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TECHNICAL ARTICLE

# Short-term vegetation recovery after alien plant clearing along the Rondegat River, South Africa

Jennifer M. Fill[1,2], Suzaan Kritzinger-Klopper[1], Brian W. van Wilgen[1]

**The outcomes of ecosystem restoration projects should be periodically monitored to inform subsequent adaptive management decisions. In 2012, a project was begun to remove both invasive alien plants and fish from the Rondegat River in South Africa. Although the initial post-intervention dynamics of aquatic fauna have been documented, the results of the simultaneous clearing of dense riparian stands of alien trees and shrubs have not been reported. We examined native riparian vegetation recovery over 3 years after alien plant clearing. We documented increased cover of native riparian shrubs, but a simultaneous increase of alien and native weedy grass cover. Secondary invasions, especially by grasses, can have strong effects on ecosystem dynamics and achieving the goals of restoration may therefore require additional active management. Our findings provide an initial baseline reference for future monitoring and adaptive management decisions.**

**Key words:** ***Acacia mearnsii*, fynbos, invasion, river restoration**

### Implications for Practice

- For some restoration projects, passive restoration may be sufficient for short-term recovery of dominant native species after alien plant clearing.
- However, secondary invasions could complicate outcomes and require additional interventions in the long term.

## Introduction

To be most beneficial, ecosystem restoration projects should implement plans for monitoring progress toward restoration targets over the long term. Periodic surveys of outcomes are essential for informing continuous adaptive management decisions. Long-term monitoring is also required to reveal how the restoration trajectory might be influenced by contextual factors such as land ownership patterns and land practices (Ruiz-Jaen & Aide 2005). For restoration projects that involve alien invasive species control, the ecological and social context can determine not only the permanence of invasive species' elimination but also the continuity of native species' reproduction and persistence (Richardson et al. 2007). However, despite their utility for informing restoration practice, the outcomes of ecosystem restoration projects that address multiple alien invasions are rarely documented (Gaertner et al. 2012; Kuebbing et al. 2014), even in the short term.

In this study, we focused on a project that targeted the removal of both alien fish and alien plants in an ecologically important river system in the Western Cape Province, South Africa. Invasive alien fish had virtually eliminated endemic fish from sections of the Rondegat River (Lowe et al. 2008). Government agencies treated the river with the piscicide rotenone to eradicate alien fish and facilitate endemic fish recovery (Weyl et al. 2013). The project also included the simultaneous clearing of dense stands of invasive alien trees along the river to restore the riparian zone to its former natural condition (Impson et al. 2013). Invasive alien plants have been widely recognized as a threat to the Western Cape's endemic flora. For several decades the South African government has funded alien plant clearing efforts both to provide employment and to remove alien species (van Wilgen et al. 2012), with the expectation that native vegetation should recover to its former state. Although almost all of these projects have been characterized by a lack of rigorous goal-setting and planning (van Wilgen & Wannenburg 2016), there has been an implicit understanding that the goal has been to reduce the levels of invasion to a maintenance level, at which it would be possible to maintain the site in an uninvaded state at relatively low cost in perpetuity (Fill et al. 2016). The focus of scientific assessments at this site to date has been entirely on aquatic fauna (Weyl et al. 2013, 2014; Woodford et al. 2013; Bellingan et al. 2015), and the effectiveness of the project in restoring riparian vegetation has not been reported. In this short article, we present the findings of a monitoring program intended to document the initial condition of the vegetation prior to invasion by alien trees and shrubs, the effects of invasion on the vegetation, and the recovery of natural vegetation following clearing of alien vegetation along the Rondegat River. Our goal was to complement the other studies on the aquatic fauna recovery following the removal of

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[1]Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa
[2]Address correspondence to J. M. Fill, email jenna999@gmail.com


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alien bass and riparian plants, so as to provide a more complete picture of riparian ecosystem-level responses to the control measures applied.

