South African Journal of Botany 119 (2018) 63–68

Contents lists available at ScienceDirect

South African Journal of Botany

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

Medium-term vegetation recovery after removal of invasive *Eucalyptus camaldulensis* stands along a South African river

S. Ruwanza [a,*], M. Gaertner [b,c], K.J. Esler [d], D.M. Richardson [b]

[a] Centre for Invasion Biology, Department of Ecology and Resource Management, University of Venda, Private Bag X5050, Thohoyandou 0950, South Africa
[b] Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa
[c] Nürtingen-Geislingen University of Applied Sciences (HFWU), Schelmenwasen 4-8, 72622 Nürtingen, Germany
[d] Centre for Invasion Biology, Department of Conservation Ecology and Entomology, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa

ARTICLE INFO

Article history:
Received 18 April 2018
Received in revised form 21 June 2018
Accepted 1 August 2018
Available online 30 August 2018

Edited by SJ Siebert

Keywords:
Biological invasions
Monitoring
Restoration ecology
Revegetation
Secondary invasion
Tree invasions

ABSTRACT

Effective ecological restoration requires detailed monitoring to determine the success achieved through different interventions in achieving objectives. In 2017, we resurveyed riparian sites along the Berg River in the Western Cape, South Africa, that have been cleared of invasive stands of *Eucalyptus camaldulensis* in 2010 using two clearing methods (fell-and-stackburn and fell-and-remove) and two restoration approaches: passive (where vegetation was allowed to recover without intervention) and active (assisted recovery). A significant increase in vegetation cover ($P < .001$) and diversity ($P < .05$) of native riparian species was recorded in passive restoration plots, but an increase in the cover of woody invasive alien plants was also observed. Only four of the nine native species that were planted to fast-track restoration were still present in the active restoration plots, but the abundance of these native species was significantly ($P < .001$) lower in 2017 than in 2011. We conclude that native vegetation recovery following *E.camaldulensis* removal seven years ago is following a positive recovery trajectory in both passive and active restoration sites, as shown by the increased occurrence of native trees and shrubs, e.g. *Maytenus oleoides, Melianthus major* and *Searsia angustifolia* which were not present before clearing. However, the reinvasion of cleared sites by woody invasive alien plants has the potential to slow down and potentially halt the recovery process. Further management interventions, e.g. removal of reinvading woody invasive alien plants, are required, emphasizing the sustained engagement to ensure restoration in these ecosystems.

1. Introduction

Invasion of riparian ecosystems by alien plants causes major problems in many parts of South Africa(Esler etal., 2008; Le Maitre etal., 2011). Massively increased biomass in dense invasive tree stands leads to increased evapotranspiration and decreased surface water runoff and ground water recharge (Görgens and Van Wilgen, 2004), leading to reduced streamflow (Dye and Poulter, 1995; Le Maitre etal., 2000). Native species are displaced in invaded sites (Richardson and Van Wilgen, 2004), causing significant changes to vegetation composition, function and structure (Vosse etal., 2008; Tererai etal., 2013). Invasive alien plants in South African riparian systems also exacerbate problems with fire at the urban–wildland interface (Gaertner etal., 2016). They also create ecosystem disservices, e.g. by acting as disease vectors and causing allergies (Potgieter etal., 2017; Vaz etal., 2017).

Given the many problems that invasive alien plants cause in riparian ecosystems in South Africa, considerable resources have been devoted to managing these invasions (Holmes etal., 2005). The Working for Water (WfW) programme, a national poverty alleviation initiative aimed at protecting and maximizing water resources in rivers, has been championing invasive alien plant control (Van Wilgen etal., 2012). Although previous studies evaluating the efficacy of the WfW programme have shown improvements in stream flow following alien clearing (Dye and Poulter, 1995; Prinsloo and Scott, 1999), evaluations of vegetation recovery have shown mixed results (Galatowitsch and Richardson, 2005; Blanchard and Holmes, 2008; Reinecke etal., 2008; Ruwanza etal., 2013; Fill etal., 2018). Some of the challenges associated with vegetation recovery failure following alien plant removal by WfW include secondary invasions (Ruwanza etal., 2013; Fill etal., 2018), low native seed germination (Pretorius etal., 2008), lack of native species in the soil seed bank (Galatowitsch and Richardson, 2005) and harsh environmental conditions (e.g., drought) that hinder native species establishment (Ruwanza etal., 2013).

The assessment of invasive alien plant management initiatives requires monitoring over timescales appropriate for gauging the effectiveness of interventions. Unfortunately most restoration projects, including the WfW projects, have been characterized by a lack of such monitoring (Van Wilgen and Wannenburgh, 2016; Fill etal., 2018).

* Corresponding author at: Department of Ecology and Resource Management, University of Venda, Private Bag X5050, Thohoyandou 0950, South Africa.
E-mail address: ruwanza@yahoo.com (S. Ruwanza).

https://doi.org/10.1016/j.sajb.2018.08.002
0254-6299/

Monitoring of ecological restoration initiatives is essential for investigating trajectories to recovery, thereby providing crucial information for adaptive management to direct succession as required (Prach etal., 2007). This paper presents results of vegetation recovery monitoring seven years after the initial alien plant clearing, our aim being to document trajectory of recovery of native plant species following *Eucalyptus camaldulensis* removal along the Berg River.

