Spekboom Thicket Restoration Research

Achievements, Current research & Goals

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Promoter: Prof. Richard Cowling

Nelson Mandela Metropolitan University
for tomorrow

Gamtoos-Besproeiingsraad
Gamtoos Irrigation Board

NRF

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Deserti

Finally, we find no strong evidence, other than for the Noorsveld, to support Acocks' (1953) assertion that the karoo has expanded into the south-eastern Cape river valleys at the expense of sub-tropical thickets. The community changes shown in this study, nonetheless, have profound relevance for long-term agricultural productivity in the region. Desertification implies a conversion from more productive to less productive states (Acocks, 1953; United Nations, 1978; Roux & Theron, 1987). This is true for all the FLC sites in areas of sub-tropical thicket, which showed a general decline in cover of mid-high and tall evergreen trees and shrubs and utilizable succulents, and an increase in dwarf and

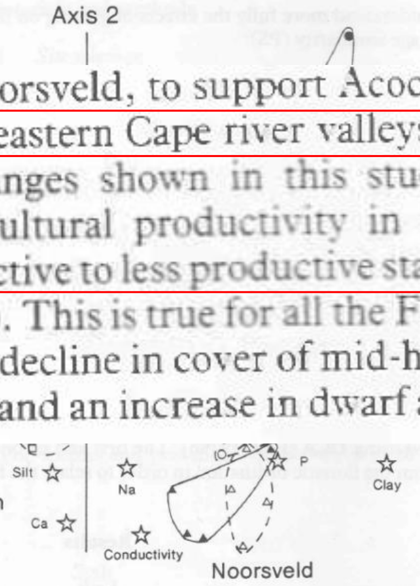


Figure 3. Correspondence analysis ordination of the first two axes for soil variables (0–50 mm depth) from four veld types (Acocks, 1953) in the lower Sundays River Valley. Closed symbols indicate control sites; open symbols indicate fence-line contrast (continuously-grazed) sites (see text).

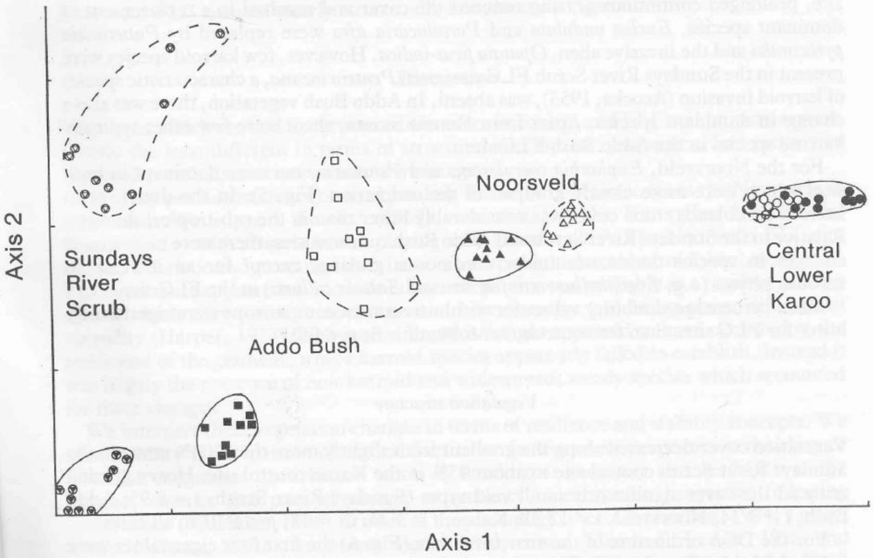
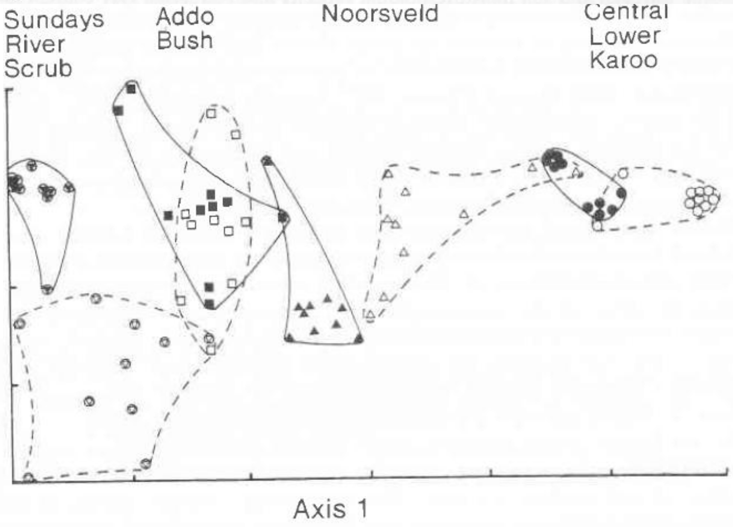


Figure 5. Detrended correspondence analysis (DCA), ordination of floristic data from 80 plots from four veld types in the lower Sundays River Valley. Closed symbols indicate control sites; open symbols indicate fence-line contrast (continuously grazed) sites (see text).



igure 6. Detrended correspondence analysis (DCA), ordination of structural data from 80 plots rom four veld types in the lower Sundays River Valley. Closed symbols indicate control sites; open ymbols indicate fence-line contrast (continuously grazed) sites (see text).

Effects of elephants and goats on the Kaffrarian succulent thicket of the eastern Cape, South Africa

G.C. STUART-HILL*

Journal of Applied Ecology
1992, **29**,
699–710

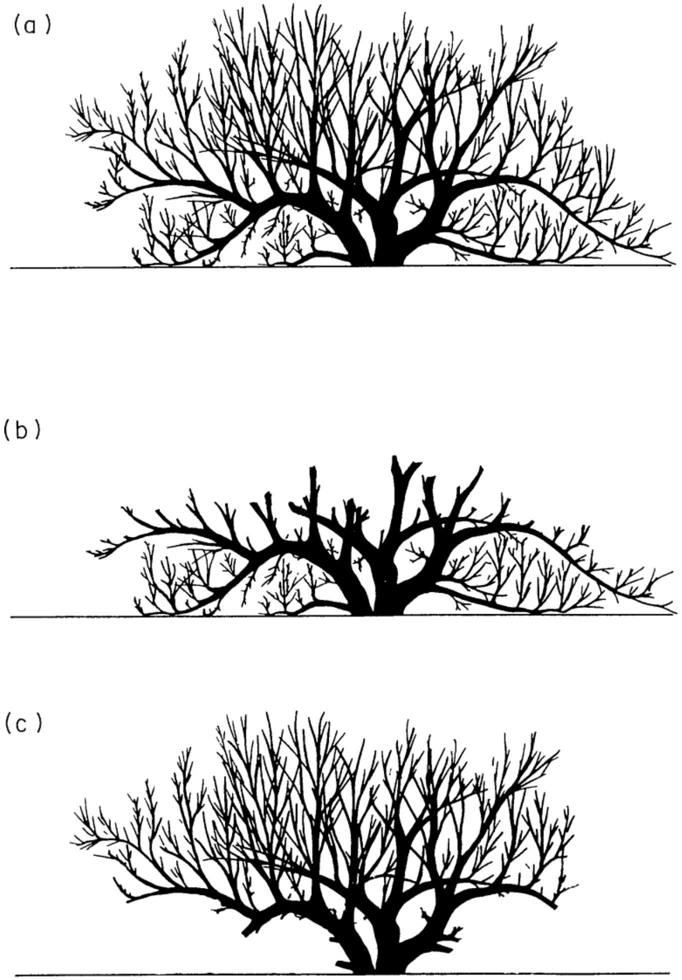


Fig. 1. Effect of (a) no browsing, (b) elephant browsing and (c) goat browsing on the growth habit and vegetative propagation of *Portulacaria afra*.