## Methods

### Study Area

The Rondegat River (32°24′S; 19°05′E) flows in a north-westerly direction for 25 km from its source in the Cederberg Wilderness Area to its confluence with the Olifants River at the Clanwilliam Dam (Fig. 1). The catchment is underlain by sandstones of the Peninsula Formation of the Table Mountain Group, and receives approximately 700 mm mean annual rainfall, of which the majority falls in winter (June–August). The river flows through relatively pristine fynbos vegetation within the protected area, and then through privately owned land in the lower reaches. Fynbos is an evergreen shrubland associated with infertile, sandy soils in winter and aseasonal rainfall areas of southwestern South Africa (Cowling et al. 1997). The Rondegat is recognized as one of South Africa's Freshwater Ecosystem Priority Areas (Nel et al. 2011), representative of the mountain streams, upper foothills, and lower foothills of the Western-Folded Mountains, which contains a conservation-worthy assemblage of threatened and endemic fish species.

A project targeting the local eradication of alien North American smallmouth bass, *Micropterus dolomieu* (Lacepède 1802), was initiated in the lower river in 2012 (Fig. 1). In anticipation of the alien fish control project, a related project was initiated in 2010 to remove dense stands of alien trees, mainly black wattle (*Acacia mearnsii* De Wild.), blackwood (*Acacia melanoxylon* R. Br.), and gum trees (*Eucalyptus grandis* W. Hill ex Maiden), from the middle and lower reaches of the river (Impson et al. 2013). Initial alien clearing operations were carried out between July 2010 and June 2012 over 437 ha. Trees were felled, and the stumps treated with herbicides to prevent resprouting. Felled material was removed for use as firewood, or was piled on sandbanks and burnt (Impson et al. 2013). Follow-up treatments were carried out in October 2013 and between November 2015 and 2016 to remove reemergent seedlings of alien plants. Native vegetation was expected to reestablish from indigenous plants that had not been out-competed by alien plants, or from seed banks present in the soil.

### Vegetation Sampling

We sampled vegetation in the mid-to-lower section of the river (Fig. 1). We used a space-for-time substitution design to examine vegetation recovery along a continuum from uninvaded fynbos, to an invaded state, followed by clearing, and subsequent use of cleared areas as pastures for cattle (Fig. 2). We established four monitoring plots in uninvaded fynbos, four in an area still invaded by alien trees and shrubs, six in areas that had been cleared of alien trees, and four in cleared areas converted to pastures. These four land use types were intended to represent the condition of the riparian zone before and during invasion, and after clearing on land that was either allowed to return to natural vegetation, or that was used for pasture. Plots were paired, one on the eastern and one on the western bank, and oriented 1 m × 10 m perpendicular to the river (i.e. the long axis perpendicular to the bank), including the bank. Vegetation data were collected in March and October 2014, November 2015, and April 2016 to maximize our ability to detect all species present. All plant species within a plot were recorded and percentage projected canopy cover for each species was estimated. We compiled a list of all species detected on each plot during the first survey. At subsequent surveys we added any new species and their cover estimates to the list for individual plots. If a species was repeatedly recorded on a site, we averaged the cover values for that species over time, and used these average cover values in further analysis. Two invaded plots were cleared in November 2015; these were not resurveyed as they were intended to show an ongoing invaded state, and we included data collected in March and October 2014 in these plots.

### Analyses

Species encountered on the plots were assigned to six growth-form categories (tall shrubs, low shrubs, forbs, sedges, grasses, geophytes, and restios). The restio family (Restionaceae) are sedge-like perennials frequently found in seasonally saturated soils (Manning 2007). They are restricted primarily to the southern hemisphere, and particularly to fynbos (Manning 2007). Tall shrubs, low shrubs, and forbs were further recorded as either native or alien; all restios, geophytes, and sedges were native. We combined native and alien grasses due to the uncertain status of some species (e.g. there is not agreement as to whether Bermuda grass *Cynodon dactylon* (L.) Pers. is indigenous or alien). Although palmiet (*Prionium serratum* (L.f.) Drege), as a woody graminoid, may technically be considered a separate group alongside sedges and restios, we included it in the tall shrub category because of its robust growth form (Manning 2007).