2. Methods

The study area (between the towns of Wellington and Hermon) is part of the Berg River in the Western Cape Province of South Africa (Fig.1). The river, which is approximately 294 km long and covers a catchment area of nearly 7715 km^2, flows into the Atlantic Ocean at Velddrif (De Villiers, 2007). The vegetation type at the study area is classified as renosterveld, an evergreen shrubland dominated by *Elytropappus rhinocerotis*(Mucina and Rutherford, 2006). Although renosterveld is fire prone (Cousins etal., 2018), vegetation along the Berg River rarely burns, allowing the persistence of patches of natural vegetation dominated by fire-sensitive species of riparian trees and shrubs such as *Diospyros glabra*, *Kiggelaria africana*, *Melianthus major*, *Podocarpus elongatus* and *Searsia angustifolia*. Long sections of the river are, however, invaded by *E.camaldulensis* and other invasive shrubs and trees, notably *Acacia mearnsii* and *Populus* spp. (Forsyth etal., 2004; Tererai etal., 2013). *Eucalyptus camaldulensis* invasion along the river is estimated to have started about 50 years ago (Geldenhuys, 2008).

2.1. Experimental design

To assess vegetation recovery seven years after the initial clearing, fell-and-stackburn, fell-and-remove and natural sites (dominated by thick riparian native trees and shrubs, with an understory of grasses and herbs) were resurveyed in spring 2017. Each of the above-mentioned sites were replicated three times. Prior to clearing in 2010, the fell-and-stackburn and fell-and-remove sites were heavily invaded (>75 canopy cover) by *E.camaldulensis*. In the fell-and-stackburn sites, cut *E.camaldulensis* biomass was stacked and burned on site, whereas in the fell-and-remove sites, cut biomass were removed from the sites using harvesting machines. The natural sites were dominated by natural vegetation and represented the reference sites (Ruwanza etal., 2013). The 2011 experimental design in fell-and-stackburn and fell-and-remove sites consisted of 12 permanently marked plots per site, with each plot measuring 5 m × 5 m with a 5 m buffer zone. Four of the plots were used to assess natural recovery of species (passive restoration) and the remaining eight for active restoration (four for seed broadcasting and the other four for planting cuttings) (see Ruwanza etal. (2013) for a list of species which were used for seed broadcasting and the quantities of seeds used). In 2017, the four passive restoration plots and four seed broadcast active restoration plots per site were resurveyed. None of the plots planted with cuttings were resurveyed because cuttings failed to establish in all treatments (Ruwanza etal., 2013). All four reference plots per site were resurveyed to determine the presence of existing species in natural sites.

2.2. Data collection

In spring (September) 2017, detailed vegetation surveys (following the same methods as used in 2011; Ruwanza etal., 2013) were undertaken in all plots. Within each 25 m^2 plot, species richness and densities for all the trees and shrubs were determined from counts of individual plant species. Species richness and densities for all herbs and graminoids were determined in 1 m^2 plots and placed at the edge