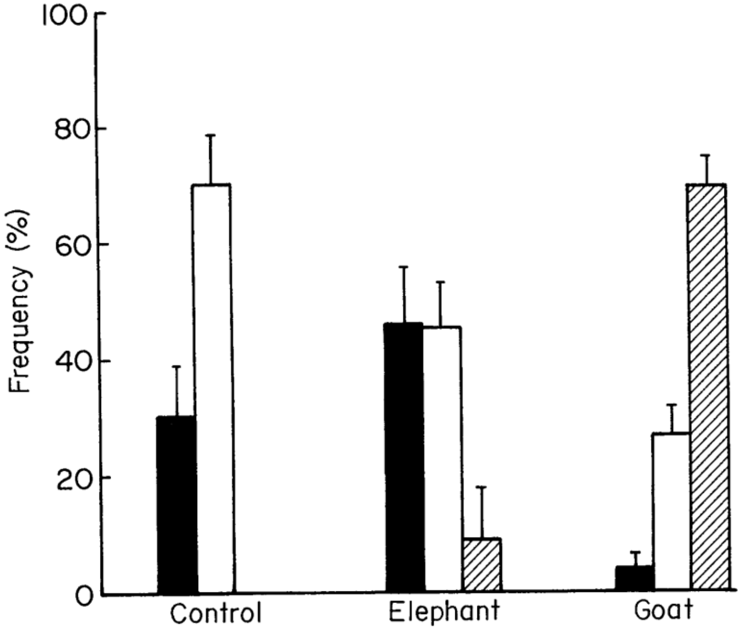


Fig. 9. Population frequency distributions of canopy profiles for *P. afra* plants growing under the impact of elephants, goats and neither elephants nor goats (control). Triangular canopies with bases on the ground (■), box-shaped canopies (□) and umbrella-shaped canopies (▨) (upper 95% confidence limit of the mean).

THE PATTERNS WITHIN, AND THE ECOLOGICAL PROCESSES THAT SUSTAIN, THE SUBTROPICAL THICKET VEGETATION IN THE PLANNING DOMAIN FOR THE SUBTROPICAL THICKET ECOSYSTEM PLANNING (STEP) PROJECT

J.H.J. Vlok & D.I.W. Euston-Brown

TERRESTRIAL ECOLOGY
RESEARCH UNIT

Terrestrial Ecology Research Unit
University of Port Elizabeth
Port Elizabeth 6031

Report No. 40
December 2002

SYSTEM PLANNING PROJECT
TEP)

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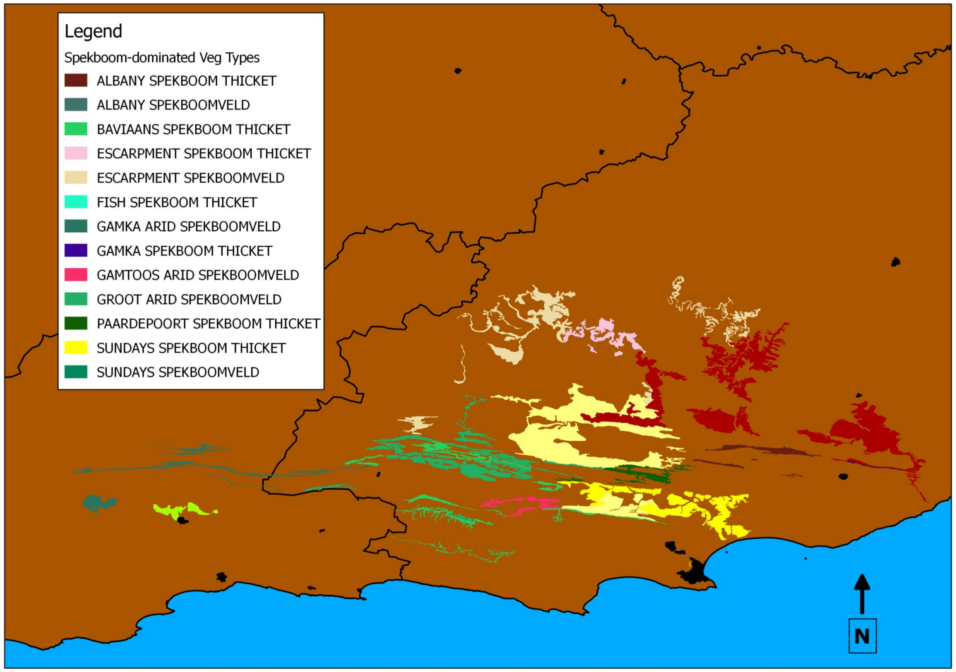
OME, SOUTH AFRICA



We present the approach and results of an intuitive, expert-based mapping exercise to identify subtropical thicket (including Acocks' (1953) Valley Bushveld, Noorsveld and Spekboomveld) vegetation types as features for conservation planning. The study area comprised 105 500km² in southern and south-eastern South Africa, the planning domain for the Subtropical Thicket Ecosystem Planning (STEP) Project. We developed a four-tier typological hierarchy based on geography, floristics, structure and grain. This yielded 112 unique thicket vegetation types, 78 of which comprised thicket clumps in a matrix of non-thicket vegetation (mosaics). By identifying mosaics, we expanded the subtropical thicket concept and increased its extent in the study area by between 1.8 and 2.8 times that of earlier assessments. We also compiled a list of plant species that yielded a rich flora of 1 558 species, 20% of which are endemic to our expanded thicket biome. Consistent with previous studies, endemics were strongly associated with succulent members of the Aizoaceae, Asphodelaceae, Euphorbiaceae, Apocynaceae and Crassulaceae. We discuss our results in terms of Acocks' (1953) typology as well as those of more recent treatments, and comment on the evolution of subtropical thicket vegetation. Although some confusion regarding the delimitation and characterisation of thicket was resolved by this study, much more research is required to develop and test hypotheses on the determinants of thicket boundaries and the origins and evolution of thicket species.

