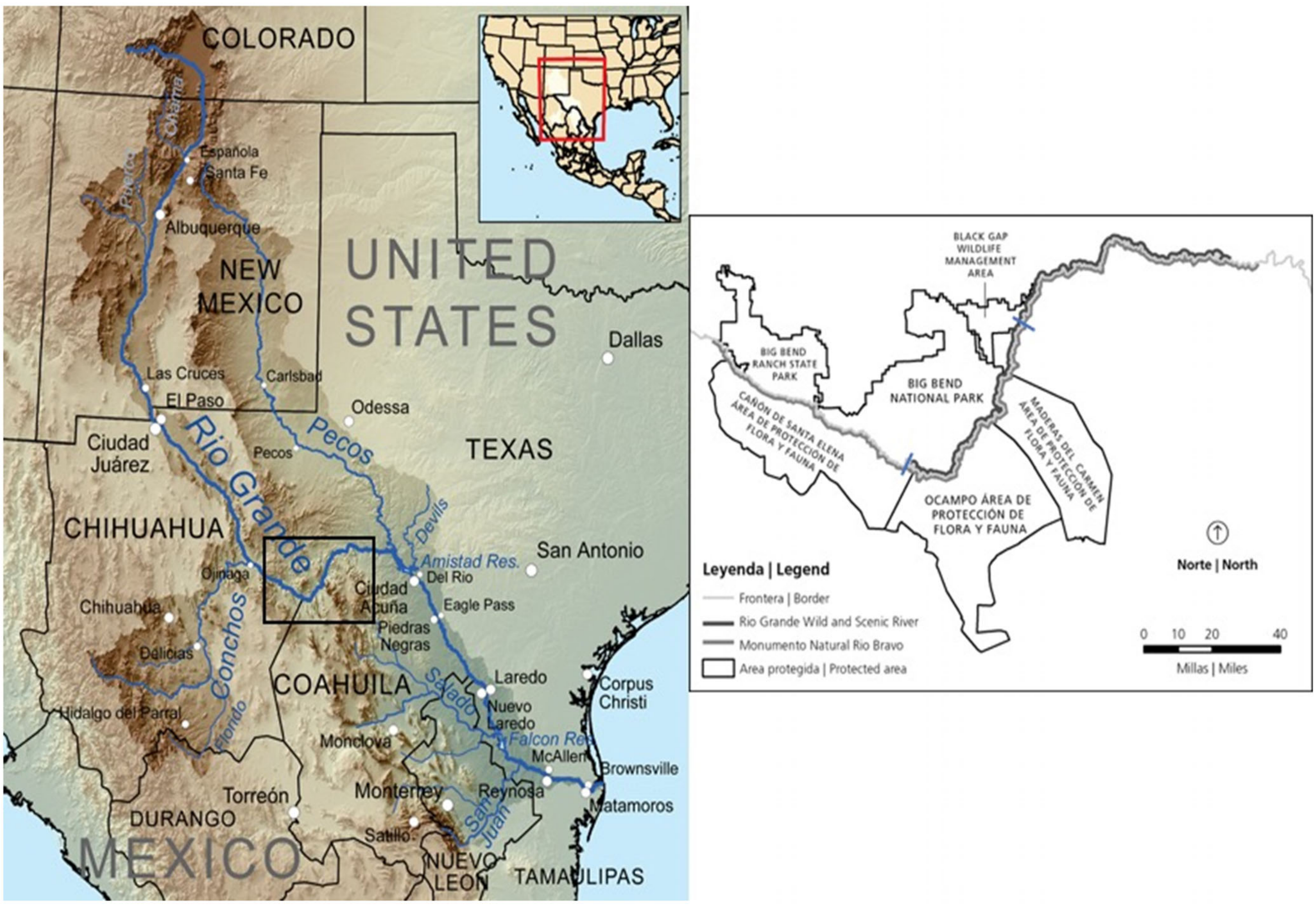

FIGURE 1 Map of the binational reach of the RGB through the Big Bend region, whose central feature is a core of protected areas on both sides of the international border that cover over 13,000 km^2 (5,000 mi^2). Giant cane management actions have been conducted along over 90 km (56 miles) of the RGB (the reach between the two hash marks inserted in map on right). *Map by Marie Landis, Big Bend National Park* [Color figure can be viewed at wileyonlinelibrary.com]