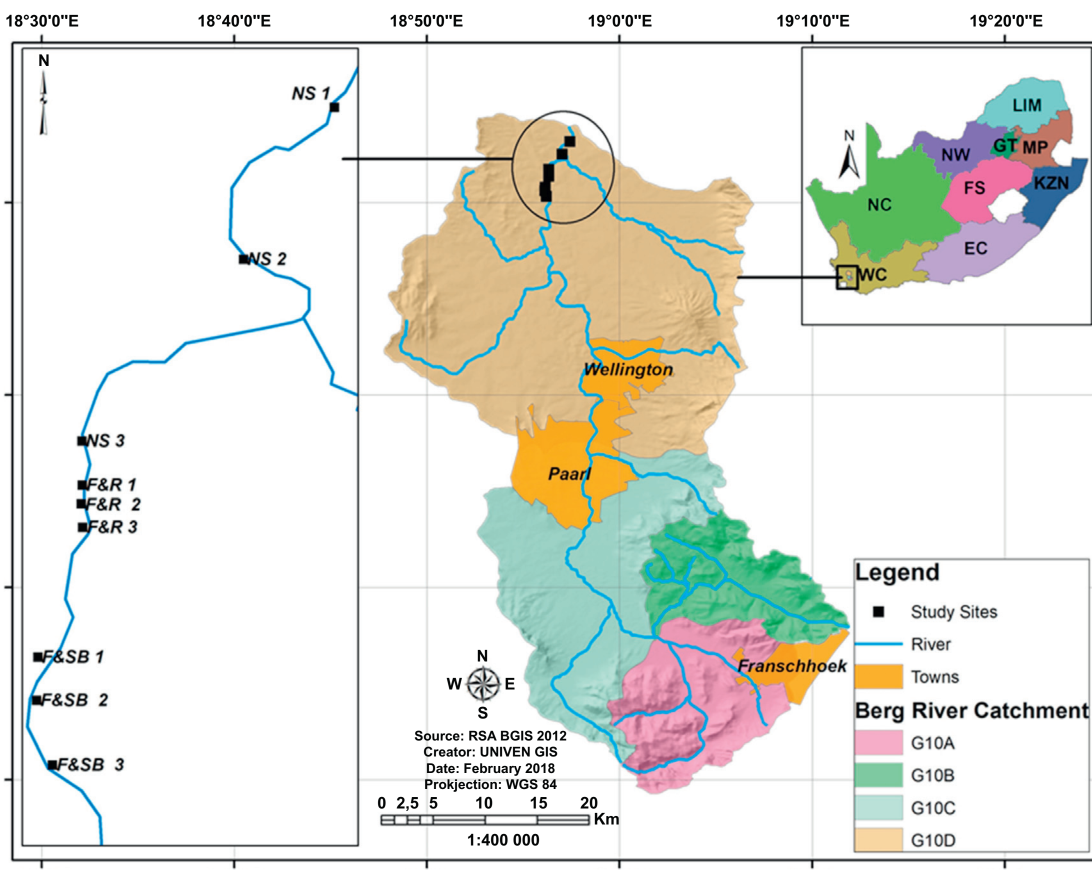

Fig.1. The study area in the Western Cape, South Africa, showing revisited sites subjected to different treatments for removing invasive stands of *Eucalyptus camaldulensis* along the Berg River, namely fell-and-stackburn (F&SB), fell-and-remove (F&R), and natural sites (NS). Three replicate plots were enumerated at each site.

of the plot. Total vegetation cover for all the growth forms in the above-mentioned plots was visually estimated to the nearest 5 or 1% when species occupied less than 5% cover. All the species were collected and visually identified in conjunction with local plant books (Manning, 2007; Manning and Goldblatt, 2012) and the PlantzAfrica online directory (South African National Biodiversity Institute, 2017). The growth form classes used in this study are trees, shrubs, herbs and graminoids (Goldblatt and Manning 2000). On active restoration plots, where seeds of native species were broadcasted, the presence of these target species was monitored by counting the total number of established plants and expressing these numbers as a percentage of the total seeds introduced via broadcasting in 2010.

2.3. Data analysis

The effects of different clearing treatments on species richness, Shannon-Wiener diversity index (H′), Simpson's index of diversity (1-D), Evenness index (J), vegetation cover and percentages from counts of introduced native plants were compared using repeated measures ANOVA for comparisons between spring 2011 and 2017. Proof of normality was tested using Kolmogorov–Smirnov tests and proof of homogeneity of variances was tested using the Levene test. Data were normally distributed and where ANOVAs were significant, Tukey's HSD unequal *n* test was used to determine differences between treatments at $P < .05$. Data were analyzed using STATISTICA version 13 (StatSoft Inc., 2015).

3. Results

Seven years following *E.camaldulensis* clearing through fell-and-stackburn and fell-and-removal, sites were dominated by trees andshrubs, in contrast to the dominance of herbs and graminoids oneyear after clearing. The cover of native trees and shrubs in both fell-and-stackburn and fell-and-remove sites was significantly ($P<.001$) higher in 2017 than in 2011 (Table 1). The cover of alien trees and shrubs in both fell-and-stackburn and fell-and-remove siteswas significantly ($P < .001$) higher in 2017 than in 2011 (Table 1). However, there were no significant ($P > .05$) interactions in cover ofboth native and alien trees and shrubs between clearing treatments and years (Table 1). Besides invasive alien trees of *Acacialongifolia* (above 41% frequency of occurrence), *A. mearnsii* and *E.camaldulensis* (above 81% frequency of occurrence, respectively) being present in cleared sites, native species now appeared on most sites (Table 2).

The cover of native herbs and graminoids showed significant differences between clearing treatments ($P < .001$) but not across years ($P>.05$). In contrast, the cover of alien herbs and graminoids showed significant ($P < .001$) differences between clearing treatments ($P<.001$) and across years ($P < .01$). These differences among clearing treatments and years for alien herbs and graminoids were more visible in fell-and-remove sites than in fell-and-stackburn sites (Table 1). In general, the cover of alien herbs and graminoids was higher in 2011 than in 2017. Interactions between clearing treatments and years in cover of both native and alien herbs and graminoids showed no significant ($P > .05$) difference (Table 1).

Species richness, as reflected in the Shannon-Wiener and Simpson's indices of diversity and the Evenness index, differed significantly among the different clearing treatments ($P < .001$), years ($P < .05$) and there was an interaction between clearing treatments and years ($P < .001$: Fig.2). The fell-and-remove site had higher species richness and Shannon-Wiener indices than the fell-and-stackburn and natural sites (Fig.2). Similarly, the above-mentioned indices of diversity were lower in 2017 than in 2011 (Fig.2), except for natural sites which showed insignificant changes. Simpson's indices of diversity and evenness were significantly ($P < .01$) higher in fell-and-remove and natural sites than in fell-and-stackburn sites in 2017 (Fig.2). However, yearly comparison of the two above-mentioned indices of diversity indicate that they both were significantly ($P < .001$) lower in 2017 than in 2011 (Fig.2).