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03, 69(1): 27–51

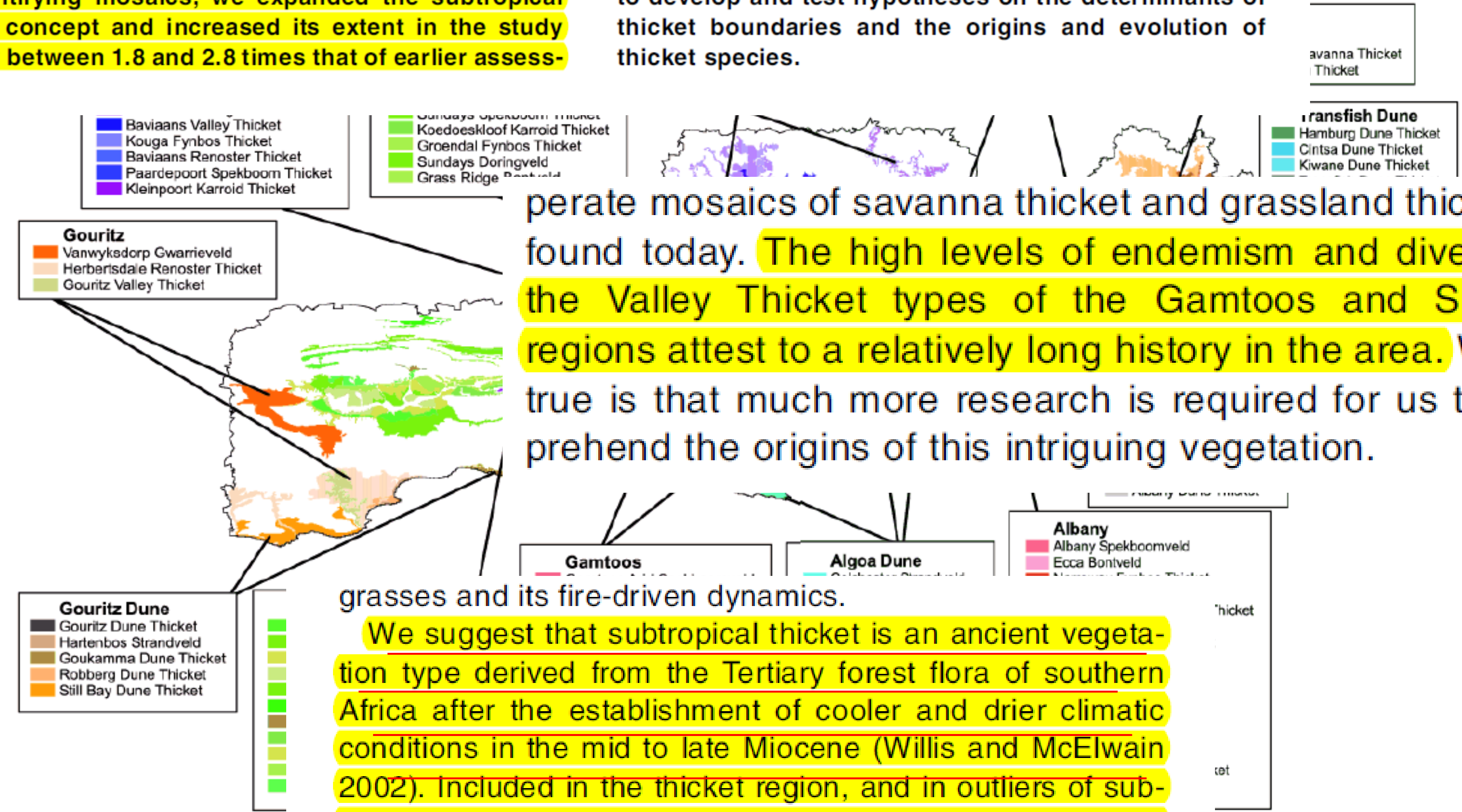


Figure 5: The distribution of the 11

perate mosaics of savanna thicket and grassland thicket are found today. The high levels of endemism and diversity in the Valley Thicket types of the Gamtoos and Sundays regions attest to a relatively long history in the area. What is true is that much more research is required for us to comprehend the origins of this intriguing vegetation.

grasses and its fire-driven dynamics.

We suggest that subtropical thicket is an ancient vegetation type derived from the Tertiary forest flora of southern Africa after the establishment of cooler and drier climatic conditions in the mid to late Miocene (Willis and McElwain 2002). Included in the thicket region, and in outliers of subtropical thicket vegetation elsewhere in southern Africa, are a number of monotypic genera of tropical origin (e.g.

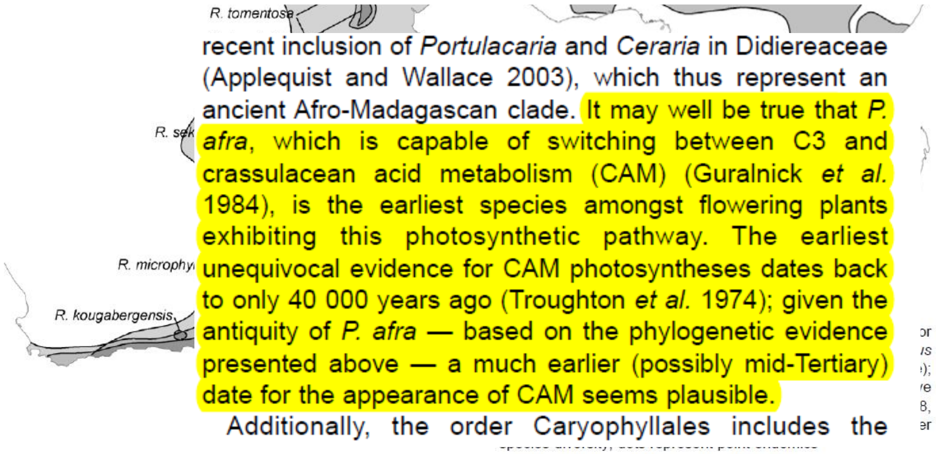
Minireview

On the origin of southern African subtropical thicket vegetation

RM Cowling*, • •Proche• •and JHJ Vlok

South African Journal of Botany 2005, 71(1): 1–23

The origin and affinities of southern African subtropical thicket have been misunderstood and neglected. This formation was only recognised as a biome distinct from savanna and karoo in the mid 1990s. One hypothesis states that it is a young vegetation type, assembled from forest, savanna and karoo elements after Holocene climatic amelioration. Others have suggested an ancient history for thicket. Here we review fossil and phylogenetic data in order to provide a better assessment of the origins of thicket. Albeit patchy, the fossil data are suggestive of a Palaeogene origin for this formation. A review of molecular phylogenetic data of extant thicket lineages indicated three major patterns: (i) ancient Cretaceous elements, including *Encephalartos* and the Strelitziaceae, (ii) basally branching lineages — many of which dominate contemporary thicket — that evolved in the Eocene (e.g. in the Celastraceae, Sapindaceae, Didiereaceae, Crassulaceae: Cotyledonoideae), and (iii) lineages derived from adjacent biomes that diversified in thicket in association with Neogene climatic deterioration (e.g. Aizoaceae, Asteraceae). We provide a narrative account of the evolution of thicket, which concludes that it is an ancient formation, extending back at least to the Eocene and derived initially from elements in the forest formations that prevailed in Upper Cretaceous and early Palaeogene times. As a biome, thicket is not uniquely southern African, being part of a formation that was globally widespread in the Eocene and which is extant in many parts of the world. Future research on the origins of thicket should focus on providing dates for major dichotomies as a complement to the rapid emergence of molecular phylogenies, as well as data on the genetic variation in populations of taxa categorised as ancient or young, and widespread or range-restricted.