FIGURE 2 The international reach of RGB through Big Bend is rugged, remote, and passes through narrow canyons interrupted by wide alluvial valleys (photo by A. Melton) [Color figure can be viewed at wileyonlinelibrary.com]

deposited sediment. As the channel narrows further, high quality riparian and aquatic backwater habitats are buried, which threatens the habitat of a variety of native taxa, including habitat critical to the endangered Rio Grande Silvery minnow (*Hybognathus amarus*) and other native pelagic fishes (Edwards & Contreras-Balderas, 1991). Channel narrowing also reduces the capacity of the channel to contain flow, which results in increased overbank flooding and damage to riverside towns and infrastructure.

1.1 | The debate: Should we manage giant cane along the RGB?

Spurred by the general hydroecological deterioration of the RGB, a diverse team of federal and state water and land managers, scientists, riverside communities, and non-governmental agencies on both sides of the border joined forces in an effort to restore the structure, function, and biological integrity of this international river reach (Briggs, Bennett, Dean, Sifuentes & Hoth, 2008). Whether or not to initiate a program to manage giant cane as part of the international restoration response was a hotly debated topic. Stakeholders in favor of giant cane management touted 1) The importance of reversing the channel narrowing effects of giant cane establishment; 2) Reduced channel capacity as a result of channel narrowing that increases the risk of flood damage to riverside towns and infrastructure; 3) The threat of increased fire severity and frequency; 4) Loss of river access and riverside campsites; and 5) Improved ability of high flow events to mobilize and evacuate accumulated sediment following giant cane eradication. Those against giant cane management were concerned about 1) The potential negative consequences of herbicide use (as part of managing giant cane) on the riparian and aquatic resources of a river designated in both Mexico and U.S. as Wild and Scenic; and 2) That the proliferation of giant cane along the RGB is driven, at least in part, by a flow regime that has been dramatically altered to meet human needs. The point being that if streamflow management along the RGB's cannot be improved for benefit of native riparian plants, giant cane may rapidly reestablish after eradication, thus precipitating an endless and expensive cycle of maintenance.

The potential benefits of giant cane management ultimately outweighed the consequences, and the binational team initiated a pilot giant cane management program in 2008. The decision to move forward centered around four central premises. The management of giant cane along the RGB needed to: 1) Be one component of a multipronged binational conservation response that included working with water managers in both the U.S. and Mexico to address streamflow management issues; 2) Start small and be expanded only after evaluating initial results; 3) Be carefully planned with all binational participants contributing to an annual giant cane management plan; and 4) Include a robust vegetation monitoring program to support an adaptive management response.

1.2 | Study area

This study took place along a 90 km reach of the RGB through Big Bend, spanning from Hot Spring Canyon to Boquillas Canyon (Figure 1). The Big Bend reach is named after the characteristic "bend" in the RGB, which forms the international boundary between Texas in the United States and Chihuahua-Coahuila in Mexico. The water between its banks – much of it supplied by its main tributary, the Rio Conchos – and its critical riparian ecosystems comprise the region's ecological backbone, providing water, food, and shelter for numerous native species of wildlife and human residents. The Big Bend portion of the basin lies in the Chihauan Desert and receives an annual average of 316 mm in precipitation, most of which comes as widely scattered summer monsoon thunderstorms (McRoberts and Nielsen-Gammon, 2010) Three protected areas in the U.S. – Big Bend National Park, Big Bend Ranch State Park, and Black Gap – and three in México – Cañón de Santa Elena, Ocampo, and Maderas del Carmen – protect over 1,000,000 ha (4,000 mile^2) of relatively intact Chihuahuan desert habitat and a 180-mile reach of the Rio Bravo.