Of the nine-native species that were broadcast in active restoration sites in 2011, only four species (*K.africana*, *Leonotis leonurus*, *M.major* and *S.angustifolia*) occurred in both fell-and-stackburn and fell-and-remove sites in 2017 (Table 3). Comparisons of clearing treatments in 2017 indicate that *K.africana, L. leonurus* and *M.major* had significantly ($P < .001$) higher percentage counts in fell-and-remove than in fell-and-stackburn sites (Table 3). This contrasts with 2011 results which showed that the above-mentioned species were significantly ($P < .05$) more abundant in fell-and-stackburn than in fell-and-remove sites (Table 3). Comparison across years indicates that species percentage counts for all the four-identified species were significantly ($P < .001$) higher in 2011 than in 2017.

4. Discussion

Seven years after clearing of invasive *E.camaldulensis* stands, native trees and shrubs are now present in passive restoration sites, indicating native species recovery is taking place. No recruitment of native trees and shrubs was reported in passive restoration sites one year after clearing (Ruwanza etal., 2013). Our recent results concur with previous studies that have shown successful spontaneous native species recovery years after alien plant removal (Reinecke etal., 2008). Similarly, Ndou and Ruwanza (2016) showed that native species diversity was higher in 11- and 15-year-old sites than in 6-year-old sites that were cleared

Table 1
Percentage cover of species recorded in restoration sites along the Berg River between 2011 and 2017.

	2011			2017			Repeated ANOVA (F-values)		
Species/treatment	Fell-and-stackburn	Fell-and-remove site	Natural sites	Fell-and-stackburn	Fell-and-remove site	Natural sites	Clearing treatments	Years	Clearing x years
Natives									
All natives	13.75 ± 2.14^c	49.58 ± 3.45^b	60.42 ± 4.01^a	23.75 ± 2.14^c	54.58 ± 3.45^a	63.42 ± 4.01^a	94.23***	4.97*	0.60ns
Trees and shrubs	0.00 ± 0.00^c	6.25 ± 1.64^b	60.42 ± 4.01^a	4.00 ± 0.10^c	9.45 ± 1.65^b	65.92 ± 8.48^a	361.38***	3.83**	0.08ns
Herbs	11.25 ± 2.55^c	48.33 ± 3.50^a	18.75 ± 4.31^b	13.25 ± 2.56^c	52.17 ± 3.54^a	20.75 ± 6.05^b	64.84***	0.82ns	0.05ns
Graminoids	0.00 ± 0.00^b	35.83 ± 5.96^a	0.00 ± 0.00^b	2.00 ± 0.15^b	36.38 ± 5.96^a	2.33 ± 0.18^b	69.89***	0.40ns	0.02ns
Aliens									
All alien species	49.58 ± 5.85^b	65.83 ± 2.37^a	10.83 ± 2.81^c	56.58 ± 5.85^b	75.67 ± 2.64^a	9.75 ± 2.73^c	2.57ns	55.57***	0.99ns
Trees and shrubs	24.58 ± 7.96^b	33.33 ± 3.81^a	7.08 ± 3.26^c	28.85 ± 6.52^b	35.34 ± 3.81^a	6.18 ± 2.99^c	0.21ns	55.57***	0.15ns
Herbs	47.92 ± 6.47^b	64.17 ± 2.53^a	6.67 ± 2.41^d	37.92 ± 6.47^c	53.17 ± 2.53^b	6.17 ± 2.29^d	80.19***	4.30*	0.94ns
Graminoids	7.08 ± 2.85^c	31.25 ± 2.05^a	10.00 ± 3.08^c	6.42 ± 2.56^c	27.45 ± 2.05^b	8.08 ± 2.78^c	45.67***	1.08ns	0.21ns

Data are mean ± SE and results of repeated ANOVAs are shown (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$). Values within columns with the different letter superscripts are significantly different at $P < 0.05$. NS = not significant at $P > 0.05$.

Table 2
Fifteen frequently occurring trees and shrubs in fell-and-stackburn, fell-and-remove, and natural sites in 2017 follow-up restoration study along the Berg River in the Western Cape, South Africa.

Species names	Fell-and-remove sites	Fell-and-stackburn sites	Natural sites
[N]*Melianthus major*	****	***	***
[N]*Searsia angustifolia*	***	***	***
[N]*Maytenus oleoides*	****	***	****
[A]*Acacia mearnsii*	*****	*****	–
[A]*Acacia longifolia*	***	***	–
[N]*Kiggelaria africana*	***	*	*****
[N]*Diospyros glabra*	–	–	****
[N]*Maytenus acuminata*	***	*	****
[A]*Eucalyptus camaldulensis*	*****	*****	–
[N]*Podocarpus elongatus*	***	**	*****
[N]*Salix mucronata*	***	**	***
[N]*Leonotis leonurus*	***	***	**
[N]*Olea europaea subsp. africana*	–	–	*****
[A]*Rubus cuneifolius*	**	***	–
[N]*Vachellia karroo*	–	–	***

(*) Indicates that the species was present at the site and is based on calculated species occupancy frequencies categorized as * (1–20%), ** (21–40%), *** (41–60%), **** (61–80%) and ***** (81–100). (–) indicates that the species was not present. (N) indicates native species and (A) indicates alien species.