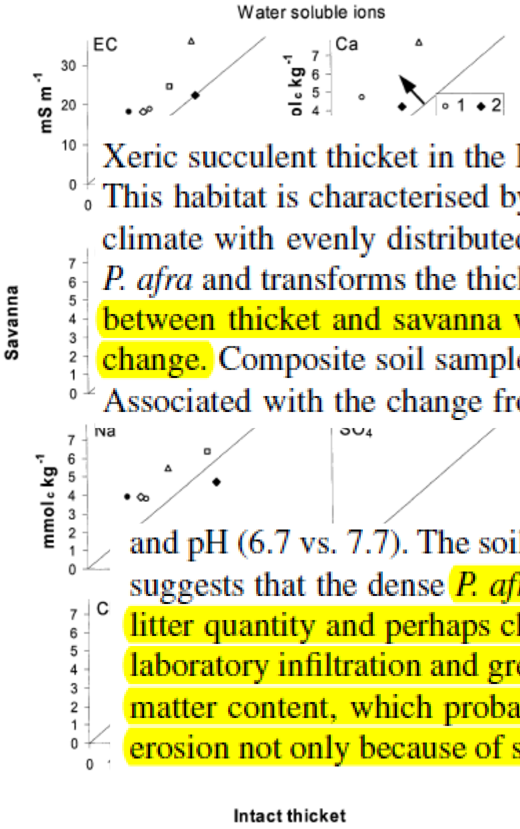
recent inclusion of *Portulacaria* and *Ceraria* in Didiereaceae (Applequist and Wallace 2003), which thus represent an ancient Afro-Madagascan clade. It may well be true that *P. afra*, which is capable of switching between C3 and crassulacean acid metabolism (CAM) (Guralnick *et al.* 1984), is the earliest species amongst flowering plants exhibiting this photosynthetic pathway. The earliest unequivocal evidence for CAM photosyntheses dates back to only 40 000 years ago (Troughton *et al.* 1974); given the antiquity of *P. afra* — based on the phylogenetic evidence presented above — a much earlier (possibly mid-Tertiary) date for the appearance of CAM seems plausible.

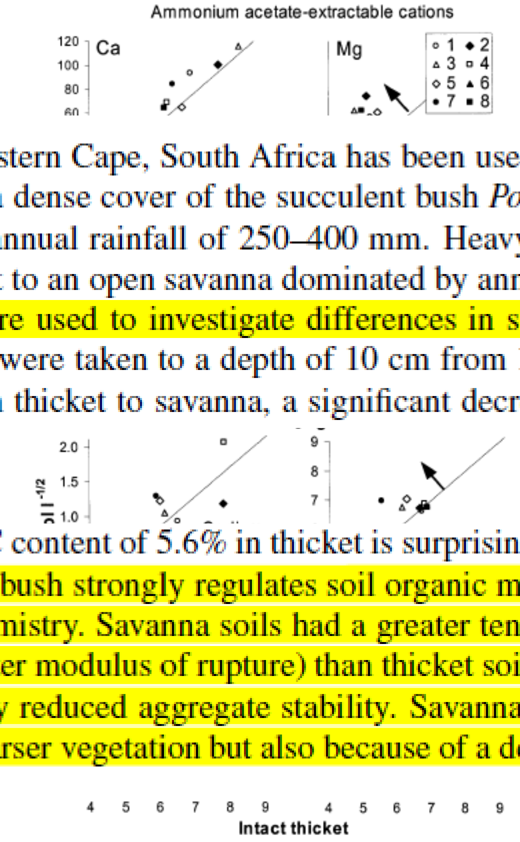
Additionally, the order Caryophyllales includes the

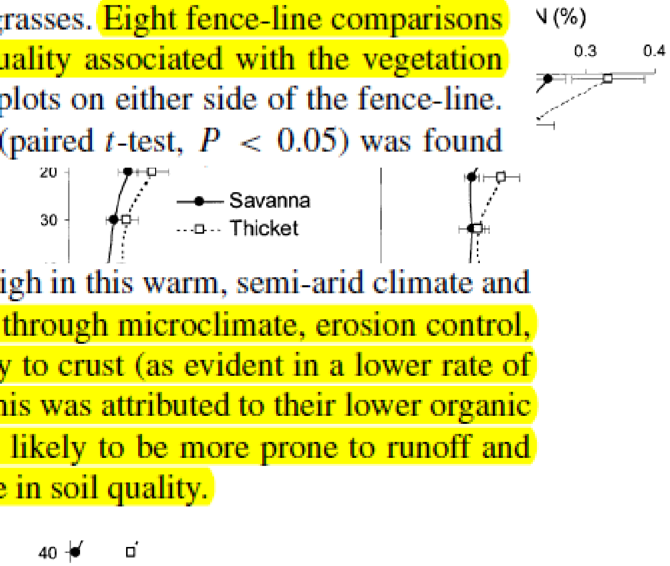
Transformation of thicket to savanna reduces soil quality in the Eastern Cape, South Africa

Anthony Mills[1,2,3] & Martin Fey[1]

Plant and Soil **265:** 153–163, 2004.







Xeric succulent thicket in the Eastern Cape, South Africa has been used for farming goats since the early 1900s. This habitat is characterised by a dense cover of the succulent bush *Portulacaria afra* and by a warm, semi-arid climate with evenly distributed annual rainfall of 250–400 mm. Heavy browsing by goats results in the loss of *P. afra* and transforms the thicket to an open savanna dominated by annual grasses. Eight fence-line comparisons between thicket and savanna were used to investigate differences in soil quality associated with the vegetation change. Composite soil samples were taken to a depth of 10 cm from 1 ha plots on either side of the fence-line. Associated with the change from thicket to savanna, a significant decrease (paired t-test, $P < 0.05$) was found

and pH (6.7 vs. 7.7). The soil C content of 5.6% in thicket is surprisingly high in this warm, semi-arid climate and suggests that the dense *P. afra* bush strongly regulates soil organic matter through microclimate, erosion control, litter quantity and perhaps chemistry. Savanna soils had a greater tendency to crust (as evident in a lower rate of laboratory infiltration and greater modulus of rupture) than thicket soils. This was attributed to their lower organic matter content, which probably reduced aggregate stability. Savannas are likely to be more prone to runoff and erosion not only because of sparser vegetation but also because of a decline in soil quality.

Figure 3. The relationship between savanna and thicket with respect to electrical conductivity, water-soluble (1:5) Ca, Mg, Na, K, NH_4, SO_4, Cl and NO_3 in composite soil samples taken to a depth of 10 cm. The solid line represents a 1:1 relationship. Arrows represent a significant increase (↑) or decrease (↓) from thicket to savanna. Each point represents one savanna-thicket comparison.