The Rio Grande was once a wide, alluvial river in the early 20th century. Heterogeneous patches of native vegetation lined its banks until significant alteration of hydrological flows occurred in over the course of the mid to late 20th century (Everitt, 1993; Everitt, 1998). Dominant riparian plant taxa included seep-willow (*Baccharis salicifolia Ruiz & Pav*.) on sand bars and willow (*Salix exigua* Nutt.) and cottonwood (*Populus spp*.) at the channel margins. However, reduction in river flow due to damming and upstream diversions have resulted in almost complete loss of flow in recent decades (Lane, Sandoval-Solis, & Porse, 2015).

The loss of river flow resulted in dramatic changes in river hydrology and increases in deposition and sedimentation, which fosterd the establishment of non-native riparian plant taxa including tamarisk (*Tamarix ramosissima* L.) and giant cane. Recently, the governments of the United States and Mexico reaffirmed their joint commitment to the Big Bend region, declaring it a "Natural Area of Binational Interest." The two federal governments, as well as state governments, civil society, academia, the private sector, and local communities have been working together to increase information exchange amongst the Big Bend protected areas, restore river flows, riparian habitats, and grasslands, manage range lands, re-introduce wildlife populations, and re-establish commerce between the Big Bend National Park and the communities across the border at Boquillas Canyon.

2 | METHODOLOGY

2.1 | Managing giant cane along the RGB and monitoring results

Efforts to manage giant cane have been widely implemented in California, Texas, Nevada, and other states (Bell, 1997; Boose & Holt, 1999; Lambert, Dudley & Saltonstall, 2010). Commonly used treatment methods include reducing above-ground biomass by prescribed fire and/or mechanical cutting, and then chemically treating foliage regrowth four to 6 weeks later (Bell, 1997; San Martín, Gourlie, & Barroso, 2019). Therefore, giant cane was treated repeatedly along the RGB by conducting prescribed fires to reduce plant biomass, followed 4–6 weeks later with targeted herbicide application on giant cane resprouts (Figure 3, Data S1). Giant cane was treated along the RGB by combining a primary treatment (consisting of using prescribed fire to reduce plant biomass, followed 4–6 weeks later with herbicide application of giant cane resprouts) with a secondary treatment 1–2 years following the primary treatment that involved spot treating surviving giant cane resprouts with herbicide (Figure 3, Data S1). Although not unique, managing giant cane eradication via the combined use of prescribed fire with follow-up herbicide treatment is not common, with prescribed fire discouraged in favor of either combining mechanical cutting of giant cane with herbicide application or using herbicide application as sole management methodology (e.g., USDA 2014; California Invasive Plant Control (https://www.calipc.org/resources/library/publications/ipcw/report8/). In selecting an appropriate riparian herbicide, we chose the herbicide Imazapyr (tradename Habitat) because it is approved by the Environmental Protection Agency in the U.S., and by the Comisión Nacional de Áreas Naturales Protegidas in Mexico for use in and near aquatic habitats. The rugged and remote country of the river in Big Bend necessitated that prescribed burns and herbicide application be carried out via canoes. By 2018, our binational team had repeatedly

FIGURE 3 Treatment of dense stands of giant cane along RGB in Big Bend (i), involves planning and conducting prescribed burns (ii), treatment of regrowth with herbicide 4–6 weeks following burning and a secondary treatment of resprouts a year later (iii), and monitoring the impacts of managing giant cane on the riparian plant community (iv). Desired biophysical conditions along the RGB are characterized by a wide, shallow channel with a patchy, diverse native riparian plant community (v). [Photos by (i, iii, iv) Mark Briggs, (ii), Tamir Kalifa, (v), Jeff Renfrow] [Color figure can be viewed at wileyonlinelibrary.com]

treated giant cane using this approach along 90 km of the RGB. The riparian vegetation monitoring program conducted to assess the results of giant cane management sought to answer two key questions: (i) Were management tactics effective at reducing the extent and cover of giant cane? and (ii) What is the response of the riparian plant community after treatment?

