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Active restoration of woody canopy dominants in degraded South African semi-arid thicket is neither ecologically nor economically feasible

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Keywords
Active biodiversity restoration; Restoration ecology; Restoration economics; Restoration efficiency; Restoration success; Subtropical thicket

Abbreviations
CART = classification and regression tree; STRP = Subtropical Thicket Restoration Programme; ZAR = South African Rand

Nomenclature
Germishuizen & Meyer (2003).

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Abstract

Question: Will the planting of nursery-propagated woody canopy species within severely degraded Arid Subtropical Thicket once dominated by the succulent shrub *Portulacaria afra* (Spekboom) be an efficient restoration strategy to employ in addition to the current restoration protocol of planting a monoculture of *P. afra* truncheons?

Location: Krompoort, a farm located on the northern footslopes of the Groot Winterhoek mountains, near Kirkwood, Eastern Cape, South Africa.

Methods: We planted, in degraded, intact and three differently aged post-restoration (*P. afra* truncheons) sites, nursery-propagated individuals of two woody canopy dominants (*Pappea capensis* and *Searsia longispina*), and two inter-canopy shrubs (*Lycium ferocissimum* and *Rhigozum obovatum*) in Sep 2008 (spring). The experiment was repeated again in May 2009 (autumn) and a succulent canopy species (*P. afra*) was added. We assessed restoration success in terms of the survival of planted individuals after 24 mo (spring planting) and 12 mo (autumn planting). The estimated cost of a restoration effort to establish two woody canopy dominant species with the large-scale planting of *P. afra* was calculated and compared with that of the already established protocol of planting only *P. afra* truncheons.

Results: Survival after spring (24 mo) and autumn (12 mo) plantings of the two woody canopy species was less than 5%, whereas survival of *L. ferocissimum* was low (19%), *R. obovatum* good (70%) and *P. afra* excellent (100%). Contrary to expectations, survival was not related to a gradient of intactness encompassing degraded, restoration and intact treatments that are associated with increasing biomass and soil carbon. The costs of incorporating the four woody canopy species into the restoration programme's protocol were 2.4 times the costs of restoring with *P. afra* alone.

Conclusions: Planting propagules of canopy species other than *P. afra* is likely to render the programme economically unfeasible, depending on the price of carbon. We conclude that biodiversity goals for the restoration programme are better achieved via spontaneous recruitment of woody canopy and other species, even though this may take more than 40 yr post restoration.

Introduction

Restoring the full complement of species, functions and services of degraded ecosystems is difficult to achieve (Ruiz-Jaen & Aide 2005; Benayas et al. 2009). However, restoration interventions should, at minimum, aim to restore viable populations of the functional groups that sustain the resilience and stability of the system (SERI (Society for Ecological Restoration International Science & Policy Working Group) 2004). This can be done via active restoration of populations of these species, or by providing evidence of their return through spontaneous colonization. Restoration projects often fail to achieve this owing to poorly formulated goals that are based on an inadequate

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understanding of the ecological functioning of the target ecosystem (Hobbs & Norton 1996; Young et al. 2005; Hobbs 2007), and/or a poor appreciation of the socio-economic constraints on achieving restoration goals (Milton et al. 2003).

Here we focus on the restoration of woody canopy species of South African subtropical thicket, which is centred on coastal forelands of the Eastern Cape Province, and is part of a global biome of semi-arid, rainforest-like vegetation whose origin dates to the mid Cenozoic (Cowling et al. 2005). Component woody canopy (2–5 m) plants (e. g. *Euclea undulata*, *Gymnosporia* spp., *Pappea capensis*, *Portulacaria afra*, *Schotia afra* and *S. longispina*) are long-lived and reproduce mainly via ramets, or occasionally via seedlings that originate mostly from vertebrate-dispersed propagules (Midgley & Cowling 1993; Cowling et al. 1997; Sigwela et al. 2009). While relatively resilient to browsing by indigenous herbivores (Stuart-Hill 1992), subtropical thicket is highly vulnerable to browsing by domestic goats. Sustained heavy browsing by goats can transform the dense closed-canopy shrubland into an open community comprising scattered and degraded thicket clumps and isolated trees in a matrix of ephemeral herbs (Hoffman & Cowling 1990; Stuart-Hill 1992; Moolman & Cowling 1994; Kerley et al. 1995; Lechmere-Oertel et al. 2005a,b) (see The Supporting Information, Photographs S1a and S1b). Particularly vulnerable are drier (<450 mm·yr^{-1}) forms of thicket (Arid and Valley forms) (Vlok et al. 2003) dominated by the tree-like leaf succulent, *P. afra* Jacq. (Stuart-Hill 1992; Lechmere-Oertel et al. 2005a,b). Of the 16 942 km^{2} of solid (unbroken canopy) thicket with a substantial *P. afra* component, 46% has been heavily degraded and 36% moderately degraded by domestic herbivores (Lloyd et al. 2002). *Portulacaria afra* is the first canopy dominant to succumb to browsing and is completely eliminated in severe cases of degradation.