We were interested in how the invaded and post-invaded states differed from the native (as a "reference level"). We were also interested in seeing how these former three states differed from each other so as to understand potential ecological concerns (e.g. particular groups that persisted or invaded, as well as native groups that colonized or persisted in these states). Because the quantile–quantile plots indicated nonnormality and transformations were unsuccessful for most of the datasets, we used the Kruskal–Wallis test to examine all possible differences among the plot types in percent cover per plot of growth forms. We used Dunn's test (R package "dunn. test") with the Bonferroni correction to conduct two-tailed post-hoc tests for differences among plot types within growth-form groups.

## Results

We detected significant differences between the plot types in the cover of alien tall shrubs ($df = 3$, $H = 13.667$, $p = 0.003$), native

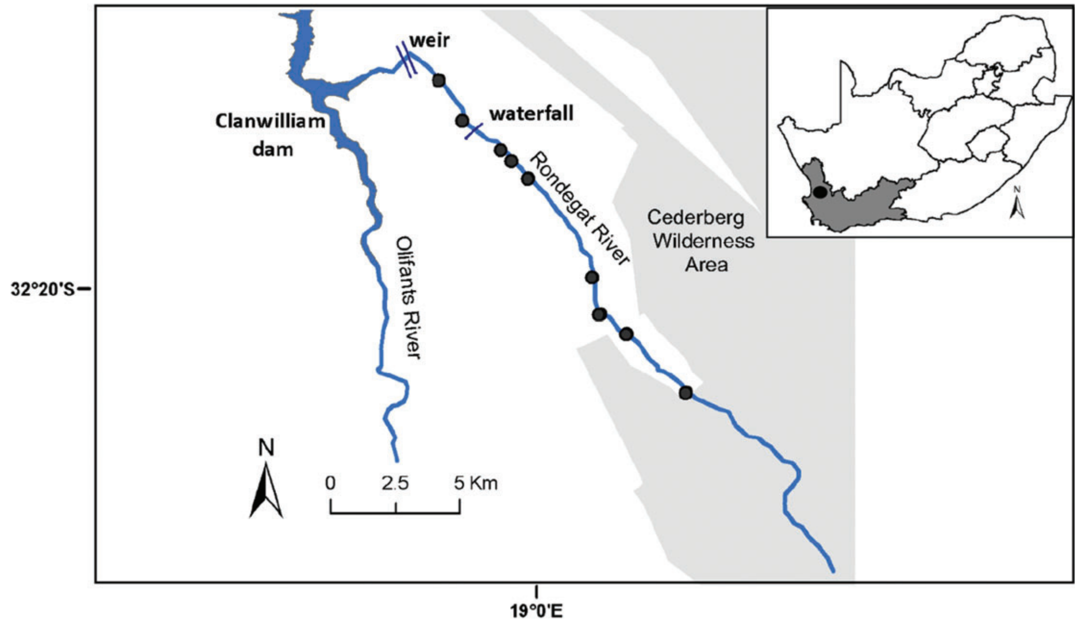


Figure 1. Location of the Rondegat River and vegetation monitoring plots (shown as dots). The inset shows the location of the study site within South Africa, and the Western Cape Province (shaded). Alien North American smallmouth bass (*Micropterus dolomieu*) were removed from the area between the waterfall and the weir, which prevents bass in the Clanwilliam Dam from reinvading the river. Alien vegetation was targeted for clearing along a portion of the river between the weir and the Cederberg Wilderness Area.

and alien grasses ($df = 3$, $H = 11.032$, $p = 0.012$), alien forbs ($df = 3$, $H = 12.478$, $p = 0.006$), and sedges ($df = 3$, $H = 13.430$, $p = 0.004$). These differences were less marked for the cover of alien and native low shrubs ($df = 3$, $H = 8.302$, $p = 0.040$, and $df = 3$, $H = 8.182$, $p = 0.042$, respectively).