Six monitoring sites were established along the 90 km reach of the RGB where giant cane management actions were conducted. Monitoring site location was based on biophysical characteristics of the site, timing, and location giant cane management actions, site access, travel time, among other considerations. At each sample site, we measured plant cover by species prior to treatment, one- to two-years following treatment, and then at irregular intervals through the end of the study in 2018. At the onset of the study in 2005, we established a set of four 2×20 m plots on active floodplain surfaces at each monitoring site that ran parallel to the river corridor. In 2014, the management team changed the sampling protocol to conform with the more widely-used Big River Monitoring (BRM) protocol (https://irma.nps.gov/DataStore/DownloadFile/604465), which describes the establishment of a set of smaller, 1×1 m at each treated site that were randomly distributed on like channel morphologic surfaces (primary floodplain, secondary floodplain, and terrace surfaces). Although the continuity of the sampling design changed over the study period, the larger number of 1×1 m plots established and measured at each monitoring site covered approximately the same sampling area as the larger 2×20 m plots that were originally used. For both protocols, we estimated the cover of all plants by species.

2.2 | Statistical analyses

We evaluated changes in plant cover and community composition at six sample sites over the study period via linear mixed-effects models, non-metric multidimensional scaling (nMDS), and similarity percentage (simper) analysis using the lme4 (Bates, Mächler, Bolker & Walker, 2015) and lmerTest (Kuznetsova, Brockhoff, & Christensen, 2013) packages for mixed models, and vegan (Oksanen, Blanchet, & Kindt, 2013) for nMDS and simper analyses. We used linear mixed-effects models to evaluate temporal changes in plant cover over the study period by species. We estimated variance components within each mixed model to account for the covariance structure of the repeated measures study design. Monitoring site was treated as a fixed effect and the year was treated as a random effect, with plots nested within sample site. The nMDS was performed on relative cover data for the pre-treatment sampling interval in 2005 and the last vegetation census in 2018. Differences in plant community composition between the pre-treatment and post-treatment time-steps were evaluated by plotting 95% confidence ellipses of the species space for these two time-steps. Finally, we identified the key species responsible for differences in nMDS species space via the simper command in vegan.

3 | RESULTS AND DISCUSSION

3.1 | What did we learn from managing giant cane along the RGB?

The mixed model, nMDS, and simper results highlight the effectiveness of this decade-long effort to manage giant cane along the RGB (Figures 4 and 5, Data S1). Giant cane cover declined significantly after treatment and in all years following treatment ($p < 0.05$). While we identified over 60 different plant species in the study, significant increases in native woody plant cover were manifest by two key native riparian species including *S. exigua* and *B. salicifolia* ($p < 0.05$), two pioneer native obligate riparian species that can rapidly colonize following disturbance in areas with suitable water availability and protection from flood scour. The nMDS results and simper analyses also revealed a significant shift in plant community composition between the pre-treatment sampling interval and the last monitoring campaign in 2018. The nMDS and simper results suggested that temporal changes in plant community composition were manifested principally by a shift away from giant cane (*A. donax*) at the onset of the study prior to treatment towards a mixed species matrix at the end of the study period. Giant cane, Bermuda grass (*Cynodon dactylon*), Fendler's sandmat (*Chamaesyce fendleri*), and seep willow (*B. salicifolia*) comprised the key species that were responsible for this shift in dominance between the pre-treatment and 2018 vegetation sampling intervals according to the Simper analysis ($p < 0.05$).