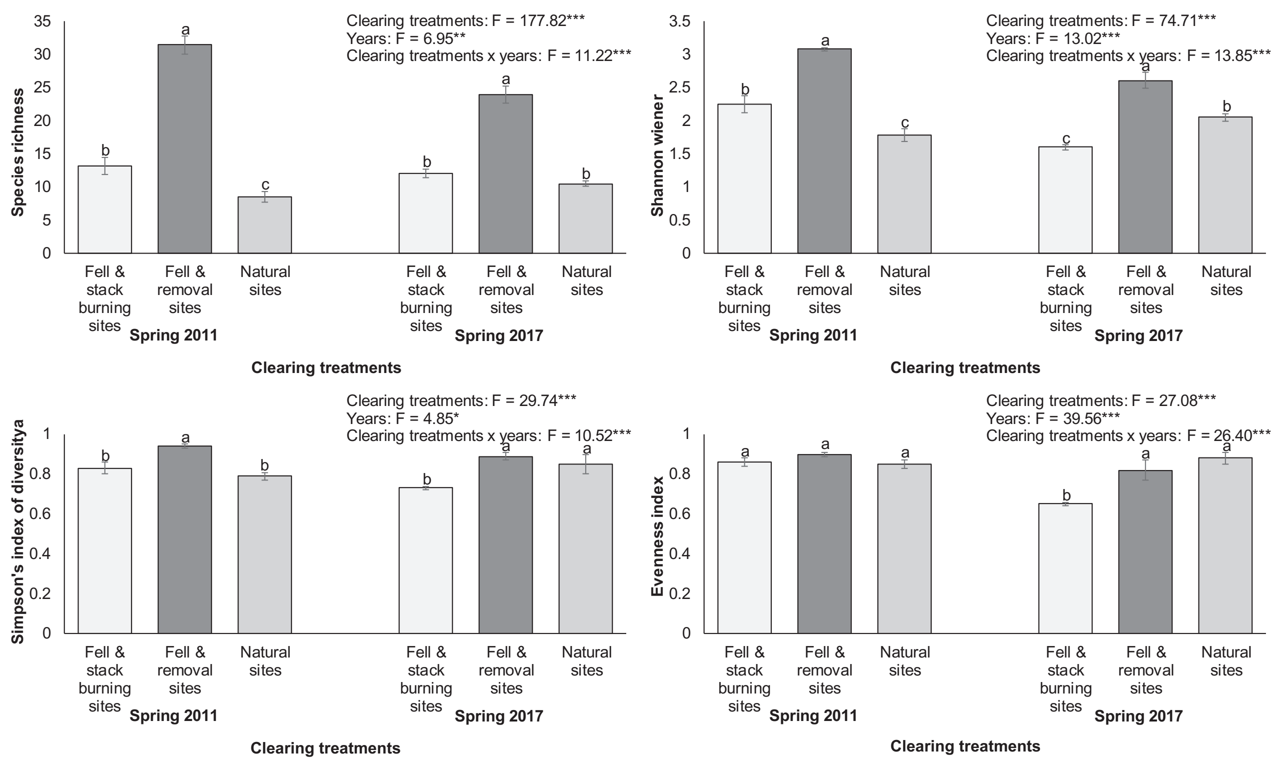

Fig.2. Indices of diversity in different clearing treatments, namely fell-and-stackburn, fell-and-remove, and natural sites between 2011 and 2017. Bars are mean ± SE and results of repeated ANOVAs are shown (*$^{*}P<.05$, $^{**}P<.01$, $^{***}P<.001$*). Bars with different letter superscripts are significantly different at $P<.05$. NS = not significant at $P>.05$.

Table 3
Percentages of species counts for the four-remaining targeted native species broadcasted in restoration treatments along the Berg River. Comparisons are between 2011 and 2017.

Species/treatment	2011		2017		Repeated ANOVA (F-values)		
	Fell-and-stackburn	Fell-and-remove	Fell-and- stackburn	Fell-and-remove	Clearing treatments	Years	Clearing treatments x years
Kiggelaria africana	14.94 ± 2.19^a	9.06 ± 2.43^a	0.11 ± 0.07^b	1.50 ± 0.58^a	1.83ns	45.34^{***}	4.79^{*}
Leonotis leonurus	51.00 ± 9.08^a	21.67 ± 6.10^b	1.00 ± 0.67^b	3.33 ± 0.83^a	6.04^{**}	38.67^{***}	8.31^{**}
Melianthus major	51.33 ± 3.84^a	26.94 ± 2.03^b	0.33 ± 0.13^b	2.33 ± 0.51^a	27.51^{***}	303.10^{***}	37.93^{***}
Searsia angustifolia	55.44 ± 5.49^a	12.00 ± 3.49^b	1.06 ± 0.28^a	1.39 ± 0.40^a	43.73^{***}	99.40^{***}	45.09^{***}

Data are mean ± SE and results of repeated ANOVAs are shown (*$^{*}P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$*). Values within columns with the different letter superscripts are significantly different at $P<0.05$. NS = not significant at $P>0.05$.

of *Acacia* species. Fill etal. (2018) reported an increase in the cover of native riparian shrubs after clearing *A.mearnsii*, *Acacia melanoxylon* and *Eucalyptus grandis* along the Rondegat River, although dominance of weedy grass cover was also reported.