Excessive browsing of *P. afra*-dominated thicket by goats reduces natural capital by reducing species diversity (Moolman & Cowling 1994; Lechmere-Oertel et al. 2005a), above- and below-ground carbon (C) stocks (Mills et al. 2005a,b), soil quality (Mills & Fey 2004; Lechmere-Oertel et al. 2005a) and plant productivity (and hence livestock and game stocking capacity) (Stuart-Hill & Aucamp 1993). Differences in plant productivity between degraded and intact thicket are especially apparent during drought years (Stuart-Hill & Aucamp 1993). Degradation also reduces the availability of wood, fruit and medicines for local communities, with a potential financial loss of ca. $150 per annum per household (Cocks & Wiersum 2003).

Spontaneous recovery of populations of canopy species (including *P. afra*) does not occur in browsing-degraded Arid and Valley forms of subtropical thicket (Stuart-Hill & Danckwerts 1988; Lechmere-Oertel et al. 2005a; Sigwela et al. 2009). Propagules of canopy species, both ramets and genets, are invariably associated with the rich layer of organic mulch that accumulates beneath the intact thicket canopy (Sigwela et al. 2009). Browsing by goats initially destroys the canopy skirt on the edge of thicket clumps (Stuart-Hill 1992), thereby altering the beneath-canopy microclimate and destroying the rich layer of organic mulch (Lechmere-Oertel et al. 2008). Deprived of an organically enriched soil medium, and subject to browsing higher up on the canopy, adult plants eventually die, thicket clumps steadily dwindle (Lechmere-Oertel et al. 2005a) and no new recruits appear (Sigwela et al. 2009). The ecosystem is locked into a degradation trajectory that can only be reversed by active restoration.

The recent emergence of the global carbon economy has provided an unprecedented opportunity to finance the restoration of degraded thicket via carbon credits (Mills et al. 2007, 2010; Marais et al. 2009). *Portulacaria afra*-dominated ecosystems store carbon in excess of 200 t·ha^{-1} (measured up to a soil depth of 50 cm), a remarkable feature for a xeric ecosystem and comparable to that of mesic forest ecosystems (Mills et al. 2005a). Most of this carbon stock is associated with *P. afra* (Mills & Cowling 2006; Lechmere-Oertel et al. 2008) and its dense canopy provides the relatively cool and dry conditions necessary for the accumulation of the extraordinarily high levels of soil carbon (Lechmere-Oertel et al. 2005a,b; Cowling & Mills 2010). Comparisons of degraded and intact sites reveal carbon losses of more than 80 t C·ha^{-1} (Mills 2003; Mills et al. 2005b). These losses are evident from the decrease in above-ground biomass, but also manifest in a massive reduction in soil organic carbon content (Mills & Fey 2004). Exploiting the opportunity provided by a long-standing (1976–1998) *P. afra* restoration trial implemented by a landowner to reduce soil erosion from degraded slopes, Mills & Cowling (2006) found that 112 t C·ha^{-1}·yr^{-1}, at a rate of 4.2 t C·ha^{-1}·yr^{-1}, was sequestered in this 27-yr period. These data provided the impetus for the South African government to fund *P. afra* restoration research and implementation. This initiative has the broad aim of creating an employment-intensive restoration economy funded by the carbon market; importantly, restoration must also achieve explicit biodiversity goals (Marais et al. 2009; Mills et al. 2009).