Figure 4. The relationship between savanna and thicket with respect to (a) (NH_4)OAc-extractable cations Ca, Mg, Na, K; (b) sodium adsorption ratio and pH in a 1:5 soil-water extract; and (c) pH in KCl and water (1:2.5) in composite soil samples taken to a depth of 10 cm. The solid line represents a 1:1 relationship. Arrows represent a significant increase (↑) or decrease (↓) from thicket to savanna.

Figure 7. The change in total C, N and C:N with depth in xeric succulent thicket. Savanna is compared with thicket. Error bars depict the standard errors of the mean.

Ecosystem carbon storage under different land uses in three semi-arid shrublands and a mesic grassland in South Africa

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R.G. Lechmere-Oertel[4] & J.D. Bosenberg[2]

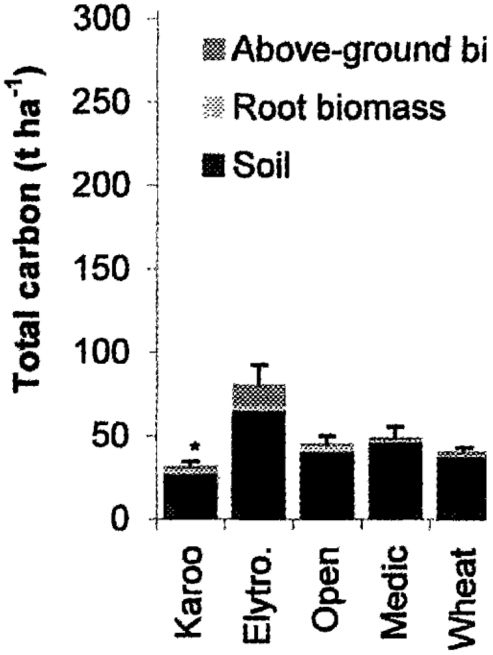


Figure 6 Total carbon sto
sites. Error bars are the
errors. *Estimates for root
Figure 2 for key to graph l

Effects of land use on C stocks

The greatest reduction in ecosystem C storage due to land use occurred in thicket, where transformation by goats reduced soil C by ~40% (0-10 cm) and biomass C by ~75%. Loss of C occurred over a relatively short time span (~50 years) and equated to 37 t ha^{-1} of soil C (0-50 cm) and 58 t ha^{-1} of biomass C. The probable mechanisms behind the decline in soil C are reduced biomass inputs, greater microbial activity due to higher soil temperatures in savanna sites (Jenkinson, 1981; Lechmere-Oertel, Kerley & Cowling, 2004c) and greater photodegradation of litter (due to greater exposure to ultraviolet light) (Moorhead & Callaghan, 1994). Mean daily maximum soil temperature was 12°C higher in open pseudo-savanna than under intact thicket (23.2 vs 35.1°C) (Lechmere-Oertel, 2004). Interception of rainfall by thicket canopy may limit microbial activity and this may reduce soil C accumulation, but this requires further investigation. Restoration of transformed thicket, such as can be achieved by planting *Portulacaria afra* Jacq. truncheons, stands to recoup ~95 t C ha^{-1}.

Effects of goat pastoralism on ecosystem carbon storage in semiarid thicket, Eastern Cape, South Africa

A. J. MILLS,[1,2]* R. M. COWLING,[3] M. V. FEY,[1] G. I. H. KERLEY,[3] J. S. DONALDSON,[2]
R. G. LECHMERE-OERTEL,[3] A. M. SIGWELA[3], A. L. SKOWNO[2] AND P. RUNDEL[4]

Austral Ecology (2005) 30, 797–804

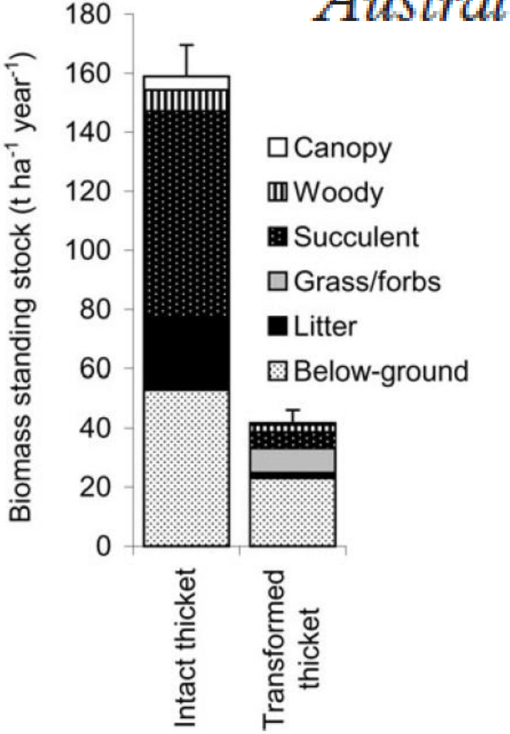


Fig. 2. Standing stock of mean biomass (dry matter) in intact thicket and adjacent transformed thicket. Standard errors given by vertical bars.

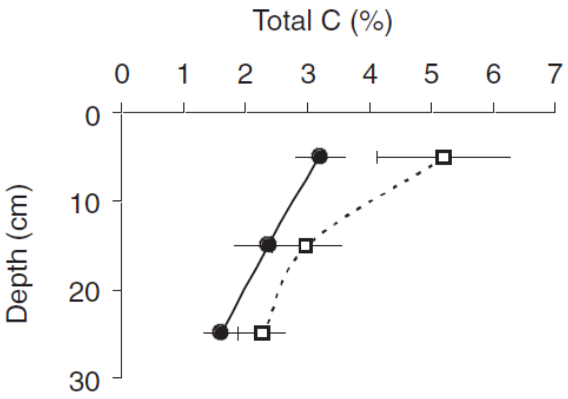


Fig. 3. Change in mean soil C with depth in intact thicket and adjacent transformed thicket. Standard errors given by horizontal bars. (–●–) Transformed thicket, (☐) intact thicket.

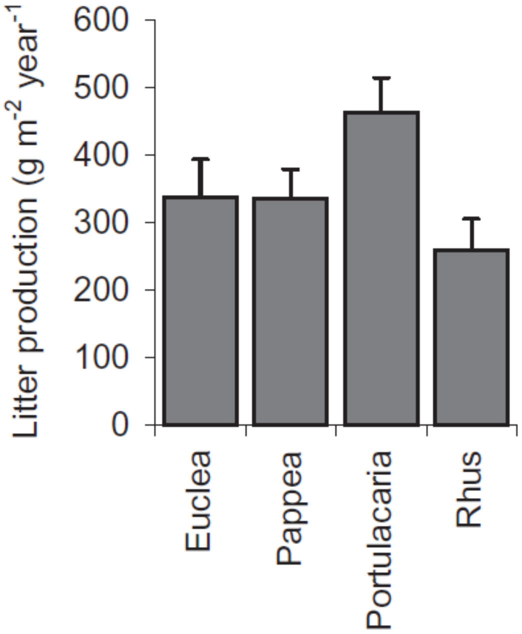


Fig. 4. Mean litter production under different shrub/tree species in intact thicket. Euclea, *Euclea undulata*; Pappea, *Pappea capensis*; Portulacaria, *Portulacaria afra*; Rhus, *Rhus longispina*. Standard errors given by vertical bars.