The presence of native trees and shrubs in passive restoration sites seven years after initial clearing could be a result of several factors that are known to facilitate vegetation recovery in cleared sites. Firstly, Galatowitsch and Richardson (2005) suggested that seed dispersal from natural areas to cleared sites takes place if patches of natural vegetation are sufficiently close to cleared sites, as is the case with our sites. Secondly, the presence of remnant native species in cleared sites can act as “recruitment foci” where seed dispersal and native plant recruitment can take place (Zahawi and Augspurger, 2006). Remnant species are known to facilitate seed dispersal by birds and to create microenvironments that favor seedling dispersal, since they act as nurse plants (Ren etal., 2008). Thirdly, Fourie (2008) indicated that the presence of a native soil-stored seed bank in cleared sites can facilitate native species recovery several years after the initial clearing. In the last-mentioned study, a soil-stored seed bank of native species was observed eight years after *Acacia* clearing. In contrast, Vosse etal. (2008) showed that the seed bank in riparian zones comprises mostly short-lived herbaceous species and that long-lived trees and shrubs are lacking. Lastly, improvements in soil physicochemical properties several years after initial clearing favor the establishment of native tree and shrubs compared to alien herbs and grasses which dominate in the first few years after clearing. These factors likely also explain the higher diversity of herbs and grasses in 2011 than in 2017. Dominance of alien herbs and grasses in recently cleared sites is a result of their ability to take advantage of the high levels of soil nutrients deposited by the removed invader. Previous studies have reported that native vegetation recovery on cleared sites increased with gradual improvement in soil nutrients (Ndou and Ruwanza, 2016).

Comparisons between the two cleared sites indicate an increase in the cover of both native and alien species in 2017 compared to 2011. This could be a result of the presence of recruiting native trees and shrubs in fell-and-stackburn sites in 2017; these were not present in 2011. Improved soil physical properties in fell-and-stackburn sites could explain the presence of trees and shrubs in these sites. For example, Madsen etal. (2012) reported that gradual decrease in soil repellency post burning increases seedling emergence and survival because of improved ecohydrological properties required for plant growth e.g. soil moisture and compaction.

One year following clearing, we reported the dominance of alien herbs and graminoids on cleared sites. In contrast, the most noticeable feature at our restoration sites in 2017 was the presence of woody invasive alien plants, namely *A.longifolia*, *A.mearnsii*, *E.camaldulensis* and *Rubus cuneifolius*. Our observation of secondary invasion echoes the findings of Reinecke etal. (2008) who reported presence and dominance of the invasive alien species *A.mearnsii* eight years after the initial clearing. The reinvasion by woody invasive alien plants in cleared sites is at least partly due to the lack of effective follow-up treatments, which has allowed continuous recruitment of invasive alien plants from the soil-stored seed bank. The reinvasion of cleared sites can have strong negative effects on native species recovery since the recruiting fast-growing invasive alien trees and shrubs can outcompete native species for resources (e.g., water and soil nutrients) thereby slowing the recovery process. The worst-case scenario is that the rapid growth rate of these recruiting invasive alien trees and shrubs at restoration sites may initiate the complete reinvasion of these sites (D'Antonio and Vitousek, 1992), negating original clearing efforts.

Although the presence of some seeded native woody plant species in the active restoration sites is a positive sign, suggesting progression towards substantial ecological restoration, the decrease in total counts between 2011 and 2017 points to poor germination and low recruitment success of sown species in these sites. These results were also observed by Pretorius etal. (2008) who reported low species presence in seeded sites eight years after *Acacia* removal. It is difficult to pinpoint the cause of the decrease in numbers of sown plants, but we assume that competition from recruiting woody invasive alien trees and shrubs played a role. Besides competition, the reduction in the presence of sown native species in 2017 compared to 2011 could be a result of the severe drought that has prevailed in the Western Cape since 2015. Low soil moisture content and high temperatures associated with drought are known to decrease seed germination and seedling survival.