We want to highlight three anecdotal results of managing giant cane along the RGB that were not quantified by monitoring. First, we observed that giant cane is much more difficult to eradicate when its roots are able to access near-surface saturated soils during the dry, hot months of the year (May–July). This includes areas that receive discharge from springs and along the shoreline where giant cane roots can access river water during low flow. Although such characteristics exist in only 3–5% of the footprint where giant cane management was conducted, the persistence of giant cane at these micro-sites could serve as footholds for more rapid reestablishment following treatment. Developing strategies that effectively control giant cane in areas where this invasive species has year-round access to saturated soils is an important future priority. Second, we have observed native coyote willow (*S. exigua*) establishing and rapidly expanding its extent and distribution along several parts of the RGB reach where giant cane management actions have taken place as well as within untreated portions of the river. Understanding the biophysical characteristics of the river's bottomland environment that allow coyote willow to outcompete giant cane requires research attention. Third, the channel is widening in some of the areas where giant cane has been eradicated despite the lack of overbank flood events during the course of the study. Although much of the channel widening that is occurring is probably due to the angle of repose of accumulated bank sediment being compromised when the stabilizing qualities of giant cane have been removed, the trend toward more desirable channel conditions is a positive outcome (Figure 6).

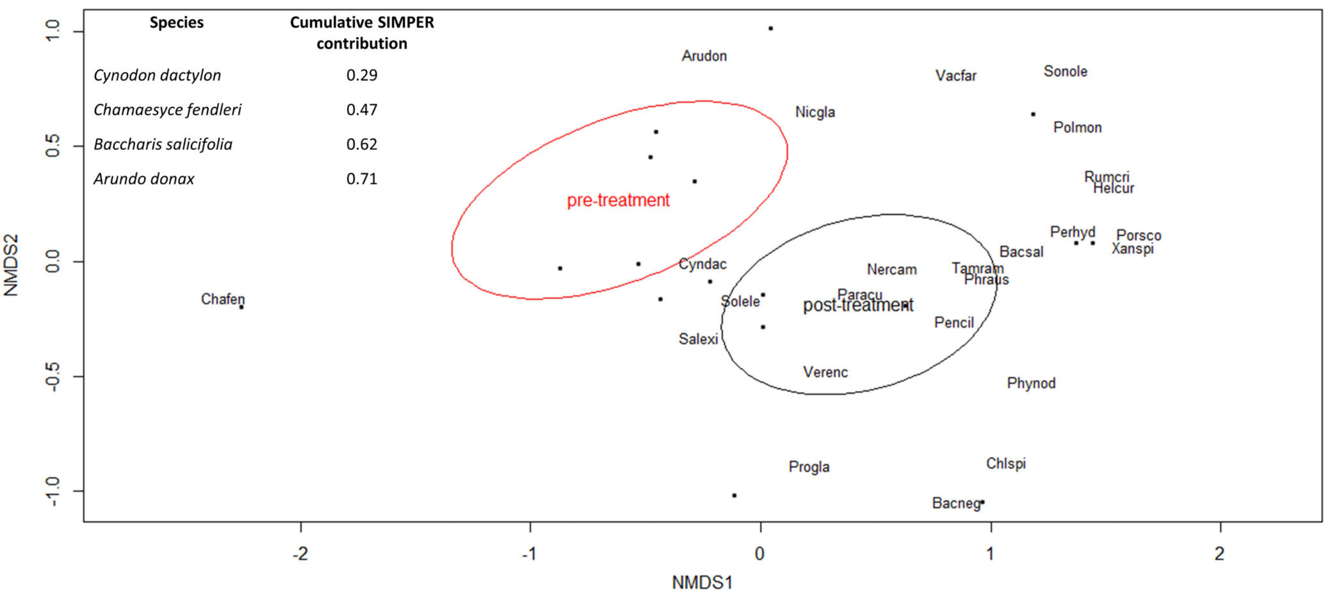

FIGURE 4 Non-metric multidimensional scaling results of giant cane treatment sites plotted with 95% confidence ellipses for the pre-treatment species space in 2008 and the post-treatment species space in the last vegetation sampling interval in 2018. The final stress for the two dimensional solution was 0.17. Species acronyms are described in Data S1 [Color figure can be viewed at wileyonlinelibrary.com]