The current methodology for the restoration of degraded *P. afra* thicket involves planting, in closely packed parallel rows, *P. afra* truncheons (height 250–650 mm; stem diameter: 15–35 mm) sourced from surrounding areas that are still relatively intact (Mills et al. 2007). The rationale for this is that, unlike other canopy species, *P. afra* establishes readily from truncheons. Furthermore, it evidently plays a key functional role in terms of its ability to rapidly sequester carbon and create microsite conditions suitable for the

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recruitment of other canopy species (Mills & Cowling 2006; Sigwela et al. 2009). Large-scale restoration is underway through the initiative of the Subtropical Thicket Restoration Programme (STRP) administered by the Working for Woodlands project of the Department of Environmental and Water Affairs (Marais et al. 2009; Mills et al. 2010). Starting in 2004, some 1630 ha have been thus restored in protected areas in the Eastern Cape Province.

A defensible biodiversity goal is that restored sites should resemble intact reference sites in terms of structure and function at the end of the restoration phase (SERI 2004; Mills et al. 2010). Given the absence of recruitment of canopy species in degraded thicket (Sigwela et al. 2009), it is uncertain when, and if, these species will establish in sites restored by planting *P. afra* truncheons. Furthermore, as above- and below-ground carbon increases with restoration age (Mills & Cowling 2006), it is reasonable to expect that survival of planted propagules of canopy species would be greater in the older than younger restoration sites. In this paper, we investigate these issues by planting nursery-propagated propagules (seedlings and/or cuttings) of two woody canopy species (*P. capensis* Eckl. & Zeyh. and *S. longispina* Eckl. & Zeyh.), that are co-dominant with *P. afra* in Arid Thicket (Vlok et al. 2003) in different aged *P. afra* restoration sites as well as in adjacent degraded and intact thicket. In order to assess the effects of propagation, transport and transplanting, we also planted, in the same sites, individuals of two woody species (*Lycium ferocissimum* Miers and *Rhigozum obovatum* Burch.). These grow in interclump patches or on clump margins in Arid Thicket (Vlok et al. 2003) and have distributions that extend into adjacent, more arid, Nama-karoo communities. We expected better survival of these two species than the two canopy ones across all restoration treatments,. As *P. afra* is the focal species for large-scale restoration initiatives, we also planted rooted truncheons of *P. afra* in all sites in order to evaluate its performance relative to the other species. We expected good survival across all sites. Finally, using a costing structure applied in the STRP, we compared the restoration costs of establishing the two woody canopy species compared with the costs of establishing only *P. afra*.

Methods

Study site

We used the same site (Krompoort farm) as that used by Mills & Cowling (2006) to estimate carbon sequestered during *P. afra* restoration. Mills & Cowling (2006) provide salient details on the site that we do not repeat here. The site vegetation is a form of Arid Thicket (Sundays Spekboom Veld) (Vlok et al. 2003) that has been extensively degraded (see the Supporting Information, Appendix S1). It is located on a gentle north-facing slope 320–400 m above sea level, and receives a mean annual precipitation of 317 mm per annum (measured between 1970 and 2009) with peaks in the autumn and spring months (Fig. 1). However, heavy rainfall can be expected in any month of the year. Rainfall recorded during the course of our experiments from Sep 2008 to Sep 2010 was more-or-less typical for the site (Fig 1).

As described by Mills & Cowling (2006), between 1976 and 1998, the Krompoort landowner planted *P. afra* cuttings at regular intervals. Cuttings were planted in rows spaced between 4.1 and 1.5 m, with the space between plants ranging from 0.8 to 1.1 m. The landowner sourced cuttings for most plantings from a montane site ca. 90 km to the northwest of Krompoort. This form of *P. afra* has an upright growth form and tends not to develop a ‘skirt’ at ground level, a feature of almost all other forms. In order to provide a range of post-restoration ages, we selected the youngest site (11 yr), an intermediate site (19 yr) and the oldest site (33 yr) (all dates as of 2009). We also selected an intact and a degraded site in close proximity to the restored sites (see the Supporting Information, Appendix S2).

