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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

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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).

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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

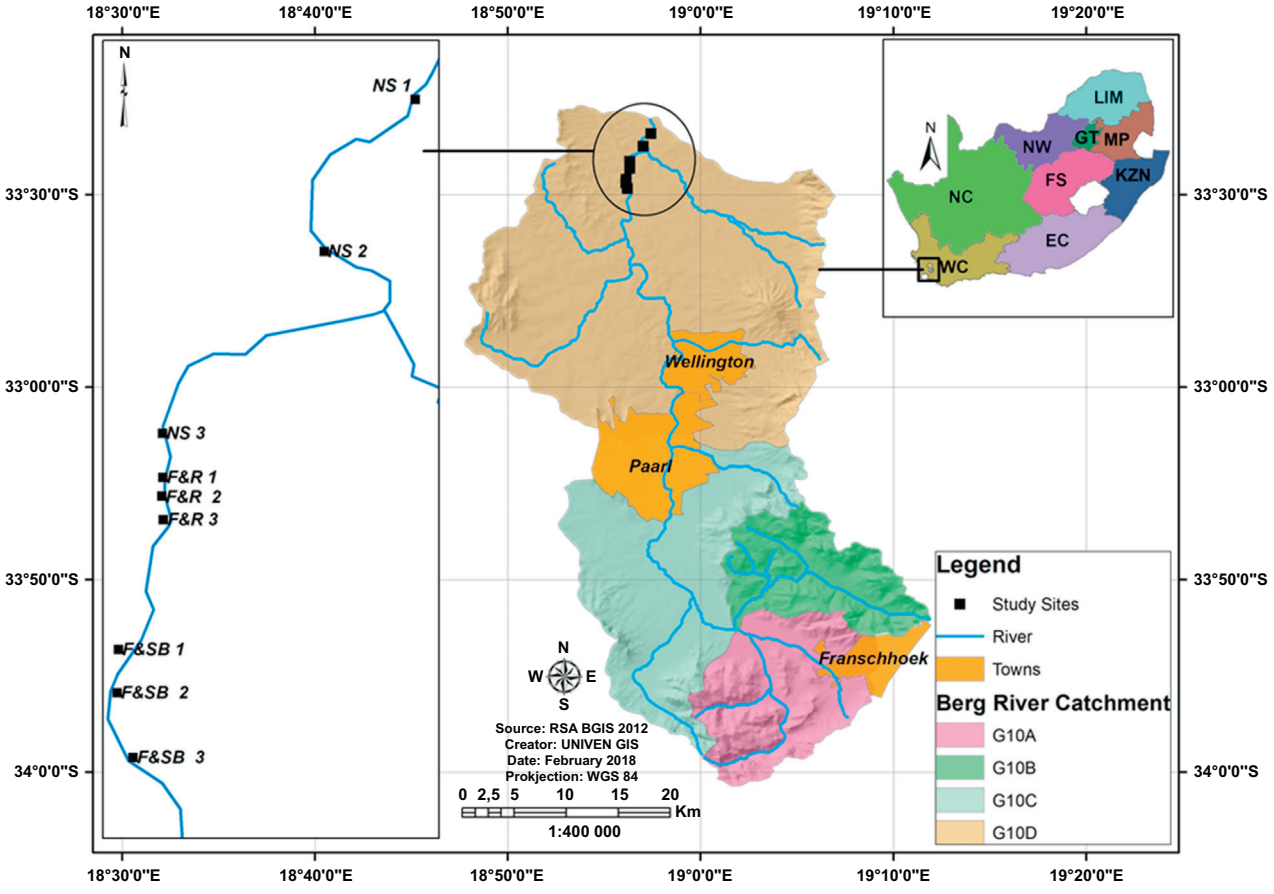

Fig.1. The study area in the Western Cape, South Africa, showing revisited sites subjected to different treatments for removing invasive stands of *Eucalyptus camaldulensis* along the Berg River, namely fell-and-stackburn (F&SB), fell-and-remove (F&R), and natural sites (NS). Three replicate plots were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