Journal of Arid Environments 62 (2005) 459–474

Patterns and implications of transformation in semi-arid succulent thicket, South Africa

R.G. Lechmere-Oertel[a,*], G.I.H. Kerley[a], R.M. Cowling[b]

Table 2
Differences in species richness and Shannon's diversity index between the paired intact and transformed

6. Conclusions

Our data quantify the patterns of transformation in spekboom thicket, showing that there is a significant reduction in the plant species and functional diversity. This loss in richness is accompanied by a very significant decrease in the percentage cover of perennial vegetation, biomass, and vertical and horizontal complexity. We show that the resulting pseudo-savanna is not necessarily a stable state, but is likely to continue to change as the only remnant of the original perennial vegetation, the canopy tree guild, experiences atypically high rates of mortality. We suggest that the end point of this trajectory is a highly eroded landscape that is covered by ephemeral plants. The implications of thicket entering such a desertified state are very serious for both production and conservation management.

Transformed	10 ± 11	225 ± 123
Z(*n*)	2.02 (4)*	0.29 (4)

Mann–Whitney *U* statistic (*Z*) significance level:
*$p < 0.05$.

Austral Ecology (2005) **30**, 615–624

Landscape dysfunction and reduced spatial heterogeneity in soil resources and fertility in semi-arid succulent thicket, South Africa

RICHARD G. LECHMERE-OERTEL,[1]* RICHARD M. COWLING[2] AND
GRAHAM I. H. KERLEY[1]

Table 3. Soil organic carbon content from other ecosystems compared with intact and transformed spekboom thicket (highlighted in bold)

fencelines using a nested anova. Our results show that intact Sundays River thicket has a distinct spatial pattern of soil fertility where nutrients and organic carbon are concentrated under the patches of perennial shrubs, compared with under canopy trees. Transformation results in a significant homogenization of this pattern and an overall reduction in the fertility of the landscape. The proportion of the landscape surface that promotes infiltration due to a distinct litter layer decreases from 60% to 0.6%. Soil moisture retention (matric potential) also decreases with transformation. We interpret these patterns within the framework of semi-arid landscape functionality.

Tropical desert, Jazan, Saudi Arabia	1.50	El-Demerdash *et al.* (1995)
Subtropical savanna, Rio Grande	2.30	Hibbard *et al.* (2001)
Mojave Desert shrubland (under shrubs)	2.42	Rundel and Gibson (1996)
Semi-arid rangeland, Spain	2.70	Cammeraat *et al.* (2002)
Himalayan plantation	2.81	Joshi *et al.* (1999)
Transformed spekboom thicket	**3.07**	
Semi-arid savanna, South Africa	3.14	Jarvel and O'Connor (1999)
Semi-arid savanna, Kenya	3.60	Belsky *et al.* (1989)
Climax forest, China	4.50	Zhang and Liang (1995)
Intact spekboom thicket	**6.87**	
Temperate Oak	7.00	Stamou *et al.* (1994)
Beech forest, Spain	16.10	Santa Regina and Tarazona (2001)

Rate of Carbon Sequestration at Two Thicket Restoration Sites in the Eastern Cape, South Africa

Anthony J. Mills[1,2,3] and Richard M. Cowling[4]

Restoration Ecology Vol. 14, No. 1, pp. 38–49

Abstract

Ecosystem carbon storage in intact thicket in the Eastern Cape, South Africa exceeds 20 kg/m^2, which is an unusually large amount for a semiarid ecosystem. Heavy browsing by goats transforms the thicket into an open savanna and can result in carbon losses greater than 8.5 kg/m^2. Restoration of thicket using cuttings of the dominant succulent shrub *Portulacaria afra* could return biodiversity to the transformed landscape, earn carbon credits on international markets, reduce soil erosion, increase wildlife carrying capacity, improve water infiltration and retention, and provide employment to rural communities. Carbon storage in two thicket restoration sites was investigated to determine potential rates of carbon sequestration. At the farm Krompoort, near Kirkwood, 11 kg C/m^2 was sequestered over 27 years (average rate of 0.42 ± 0.08 kg C m^{-2} yr^{-1}). In the Andries Vosloo Kudu Nature Reserve, near Grahamstown, approximately 2.5 kg C/m^2 was sequestered over 20 years (0.12 ± 0.03 kg C m^{-2} yr^{-1}). Slower sequestration in the Kudu Reserve was ascribed to browsing by black rhinoceros and other herbivores, a shallower soil and greater stone volumes. Planting density and *P. afra* genotype appeared to affect sequestration at Krompoort. Closely-packed *P. afra* planting may create a positive feedback through increased infiltration of rainwater. The rate of sequestration at Krompoort is comparable to many temperate and tropical forests. Potential earnings through carbon credits are likely to rival forest-planting schemes, but costs are likely to be less due to the ease of planting cuttings, as opposed to propagating forest saplings.

Key words: biomass, carbon sequestration, *Portulacaria afra*, restoration, semiarid landscapes, soil carbon, thicket.

Table 6. Carbon storage and rate of sequestration in aboveground biomass, roots, opslag, litter, and soils at Krompoort and Kudu Reserve thicket restoration sites, Eastern Cape, South Africa.

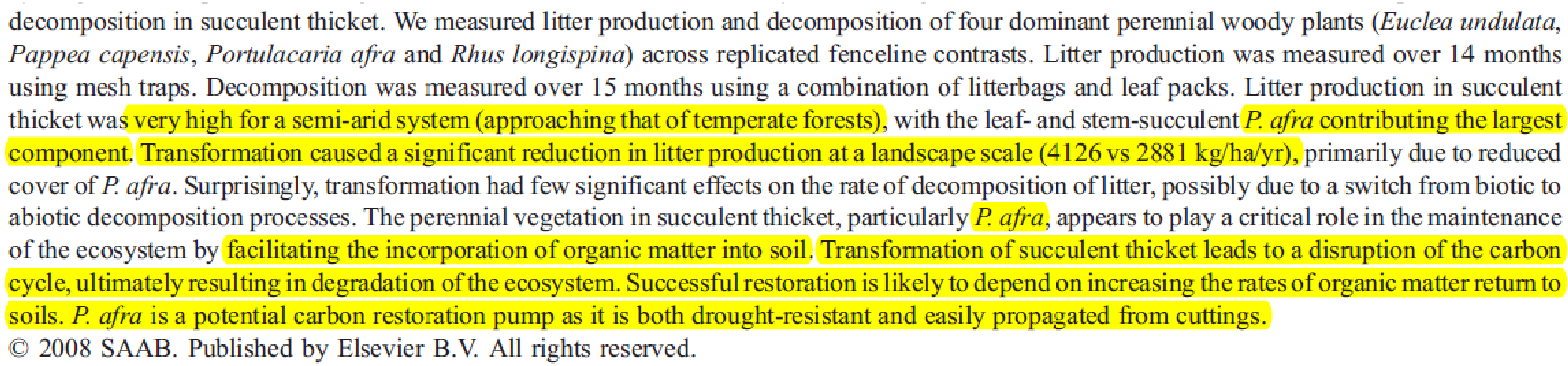
	Cover	*Biomass*	*SE*	*Root*	*SE*	*Opslag*	*SE*	*Litter*	*SE*	*Soil C*[a]	*SE*	*Total*	*SE*	*Rate*[b]	*SE*
SW Fenceline[c]		3.42	0.4												

[a] 0- to 500-mm layer for all sites.
[b] Rate of carbon sequestration calculated with the assumption that the transformed block at Krompoort and the restored open site at the Kudu Reserve represent the carbon present at the time of planting with spekboom.
[c] Thicket biomass at the Kudu Reserve was measured at the southwestern boundary of the reserve, that is, not adjacent to the restoration site. Total values for thicket are consequently not presented; $n = 5$ for each treatment at Krompoort; $n = 10$ for each treatment at the Kudu Reserve; significant differences ($p < 0.05$) between means within each group are indicated by different letters; groups at each site are separated by open lines within the table. Blank cells, no data collected or negligible material available for collection.