Planting and survival

We chose five species for the restoration experiments: three thicket canopy species (*P. afra*, *P. capensis*, *S. longispina*) and two species (*L. ferocissimum* and *R. obovatum*) that grow in interclump areas or on clump margins. All species were propagated as seedlings or cuttings using standard

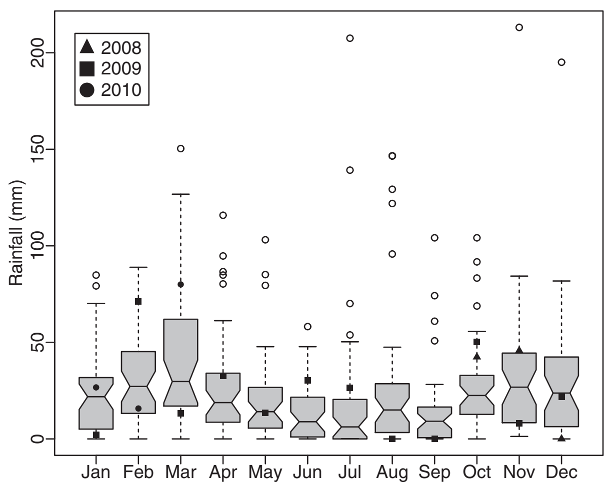

Fig. 1. Boxplots showing monthly rainfall measured at the Krompoort study site over a period of 39 yr (Jan 1970 to Sep 2008). Broad lines indicate medians, boxes indicate the lower and upper quartiles (i.e. 25% and 75% of the distribution), whiskers indicate the sample minimum and maximum, and unfilled circles show outliers. Also shown is monthly rainfall ranging from Oct 2008 to Mar 2010.

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nursery protocols (see the Supporting Information, Appendix S3) at the STRP nursery located 151 km by road from Krompoort. We use the term propagule for both cuttings and seedlings. All propagules were hardened off before planting in the field.

We planted the first batch of propagules during the last week of Sep (spring) 2008. This batch comprised 306 plants that included seedlings of *P. capensis* and *R. obovatum* and cuttings of *S. longispina* and *L. ferocissimum* (Table 1). We planted the second batch during May (autumn) 2009, comprising 387 propagules, of which 308 were the same species as the previous planting, plus 79 rooted cuttings of *P. afra* (logistic constraints precluded a spring batch for this species). Spring and autumn were chosen as planting periods to coincide with the two annual rainfall peaks recorded for the area (Fig. 1). We expected autumn-planted propagules to show higher survival than those planted in spring because they have to contend with high evapotranspiration demand during the ensuing hot summer months, shortly after being planted (Ehleringer & Sandquist 2006).

We planted the propagules in randomly located holes dug 50 mm deeper and wider than their 4-L container bags, in order to enable root expansion and to create a trough for the accumulation of water. All propagules were watered up to and including the day of planting but not thereafter. The damp soil containing the propagule (watered *in situ*) from the container bag were planted into dry soil. As thicket canopy recruits show a strong preference for shaded sites, we assessed the degree of canopy shading of each planted propagule according to the following scale: 0 = no shade, 1 = shade from one direction, 2 = shade from two directions, 3 = shade from three directions, 4 = shade from four directions, 5 = complete shade (four directions and above).

We assessed for survival of propagules by scoring them as dead or alive, 24 mo after the Sep 2008 planting and 12 mo after the May 2009 planting. We modelled the effect of species, treatment and canopy cover (covariates) on survival using conditional inference trees [a type of classification and regression tree (CART)]. These differ from standard CARTs in that they use a permutation-based statistical framework to ensure an even-handed selection of covariates and to stop splits being formed if they are not significant at some pre-specified level of significance (we used the 5% level of significance). The *P*-values were adjusted for multiple testing using the Bonferroni correction. The method is non-parametric, includes interactions in the model where necessary, is based on a sound theoretical framework and has been shown by its authors to give results that are comparable to those of traditional CARTs, but without their failings (overfitting and a biased selection of covariates when forming splits) (Hothorn et al. 2006). The analysis was performed with R (R Development Core Team 2010, R Foundation for Statistical Computing, Vienna, Austria) supplemented by the contributed packages of lattice (Sarkar 2008), Hmisc (Harrel et al. 2010) and party (ctree) (Hothorn et al. 2006).