5. Conclusions and recommendations

Although native species diversity has not been fully restored in our cleared sites, our results show that vegetation recovery in both active and passive restoration sites is progressing well, as evidenced by the increased diversity of native vegetation. Before clearing there were a few remnant native species underneath the *E.camaldulensis* stands. One year after clearing, we reported that the clearing of *E.camaldulensis* had created conditions that favored the dominance of alien herbs and graminoids (Ruwanza etal., 2013), but these components are now being replaced by native trees and shrubs. The cover of alien trees and shrubs remains high compared to that of native species. Indeed, recolonization by woody invasive alien plants has the potential to slow down the observed vegetation recovery process. If the key factor facilitating the reinvasion by woody invasive alien plants is the lack of adequate follow-up measures, then interventions are needed to develop effective monitoring and follow-up plans. Previous studies have emphasized the need for WfW to effectively remove alien plants during follow-up and to collect data during the post-clearing monitoring phase (Van Wilgen etal., 2012; Van Wilgen and Wannenburgh, 2016; Fill etal., 2018). These studies also stressed the need to include monitoring of cleared areas in project planning and to allocate sufficient funds to long-term monitoring. We reported the importance of remnant native species in facilitating vegetation recovery. A management recommendation regarding remnant native species is that clearing teams need to be aware of remnant native species beneath invasive plants prior to clearing and should avoid damaging these species during clearing operations (Holmes etal., 2008).

We reported low counts of sown native species in active restoration sites, an indication that, where active restoration is considered, more needs to be done to facilitate the germination and establishment of sown species. One way to enhance germination in active restoration is to introduce native plants in stages after clearing. For example, fast-growing and drought-resistant native pioneer species can be introduced soon after clearing. Once these pioneer species are established, seeds or seedlings of other native can then be introduced. Such staggered introduction of native species has the potential to increase native species diversity years after the initial clearing and could reduce problems with competition for resources from recruiting invasive alien species.

Acknowledgements

Thanks to the University of Venda's Environmental Unit for providing the funds to conduct the 2017 surveys. We thank the farmers in the upper Berg River catchment for permission to re-survey the sites. Thanks to DST-NRF Centre of Excellence for Invasion Biology (C·I·B) and the Working for Water Programme through their collaborative research project on “Research for Integrated Management of Invasive Alien Species” for the initial funding used to clear and monitor the sites in 2011 and 2012.

References

Blanchard, R., Holmes, P.M., 2008. Riparian vegetation recovery after invasive alien tree clearance in the fynbos biome. South African Journal of Botany 74, 421–431.

Cousins, S., Witkowski, E.T.F., Esler, K.J., 2018. Influence of fire on critically endangered Swartland Shale Renosterveld in the Cape Floristic Region. Applied Vegetation Science 21, 144–155.

D'Antonio, C.M., Vitousek, P.M., 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 23, 63–87.

De Villiers, S., 2007. The deteriorating nutrient status of the Berg River, South Africa. Water SA 33, 1–6.

Dye, P.J., Poulter, A.G., 1995. A field demonstration of the effect on stream flow of clearing invasive pine and wattle trees from a riparian zone. South African Forestry Journal 173, 27–30.

Esler, K.J., Holmes, P.M., Richardson, D.M., Witkowski, E.T.F., 2008. Riparian vegetation management in landscapes invaded by alien plants: insights from South Africa. South African Journal of Botany 74, 397–400.

Fill, J.M., Kritzinger-Klopper, S., Van Wilgen, B.W., 2018. Short-term vegetation recovery after alien plant clearing along the Rondegat River. South Africa. Restoration Ecology (in press) https://doi.org/10.1111/rec.12585.

Forsyth, G.G., Richardson, D.M., Brown, P.J., van Wilgen, B.W., 2004. A rapid assessment of the invasive status of *Eucalyptus* species in two South African provinces. South African Journal of Science 100, 75–77.

Fourie, S., 2008. Composition of the soil seed bank in alien invaded grassy fynbos: potential recovery after alien clearing. South African Journal of Botany 74, 445–453.

Gaertner, M., Larson, B.M.H., Irlich, U.M., Holmes, P.M., Stafford, L., Van Wilgen, B.W., Richardson, D.M., 2016. Managing invasive species in cities: a framework from Cape Town, South Africa. Landscape and Urban Planning 151, 1–9.

Galatowitsch, S., Richardson, D.M., 2005. Riparian scrub recovery after clearing of invasive alien trees in headwater streams of the Western Cape, South Africa. Biological Conservation 122, 509–521.

Geldenhuys, C.J., 2008. Practical guidelines for the rehabilitation of forest-related streambank vegetation with removal of invader plant stands along the Berg River, Western Cape. Working for Water Report (FW - 02/08), South Africa.

Goldblatt, P., Manning, J., 2000. Cape plants. A conspectus of the Cape Flora of South Africa. Strelitzia 9. National Botanical Institute, Pretoria.

Görgens, A.H.M., Van Wilgen, B.W., 2004. Invasive alien plants and water resources: an assessment of current understanding, predictive ability and research challenges. South African Journal of Science 100, 27–34.

Holmes, P.M., Richardson, D.M., Esler, K.J., Witkowski, E.T.F., Fourie, S., 2005. A decision-making framework for restoring riparian zones degraded by invasive alien plants in South Africa. South African Journal of Science 101, 553–564.

Holmes, P.M., Esler, K.J., Richardson, D.M., Witkowski, E.T.F., 2008. Guidelines for improved management of riparian zones invaded by alien plants in South Africa. South African Journal of Botany 74, 538–552.