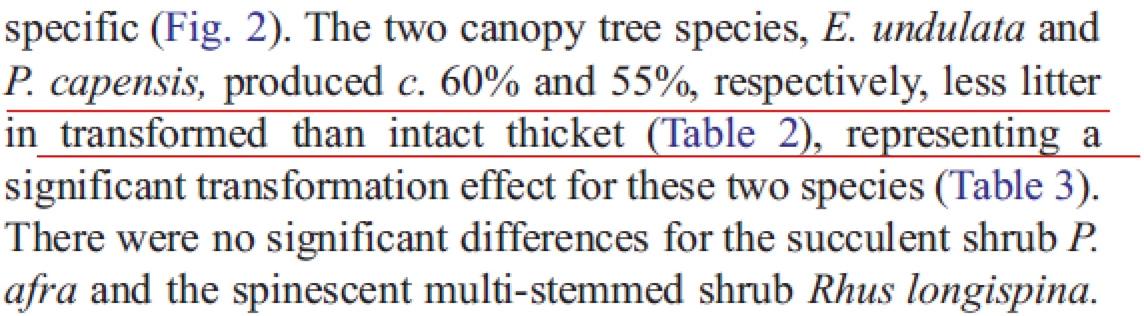
Litter dynamics across browsing-induced fenceline contrasts in succulent thicket, South Africa

R.G. Lechmere-Oertel [a], G.I.H. Kerley [a], A.J. Mills [b,*], R.M. Cowling [c]

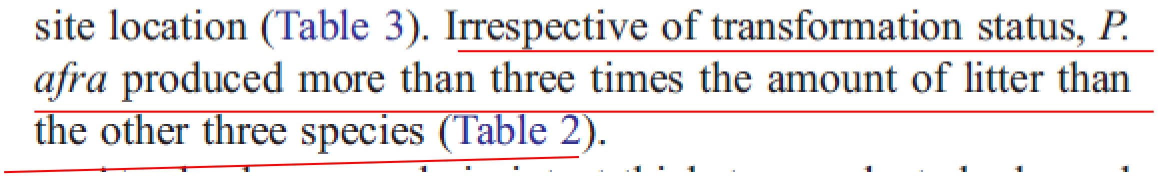
South African Journal of Botany 74 (2008) 651 – 659



decomposition in succulent thicket. We measured litter production and decomposition of four dominant perennial woody plants (*Euclea undulata*, *Pappea capensis*, *Portulacaria afra* and *Rhus longispina*) across replicated fenceline contrasts. Litter production was measured over 14 months using mesh traps. Decomposition was measured over 15 months using a combination of litterbags and leaf packs. Litter production in succulent thicket was very high for a semi-arid system (approaching that of temperate forests), with the leaf- and stem-succulent *P. afra* contributing the largest component. Transformation caused a significant reduction in litter production at a landscape scale (4126 vs 2881 kg/ha/yr), primarily due to reduced cover of *P. afra*. Surprisingly, transformation had few significant effects on the rate of decomposition of litter, possibly due to a switch from biotic to abiotic decomposition processes. The perennial vegetation in succulent thicket, particularly *P. afra*, appears to play a critical role in the maintenance of the ecosystem by facilitating the incorporation of organic matter into soil. Transformation of succulent thicket leads to a disruption of the carbon cycle, ultimately resulting in degradation of the ecosystem. Successful restoration is likely to depend on increasing the rates of organic matter return to soils. *P. afra* is a potential carbon restoration pump as it is both drought-resistant and easily propagated from cuttings.



specific (Fig. 2). The two canopy tree species, *E. undulata* and *P. capensis,* produced *c.* 60% and 55%, respectively, less litter in transformed than intact thicket (Table 2), representing a significant transformation effect for these two species (Table 3). There were no significant differences for the succulent shrub *P. afra* and the spinescent multi-stemmed shrub *Rhus longispina*.



site location (Table 3). Irrespective of transformation status, *P. afra* produced more than three times the amount of litter than the other three species (Table 2).

Restoration of degraded subtropical thickets in the Baviaanskloof Megareserve, South Africa

The role of carbon stocks and *Portulacaria afra* survivorship

Michael John Powell

Table 3.6: Mean±SE carbon stocks (t C ha^{-1}) and relative % of C pools to Total carbon stocks (TCS) for intact Baviaanskloof spekboom thickets and pooled Baviaanskloof Nature Reserve (BNR) thicket types compared to other vegetation types in Africa.

Carbon pool	**Baviaanskloof spekboom thickets**	**% of TCS**	**Baviaanskloof subtropical thickets**	**% of TCS**	**Glenday (2007) dry valley thicket**	**% of TCS**	**Glenday (2006) tropical forest**	**% of TCS**
Litter C	4.85±0.99	5.5	3.68±0.72	4.4	2.6±0.3	2	5.4±0.9	1.5
Herb C	0.61±0.17	0.7	0.89±0.16	1.1	1.08±0.4	1	0.8±0.4	0.2
Woody C	28.99±3.32	33.0	26.50±3.85	31.9	29±3	24	200±36	56.1
Deadwood C	within litter C	NA	within litter C	NA	1.5±0.3	2	1.2±0.4	0.3
Root C	3.60±0.58	4.1	4.64±0.66	5.6	9.2±0.9	8	49±9	13.7
Soil C	49.67±6.21	56.6	47.34±4.43	57.0	77±8	63	100±17	28.1
TCS	87.73±6.51		83.08±5.75		121±9		360±63	

Table 3.3: Allometric relationships predicting above ground dry plant carbon (kg) for species destructively harvested in the subtropical thickets of the Baviaanskloof Nature Reserve (CBSA = cumulative basal stem area).