Restoration costs

We used the Working for Woodlands costing structure, as applied in the STRP, for estimating the costs of restoring degraded veldt using *P. capensis* and *S. longispina*, the two woody canopy species. These costs are government subsidized, based on actual costs to the project and far below actual commercial rates. We estimated the costs of propagation of seedlings and cuttings, using the values South African Rand (ZAR) 3.81 per cutting and ZAR 4.02 per seedling provided by M. McConnachie (pers. comm. Rhodes Restoration Research Group). We estimated the planting cost based on the costs incurred by a typical contract team to plant rows of *P. afra* cuttings in a 30 ha area of degraded thicket in Addo Elephant Park, as of Oct 2009. Based on the Working for Woodlands restoration protocol, we estimated that a 30 ha site would take a team of 12 people 20 d to plant 4800 propagules at the requisite density of 160 plants·ha^{-1} (80 plants·ha^{-1} per species). We based the rate of planting per species (60 plants·ha^{-1} planted by a team of three people) on our estimates from the experimental planting. Planting costs include transport, labour, administration, equipment, subsistence and capital build-up. Capital build-up refers to the contractor's

Table 1. Number of propagules planted per treatment during two seasons (spring and autumn).

Species	Sep 2008					May 2009					Totals
	Dgrd	Rs11	Rs19	Rs33	Intc	Dgrd	Rs11	Rs19	Rs33	Intc	
Pappea capensis	15	14	17	15	14	16	13	16	15	16	151
Searsia longispina	16	17	16	14	19	15	15	15	15	15	157
Lycium ferocissimum	15	13	15	15	15	15	15	15	15	17	150
Rhigozum obovatum	15	16	15	16	14	17	15	16	16	16	156
Portulacaria afra	–	–	–	–	–	15	16	16	16	16	79

Dgrd, degraded stand; Intc, intact stand; Rs, restored stands where the number appended refers to the number of years under restoration treatment.

profit which, in theory, is to be used for growing the enterprise; it is calculated at 20% of the wage cost. We added to the transport costs the cost of transporting propagules the distance of 200 km between the nursery and the Addo restoration site. We did not include training costs in our overall estimate.

Results

Survival

For the two woody canopy species, *Pappea capensis* and *Searsia longispina,* survival was very low across all treatments and planting duration/times, with an overall value of 3% (range 0–25% across treatments) for the former, and 1% (range 0–7%) for the latter species (Fig. 2). For both species, there was no significant difference in the frequency of surviving propagules between treatments although *P. capensis* showed a significant difference ($\chi^2 = 5.27$, $P = 0.022$) between planting duration/time. *Portulacaria afra*, a succulent canopy species, showed 100% survival across all treatments 12 mo after the autumn planting. The two woody non-canopy species survived considerably better than the woody canopy ones. For *Lycium ferocissimum*, overall survival for both plantings was 19%; values across treatments ranged from 0% to 53% for the autumn planting, and 0% to 13% for the spring planting (the duration/time effect was significant: $\chi^2 = 11.6$, $P < 0.001$). There was a significant treatment effect only for the autumn planting ($\chi^2 = 15.0$, $P < 0.01$); however, survival was unrelated to restoration status of treatments. Overall survival of *Rhigozum obovatum* was 70%; values across treatments ranged from 69% to 100% after the autumn planting, and 56% to79% after the spring planting (the duration/time effect was not significant: $\chi^2 = 0.0193$, $P = 0.8896$). There was a significant treatment effect only for the autumn planting ($\chi^2 = 11.0$, $P < 0.05$); however, this was largely a consequence of total survival of propagules planted in the intact site.

The conditional inference tree analysis of survival of propagules planted in Sep (spring) 2008 and assessed after 24 mo showed primarily a species effect (high survival of *R. obovatum*) and low survival of the other species, and a canopy effect for the low-survival group less than zero survival in microsites with a canopy score > 3 (Fig. 3). The analysis for the May (autumn) 2009 planting also showed a primary species effect, separating high-survival species (*P. afra*, *R. obovatum*) from moderate (*L. ferocissimum*) and low-survival species, *S. longispina* and *P. capensis*), which were separated at the next node (Fig. 4). *Lycium ferocissimum* showed a treatment effect, with older restoration treatments having lower survival than the other treatments. Survival of propagules of the two woody canopy species, *S. longispina* and *P. capensis*, was significantly higher in microsites with a shading score > 3.