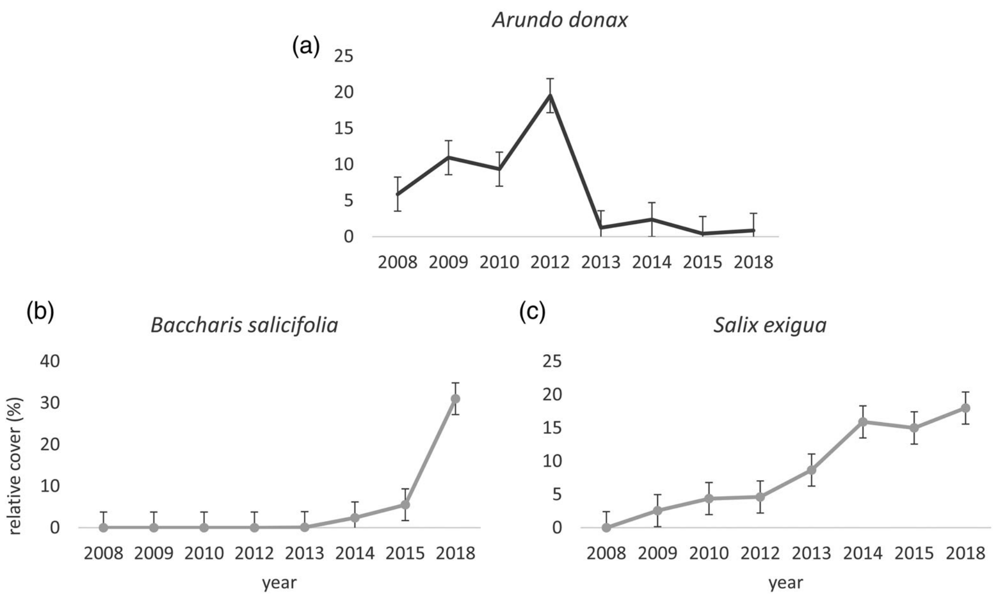

FIGURE 5 Mean ± S.E. relative cover by year of plant lifeforms and plant species that changed significantly over the study period according to the linear mixed-effects model analysis ($p < 0.05$) including (a) *Arunco donax*, (b) *Baccharis salicifolia*, and (c) *Salix exidua*. Pairwise differences and mixed-effects model significance for each model are reported in Data S1

Although the cost of managing cane along the RGB varies with location and conditions, costs to date have not been prohibitive, with total costs (logistical support, equipment, materials, and labor) for conducting for herbicide application via canoes ranging between $2000–$3,000 per ha for primary treatment, with a secondary treatments totaling less than one-fifth the cost of primary treatment. In the years ahead, we anticipate that giant cane will need to be managed in areas where it reestablishes following treatment. To maintain desirable giant cane cover into the future, we estimate the annual cost would be between $10,500 and $16,500 for the entire 90 km reach of the river that has been treated, to date.

3.2 | Management implications for the future

Results of this decade-long management program underscore how a well-coordinated binational management response can significantly reduce the extent and distribution of a highly invasive plant, with results generally mirroring those of similar invasive plant management programs elsewhere (Bunting et al., 2020; Tobin, 2018). Although parts of the RGB reach where giant cane management was conducted display more desirable channel morphologic and riparian vegetation conditions (Figure 3e), understanding the direct correlation between giant cane management actions and the biophysical changes that are occurring along the RGB remains a challenge. However, even with this