Inc, StatSoft, 2015. STATISTICA (data analysis software system), version 13. http://www statsoft.com.

Le Maitre, D.C., Versfeld, D.B., Chapman, R.A., 2000. The impact of invading alien plants on surface water resources in South Africa: a preliminary assessment. Water SA 26, 397–408.

Le Maitre, D.C., Gaertner, M., Marchante, E., Ens, E.J., Holmes, P.M., Pauchard, A., O'Farrell, P.J., Rogers, A.M., Blanchard, R., Blignaut, J., Richardson, D.M., 2011. Impacts of invasive Australian acacias: implications for management and restoration. Diversity and Distributions 17, 1015–1029.

Madsen, M.D., Petersen, S.L., Fernelius, K.J., Roundy, B.A., Taylor, A.G., Hopkins, B.G., 2012. Influence of soil water repellency on seedling emergence and plant survival in a burned semi-arid woodland. Arid Land Research and Management 26, 236–249.

Manning, J., 2007. Field guide to fynbos. Struik, Cape Town.

Manning, J.C., Goldblatt, P., 2012. Plants of the Greater Cape Floristic Region 1: The Core Cape flora. Strelitzia 29. South African National Biodiversity Institute, Pretoria.

Mucina, L., Rutherford, M.C., 2006. The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. South African National Biodiversity institute, Pretoria.

Ndou, E., Ruwanza, S., 2016. Soil and vegetation recovery following alien tree clearing in the Eastern Cape Province of South Africa. African Journal of Ecology 54, 460–470.

Potgieter, L., Kueffer, C., Larson, B., Livingston, S., O'Farrell, P., Gaertner, M., Richardson, D. M., 2017. Alien plants as mediators of ecosystem services and disservices in urban systems: a global review. Biological Invasions 19, 3571–3588.

Prach, K., Marrs, R., Pyšek, P., Van Diggelen, R., 2007. Manipulation of succession. In: Walker, L.R., Walker, J., Hobbs, R.J. (Eds.), Linking restoration and ecological succession. Springer Science + Business Media, New York, pp. 121–149.

Pretorius, M., Esler, K.J., Holmes, P.M., Prins, N., 2008. The effectiveness of active restoration following alien clearance in fynbos riparian zones and resilience of treatments to fire. South African Journal of Botany 74, 517–525.

Prinsloo, F.W., Scott, D.F., 1999. Stream flow responses to the clearing of invasive alien trees from riparian zones from three sites in the Western Cape Province. South African Forestry Journal 185, 1–7.

Reinecke, M.K., Pigot, A., King, J.M., 2008. Spontaneous succession of riparian fynbos: is unassisted recovery a viable restoration strategy? South African Journal of Botany 74, 412–420.

Ren, H., Yang, L., Liu, N., 2008. Nurse plant theory and its application in ecological restoration in lower subtropics of China. Progress in Natural Science 18, 137–142.

Richardson, D.M., Van Wilgen, B.W., 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts? South African Journal of Science 100, 45–52.

Ruwanza, S., Gaertner, M., Esler, K.J., Richardson, D.M., 2013. The effectiveness of active and passive restoration on recovery of indigenous vegetation in riparian zones in the Western Cape, South Africa: a preliminary assessment. South African Journal of Botany 88, 132–141.

South African National Biodiversity Institute, 2017. PlantZAfrica.com (online resource), http://pza.sanbi.org/. Accessed on: 15/10/2017.

Tererai, F., Gaertner, M., Jacobs, S.M., Richardson, D.M., 2013. *Eucalyptus* invasions in riparian forests: effects on native vegetation community diversity, stand structure and composition. Forest Ecology and Management 297, 84–93.

Van Wilgen, B.W., Wannenburgh, A., 2016. Co-facilitating invasive species control, waterconservation and poverty relief: achievements and challenges in South Africa's working for water programme. Current Opinion in Environmental Sustainability 19, 7–17.

Van Wilgen, B.W., Forsyth, G.G., Le Maitre, D.D., Wannenburgh, A., Kotze, J.D., Van den Berg, E., Henderson, L., 2012. An assessment of the effectiveness of a large, national-scale invasive alien plant control strategy in South Africa. Biological Conservation 148, 28–38.

Vaz, A.S., Kull, C.A., Kueffer, C., Richardson, D.M., Vicente, J.R., Kühn, I., Schröter, M., Hauck, J., Bonn, A., Honrado, J.P., 2017. Integrating ecosystem disservices and services: insights from plant invasions. Ecosystem Services 23, 94–107.

Vosse, S., Esler, K.J., Richardson, D.M., Holmes, P.M., 2008. Can riparian seed banks initiate restoration after alien plant invasion? Evidence from the Western Cape, South Africa. South African Journal of Botany 74, 432–444.

Zahawi, R.A., Augspurger, C.K., 2006. Tropical forest restoration: tree islands as recruitment foci in degraded lands of Honduras. Ecological Applications 16, 464–478.