Restoration costs

The total cost of restoring an area of 30 ha with the two woody canopy species used in our experiments was ZAR 72 252 (Table 2). This amounts to an average rate of ZAR 2408 or ZAR 602 ha^{-1} per species planted at a density of 80 propagules·ha^{-1}. Some 30% of the costs were associated with nursery propagation and transport of propagules to the restoration site. The costs of planting locally harvested truncheons of *P. afra* alone in the same area, as per Working for Woodland specifications, amounted to ZAR 50 560, or ZAR 1 685 ha^{-1}. Should the planting of *P. afra* as well as the two canopy species be incorporated as a restoration protocol for the STRP, then the total restoration costs would climb to ZAR 122 812 at a rate of ZAR 4094 ha^{-1}. This is 2.4 times greater than the cost of restoring with *P. afra* alone.

Discussion

Our study suggests that the restoration of woody canopy species in degraded Arid Thicket (spekboomveld) is neither ecologically nor economically feasible. Survival of the two woody canopy species, *Pappea capensis* and *Searsia longispina*, was so low as to be negligible. Moreover, survival showed no relationship with post-restoration age, despite this being associated with increasing cover, increasing aboveground biomass and increasing soil carbon (Mills & Cowling 2006), all factors that should, in theory, be associated with improved establishment and growth of thicket recruits (Holmes & Cowling 1993; Midgley & Cowling 1993; Sigwela et al. 2009). However, survival of both species was positively influenced by canopy cover, suggesting some nurse-effect associated with the shade cast by existing vegetation (Holmes & Cowling 1993). The two canopy species probably require a succession of high rainfall events spread over several months, and dense shading for survival and growth of propagules. The odds of the former are very low in the semi-arid thicket environment; the latter is not a feature of degraded thicket requiring restoration. Furthermore, woody canopy species recruit spontaneously in *Portulacaria afra*-restored degraded thicket having a post-restoration age of ca. 40 yr (M. L. van der Vyver et al., unpublished data).

The fact that we recorded moderate and good survival of *Lycium ferocissimum* and *Rhigozum obovatum*, respectively, suggests that transport from the nursery and planting methods were not responsible for the low survival of the two woody canopy species. The former species are associated with more xeric environments than the canopy ones

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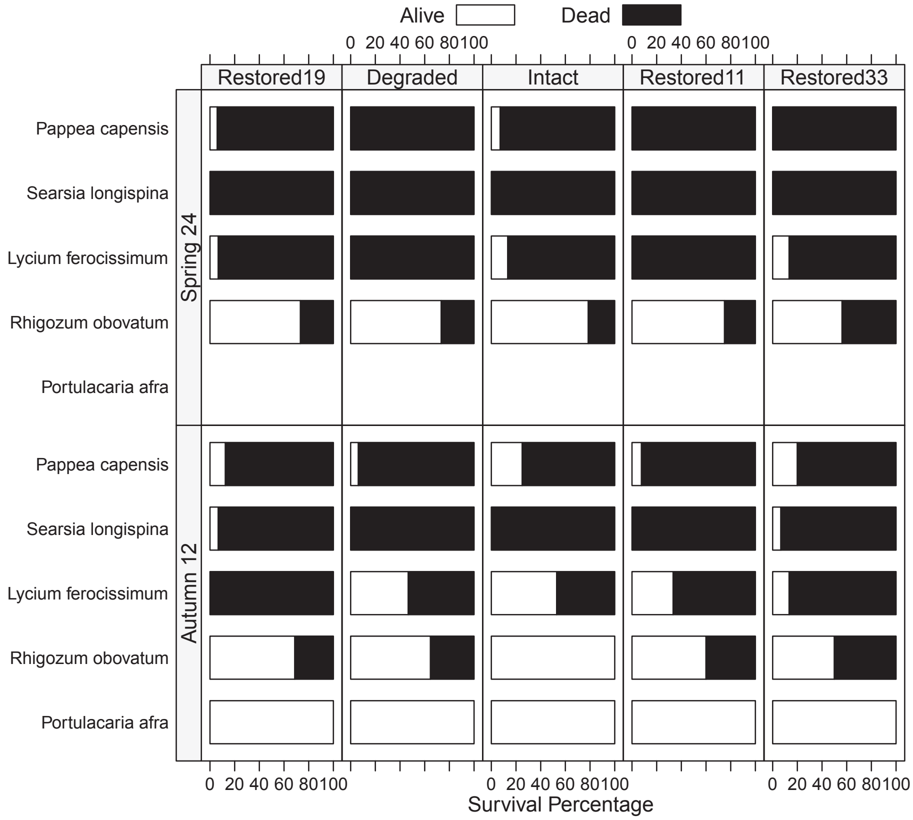

Fig. 2. Survival of propagules of five species planted in degraded, restored and intact Arid Thicket. The number appended to the name of the restored sites is post-restoration age. Spring 24 refers to the survival assessment 24 mo after the planting in Sep 2008 (spring) and Autumn 12 refers to the survival assessment 12 mo after the May 2009 (autumn) planting.