FIGURE 6 Along many parts of RGB where giant cane has been eradicated, accumulated alluvium has sloughed into the river, fostering wider and more desirable channel conditions (photo by Audra Melton) [Color figure can be viewed at wileyonlinelibrary.com]

in mind, this decade-long binational management effort suggests that 1) Dense stands of giant cane along many kilometers of river can be effectively eradicated relatively-inexpensively; 2) The one, two punch of prescribed burns followed with herbicide treatment of giant cane resprouts is an effective approach that results in high mortality; and 3) In the majority of instances, giant cane did not significantly re-establish within 3–5 years following treatment, which means that follow up treatments to maintain giant cane cover at desirable levels may not be prohibitively expensive. Currently, our binational team visits treated parts of the RGB once every 3 years to spot treat giant cane resprouts, as necessary. To date, these maintenance retreatments have proven both effective in controlling giant cane at desirable levels and inexpensive (roughly the same cost as secondary treatment (about $600/ha) and our vegetation monitoring program identified increases in percent cover of several important native riparian plant species over time which, in turn, appears to also benefit birds and butterflies (Coffey, Mackie, & Pomara, 2018).

Four considerations are important to note as we take stock of results and assess the future of managing giant cane along the binational reach of the RGB binational. First, cuts in funding threaten both the gains our binational team has made toward improving river conditions from control efforts as well as future monitoring that will provide the information needed to improve the efficacy of future giant cane management. At the same time, a biological control program led by the U.S. Department of Agriculture is introducing two giant cane specialist insects - the armored scale (*Rhizaspidiotus donacis Leonardi*) and the stem-galling wasp (*Tetramesa romana*) – that could assist in the management of giant cane in areas where burning and herbicide treatment cannot be carried out due to presence of threatened and endangered species, proximity to human communities and infrastructure, amongst other considerations. The effectiveness of these biocontrol agents on reducing the extent and distribution of giant cane are mixed (Goolsby & Moran, 2009; Showler & Osbrink, 2018). At least one study indicates that cutting of giant cane by heavy machinery may be required to increase the effectiveness of biocontrol agents (Dudley, Lambert, Kirk & Tamagawa, 2008), which would limit application to areas with road access and relatively gentle topography. Regardless, more monitoring is required to understand how the impacts of biocontrol agents may reduce the need for future active giant cane management.

We also remain concerned about the long-term consequences of repeated herbicide application. Although we utilized an aquatically-approved herbicide in a targeted manner in strict adherence to label guidelines and best management practices, unintentional drift from spraying during low river flows did occur. We simply do not know the environmental consequences of such contamination on native riparian and aquatic taxa. Securing the necessary resources to conduct a fate and transport study is a priority for evaluating the potential impacts of herbicide on the RGB riparian and aquatic ecosystems.

Finally, although long-term maintenance costs following treatment have been low, the lack of high magnitude, overbank flow events during the course of this study, and the consequences of such rare flow events on channel morphology and the riparian plant community constitutes an important unknown and emphasizes the importance of long-term monitoring to answer such important questions as: Does eradication of giant cane make underlying alluvium more vulnerable to evacuation by high flow events (thus promoting more desirable wide and shallow channel conditions)? Or, will such high flow events spark another cycle of giant cane expansion?

In the long-term, this binational effort has renewed attention on improving flow management along the RGB to address key riverine environmental needs (e.g., maintaining giant cane at desirable levels and promoting key native and aquatic species), Mexico-U.S. water treaty obligations, as well as the needs of riverside human communities (e.g., agricultural communities of the Rio Conchos). In the near term, the binational team has hit the pause button on expanding management of giant cane to untreated reaches with a focus on maintaining giant cane levels along treated reaches and monitoring to better understand long-term riparian plant recolonization following eradication, impacts of giant cane management on channel morphology, and the effectiveness of recent biocontrol introductions.

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CONFLICT OF INTEREST

We, the authors, declare no conflict of interest in preparing or publishing this manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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