Invasion of riparian vegetation by alien trees resulted in a marked reduction in the cover of indigenous shrubs and forbs (Fig. 3, Table 1). Alien tall shrubs had significantly greater cover on invaded plots than on fynbos plots ($p = 0.002$; Fig. 3). When the alien trees were cleared, indigenous shrubs recovered, and the prominence of sedges and grasses increased (Fig. 3). These latter groups had significantly greater cover in cleared areas than in the fynbos (uninvaded) plots (sedges: $p = 0.028$, grasses: $p = 0.044$; Fig. 3). Sedge cover was also significantly greater in cleared plots than in invaded plots ($p = 0.007$; Fig. 3). Although nonsignificant, grass cover was still high in pasture plots (Fig. 3). Alien forbs had significantly higher cover in pastures than in fynbos or invaded areas ($p = 0.034$; Fig. 3).

Fynbos plots had a relatively low cover of growth forms other than native shrubs and forbs (Table 1). Only two species in fynbos plots were alien (one low shrub and one forb), and cover was dominated by Palmiet (*Prionium serratum* (L.F.) Drege ex E. Mey) and native shrubs such as lance-leaved myrtle (*Metrosideros angustifolia* (L.) Sm.). Shrub cover in invaded plots was dominated by alien *Acacia* trees (Table 1). Some native tall shrubs were still present in invaded plots but with relatively low cover. Clearing reduced alien shrub cover and resulted in an increased proportion of native shrub cover (Table 1). However, native and alien grasses, particularly Bermuda grass (possibly native), perennial veldtgrass (*Ehrharta calycina* Sm., native), and Vaseygrass (*Paspalum urvillei* Steud., alien), increased in cleared plots and maintained high cover in pasture plots (Fig. 3), despite the recovery of native shrubs after clearing.

## Discussion

An implicit assumption underlying the removal of invasive alien trees along the Rondegat River was that the natural vegetation would return without further interventions (passive restoration). We found that clearing greatly reduced alien plant cover, and this allowed the remnant native shrubs to recover. Native species richness was also much higher in cleared sites and in pastures than in invaded sites (Table 1). The persistence of indigenous shrubs and the high native species richness suggest that, given time, these areas could approach greater similarity to native communities, and that there may be no need for active restoration.

However, there was also a rapid secondary invasion of cleared sites by alien and native weedy grasses. Clearing invasive nitrogen-fixing alien *Acacia* species is known to increase the growth rates of weedy native grasses such as perennial veldtgrass, and although this increased growth might not persist if grazing were halted (Fisher et al. 2009), it might still take several years for soil nutrients and processes to return to preinvasion levels (Nsikani et al. 2017). Because there is little long-term information about ecosystem trajectories following secondary invasion (Pearson & Ortega 2009), continued monitoring should provide information that could inform decisions on whether to intervene at a later stage. For example, exotic grasses dominated in agricultural sites in Argentina after 20 years following abandonment

Figure 2. A section of the Rondegat River before clearing of alien trees and shrubs (top) and after clearing (bottom).

(Tognetti et al. 2010). Secondary dominance, especially by grasses that are invasive, can have strong effects on ecosystem dynamics and may require additional active management (Symstad 2004). For example, cheatgrass strongly alters fire regimes in ecosystems of the western United States (Brooks et al. 2004). Because the species is favored by fire, active