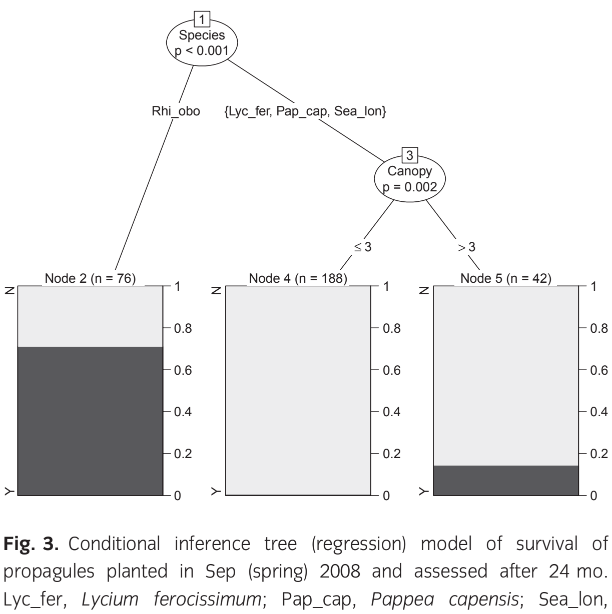

Fig. 3. Conditional inference tree (regression) model of survival of propagules planted in Sep (spring) 2008 and assessed after 24 mo. Lyc_fer, *Lycium ferocissimum*; Pap_cap, *Pappea capensis*; Sea_lon, *Searsia longispina* and Rhi_obo, *Rhigozum obovatum*. The *y*-axis of each terminal panel shows the proportion of propagules that survived (Y/filled) compared with those that died (N/tinted).

and can cope better with the harsh, post-planting constraints on plant function (Ehleringer & Sandquist 2006). Both species survived significantly better after autumn planting; whether this is a response to a cooler post-planting environment, or just a matter of time (survival was assessed 12 mo after the autumn planting and 24 mo after the spring planting), is impossible to say. Despite the higher survival, almost all individuals of both species showed negative growth over the duration of the experiment (M.L. van der Vyver, unpublished data). Nonetheless, both species show promise for small-scale restoration projects where achieving biodiversity goals are paramount. *Lycium ferocissimum* produces regular and large crops of fruits attractive to numerous birds and may well play a keystone role in the establishment of seedlings of woody canopy species that are similarly dispersed (Skead 1967).

Restoration goals must strive to be realistically cost-effective (Aronson et al. 2006). The costs of incorporating the two woody canopy species into the STRP restoration protocol were more than double the costs of restoring with *P. afra* alone. Our propagation cost estimates were based on actual costs obtained from a government subsidized

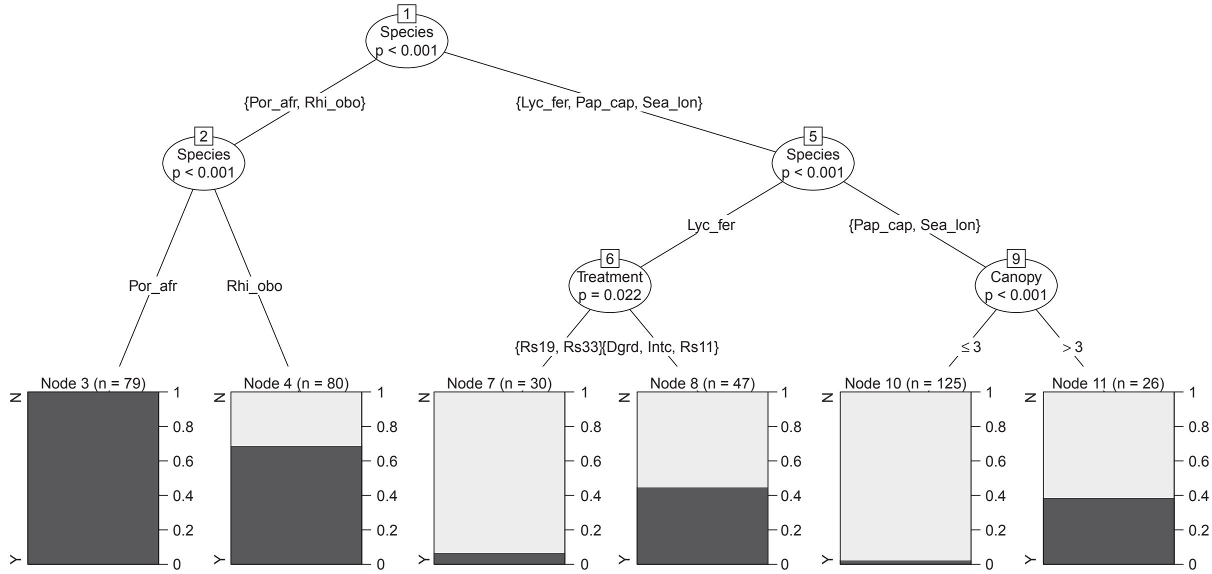

Fig. 4. Conditional inference tree analysis of survival of propagules planted in autumn 2009 and assessed after 12 mo. Rs33, Rs19 and Rs11 are abbreviations for the different aged restoration treatments with appended numbers indicating post-restoration age. Por_afr, Lyc_fer, Pap_cap, Sea_lon and Rhi_obo are species name abbreviations (see Table 1 for full names). The *y*-axis of each terminal panel shows the proportion of propagules that survived (Y/black) compared with those that died (N/grey).

Table 2. Summary of cost estimation for planting an area of 30 ha with nursery propagated cuttings and seedlings of two canopy species by a typical Working for Woodlands contractor team.

Cost item	Amount (ZAR)
Propagation	
2400 cuttings (ZAR 3.81) each	9144
2400 seedlings (ZAR 4.02) each	9648
Propagation subtotal	18 792
Planting	
Transport	10 384
Labour	19 445
Equipment	10 192
Administration	1230
Subsistence	8320
Capital build-up	3889
Planting subtotal	53 460
Total	72 252

Units are in South African Rand (ZAR). Capital build-up refers to the contractor's profit for completing the contract, and is calculated at 20% of wage cost. The estimation involves a total number of 4800 propagules planted at a density of 80 plants·ha^{-1} per species. See text for more details.

nursery and thus actual commercial costs for a similar venture would be much higher. As the STRP is a real-world restoration programme, where restoration costs must be financed by trading carbon credits (Galatowitsch 2009; Mills et al. 2009), planting propagules of canopy species other than *P. afra* would erode profit margins and is likely to render the STRP economically unfeasible, depending on the price of carbon.

Survival of *P. afra* cuttings was 100% across all treatments. Hence, *P. afra* is an ideal candidate for restoring degraded thicket. (Survival of locally harvested truncheons is lower than this and depends on a suite of factors that are the subject of ongoing investigation.) The species is also responsible for rapidly restoring canopy cover and above- and below-ground carbon and, hence, the ecological features that underpin thicket structure and functioning (Lechmere-Oertel et al. 2005a,b, 2008; Mills & Cowling 2006, 2010; Sigwela et al. 2009). However, in order to achieve certification for carbon trading, the STRP needs to demonstrate that its restoration protocol will yield more than a monoculture of *P. afra* (Bekessy & Wintle 2008). Fortunately, as pointed out above, woody canopy and other species recruit in sufficient numbers in sites with a post-restoration age (*P. afra* truncheons only) of greater than 40 yr, resulting in a compositional structure that is indistinguishable from intact thicket (M. L. van der Vyver et al., unpublished data). Hence, achieving biodiversity restoration goals for spekboomveld does not require costly restoration of woody canopy species. This will save the STRP a considerable amount of money and make the project more attractive to investments from the growing carbon economy.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Photo S1a & b. Fenceline contrasts in areas near Krompoort study area showing intact and degraded Spekboom-dominated thicket.

Appendix S1. Location map of the experimental site Krompoort.

Appendix S2. Google Earth© image of Krompoort study area.

Appendix S3. Nursery propagation methods.

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