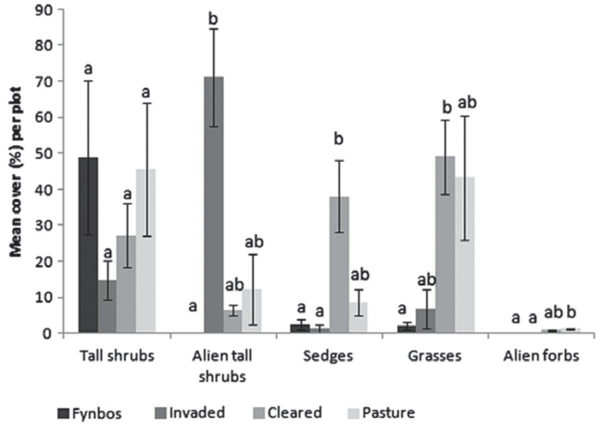


Figure 3. Mean (±SE) percent cover of growth forms on vegetation monitoring plots along the Rondegat River. Different letters indicate significant differences among the plot types. We included native tall shrubs despite no significant differences due to their value for restoration and therefore to provide a visual assessment of trends in cover.

restoration methods are often necessary to restore communities invaded by cheatgrass (Brooks et al. 2004) Thus, although little information is available for fynbos, it is possible that active restoration could be necessary to restore native riparian communities, including removal of secondary species and planting of native species, which could assist in restoring soil characteristics (Nsikani et al. 2017).

Our findings provide an initial baseline reference for future monitoring and adaptive management decisions. Despite the importance of monitoring, it is seldom included, let alone required, in river restoration projects (Bash & Ryan 2002). Organizational and financial barriers to monitoring exist in South Africa as they do elsewhere; yet monitoring needs to be included in the planning of projects, and it needs to be continually accounted for when allocating funds (van Wilgen et al. 2012; van Wilgen & Wannenburg 2016). In this case, although funding for alien plant clearing was derived from one source, funding for plant monitoring was opportunistically sourced from other funds for aquatic biota surveys. This funding

**Table 1.** Mean (± SE) percent cover of growth forms on 18 plots along the Rondegat River, South Africa, and total number of species in each plot category (the categories were: fynbos—natural vegetation that had never been invaded; invaded—areas with dense cover of alien trees; cleared—areas where previously dense invasions had been cleared, and allowed to return to natural vegetation; and pasture—areas where previously dense invasions had been cleared, and were used as pastures).

| *Growth Form* | *Fynbos* | *Invaded* | *Cleared* | *Pasture* |
|---|---|---|---|---|
| Tall shrub | 48.9 (21.5) | 14.7 (5.4) | 27.3 (8.8) | 45.6 (18.6) |
| Alien tall shrub | 0.0 (0.0) | 71.1 (13.6) | 6.5 (1.5) | 12.2 (9.8) |
| Low shrub | 0.9 (0.1) | 0.3 (0.3) | 3.3 (1.5) | 2.0 (0.6) |
| Alien low shrub | 0.4 (0.2) | 0.0 (0.0) | 0.0 (0.0) | 0.4 (0.2) |
| Forb | 49.9 (15.9) | 6.6 (3.8) | 11.6 (6.1) | 5.9 (2.1) |
| Alien forb | 0.0 (0.0) | 0.0 (0.0) | 0.8 (0.3) | 1.3 (0.2) |
| Sedge | 2.4 (1.4) | 1.3 (1.1) | 38.1 (9.9) | 8.6 (3.5) |
| Grass | 2.0 (1.1) | 6.8 (5.4) | 49.1 (10.3) | 43.4 (17.2) |
| Geophyte | 2.3 (1.3) | 0.0 (0.0) | 1.9 (1.4) | 2.4 (1.4) |
| Restio | 4.0 (1.9) | 0.4 (0.2) | 0.7 (0.5) | 0.0 (0.0) |
| Total number of species | 27 | 26 | 69 | 60 |

is short term and it is unknown whether there will be funds for future surveys. Without monitoring, especially over the long term, practitioners would be limited in their ability to assess progress toward the achievement of restoration objectives. The authors of a survey of river restoration projects over two decades in California concluded that because monitoring was seldomly implemented, any lessons that may have arisen from experience in these projects had to be derived from anecdotal accounts, and was consequently of much lower value (Kondolf et al. 2007). Repeated surveys of restoration outcomes should further our understanding of the long-term potential for success and the relative importance of annual fluctuations of recovery indicators (Muotka et al. 2002; Louhi et al. 2016).

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