Species	**n**	**R equation**	**R^2 value**	**F**	**df**	**p**	**SE**
Acacia karroo	15	Log$_{10}$ y (C (kg) = 2.034(**Log$_{10}$ canopy area (m^2)**) - 1.20113	R^2 = 0.9513	253.72	(1,13)	<0.000001	0.18367
Aloe ferox	*25*	Log$_{10}$ *y* (C (kg) = 1.4306(**Log$_{10}$ CBSA (m^2)**) + 3.6975	R^2 = 0.7780	80.60	(1,23)	<0.000001	0.39567
Crassula ovata	21	Log$_{10}$ y (C (kg) = 1.1337(**Log$_{10}$ CBSA (m^2)**) + 1.9764	R^2 = 0.9672	559.53	(1,19)	<0.000001	0.19500
Ehretia rigida	24	Log$_{10}$ y (C (kg) = 0.9623(**Log$_{10}$ CBSA (m^2)**) + 2.485	R^2 = 0.6343	38.16	(1,22)	<0.000001	0.35008
Euphorbia grandidens	25	Log$_{10}$ y (C (kg) = (**Log$_{10}$ CBSA (m^2)**)	R^2 = 0.9249	135.47	(1,23)	<0.000001	0.19868
Grewia robusta	37	Log$_{10}$ y (C (kg) = 1.0044(**Log$_{10}$ canopy area (m^2)**) - 0.6259	R^2 = 0.8502	198.58	(1,35)	<0.000001	0.39335
Jatropha capensis	21	Log$_{10}$ y (C (kg) = 0.9067(**Log$_{10}$ canopy area (m^2)**) - 0.7349	R^2 = 0.5728	25.47	(1,19)	0.000072	0.43507
Lycium ferocissimum	35	Log$_{10}$ y (C (kg) = 0.8615(**Log$_{10}$ CBSA (m^2)**) + 1.7706	R^2 = 0.7676	108.98	(1,33)	<0.000001	0.48157
Pappea capensis	22	Log$_{10}$ y (C (kg) = 1.3355(**Log$_{10}$ canopy area (m^2)**) + 0.1357	R^2 = 0.9265	251.99	(1,20)	<0.000001	0.24783
Plumbago auriculata	21	Log$_{10}$ y (C (kg) = 1.0821(**Log$_{10}$ CBSA (m^2)**) + 2.7320	R^2 = 0.9296	250.93	(1,19)	<0.000001	0.16392
Portulacaria afra	5	Log$_{10}$ y (C (kg) = 1.1043(**Log$_{10}$ CBSA (m^2)**) + 2.4464	R^2 = 0.9696	96.47	(1,3)	0.002240	0.12412
Pteronia incana	49	Log$_{10}$ y (C (kg) = 1.4032(**Log$_{10}$ canopy area (m^2)**) - 0.4224	R^2 = 0.9679	1419	(1,47)	<0.000001	0.15833
Putterlickia pyracantha	46	Log$_{10}$ y (C (kg) = 1.0622(**Log$_{10}$ CBSA (m^2)**) + 2.7834	R^2 = 0.7784	154.58	(1,44)	<0.000001	0.33364
Rhus longispina	24	Log$_{10}$ y (C (kg) = 1.1012(**Log$_{10}$ canopy area (m^2)**) - 0.2938	R^2 = 0.5077	22.68	(1,22)	<0.000001	0.45575

The impact of browsing-induced degradation on the reproduction of subtropical thicket canopy shrubs and trees

A.M. Sigwela [a], G.I.H. Kerley [a], A.J. Mills [b], R.M. Cowling [c,*]

South African Journal of Botany 75 (2009) 262 – 267

Table 4

The regeneration dynamics of South African subtropical thicket are poorly understood. This lack of knowledge hampers the development of appropriate restoration protocols in degraded landscapes. To address this we compared the magnitude of seed production and the frequency seedlings of canopy species in intact and browsing-degraded forms of *Portulacaria afra*-dominated thicket. Severe browsing had a negative impact on sexual reproduction of canopy species. Seed production for all species was lower in the degraded than the intact states of both vegetation types. In the case of seedlings, almost all individuals were associated with beneath-canopy microsites, irrespective of degradation status. Exceptions were *P. afra*, *Putterlickia pyracantha* and *Grewia robusta*. Of the 511 seedlings that we observed, 480 (94%) were found in the beneath-canopy microsite and 31 (6%) in the open. In both intact and degraded sites, there were significantly fewer seedlings (all species combined) in open microsites than would be expected on the basis of the aerial extent of this microsite. The results show firstly that preservation of remnant clumps of closed-canopy thicket in degraded landscapes is of paramount importance for restoration, and that for recruitment of a wide range of canopy species to occur outside of these remnant clumps, it is essential to restore closed-canopy conditions as speedily as possible.

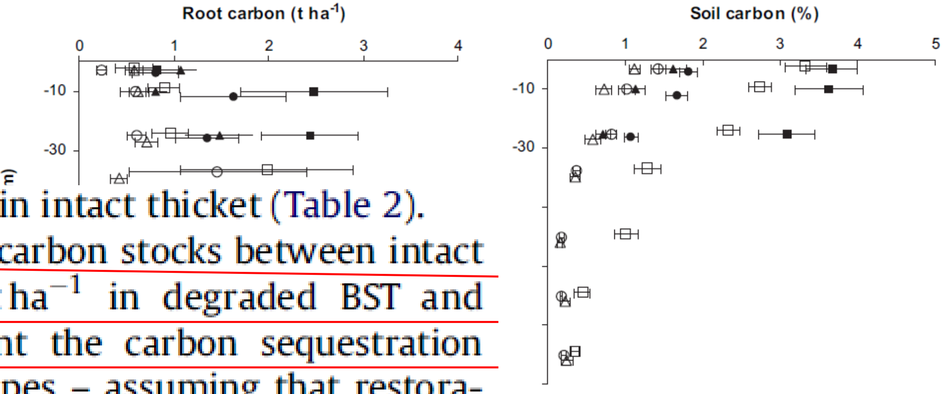
Intact	0.29	0.71	18	425	128.5	314.5	212.5	***
Degraded	0.84	0.16	13	55	57.1	10.9	134.0	***

Expected frequencies are based on the proportion of the two microsites in intact versus the degraded states. ***= $P<0.001$.

Below-ground carbon stocks in intact and transformed subtropical thicket landscapes in semi-arid South Africa

Journal of Arid Environments 74 (2010) 93–100

A.J. Mills [a,*], R.M. Cowling [b]



degraded thicket and old lands than in intact thicket (Table 2).

The differences in below-ground carbon stocks between intact BST and transformed BST (70 ± 8 t ha^{-1} in degraded BST and 59 ± 9 t ha^{-1} in old lands) represent the carbon sequestration potential in the transformed landscapes – assuming that restoration back to a thicket structure will return all the lost carbon. These large below-ground sequestration potentials rival those in most mesic forests (Johnson, 1992; Rhoades et al., 2000; Tilman et al., 2000; Willams et al., 2008). This exceptional sequestration potential in a semi-arid vegetation type, together with the low costs of restoration of BST (which do not include nursery costs because

Table 3

Soil carbon stocks to depths of 25 cm and 110 cm in Baviaans Spekboom Thicket in three land categories in the Baviaanskloof Nature Reserve.

		0-25 cm			*	*	25-110 cm			*	0-110 cm	
		Mean	SE	N			Mean	SE	N		Mean	SE
Intact	outside	38	2	47	*a*		40	5	14	*X*	78	5
	under	*52*	*5*	*47*		*p*	*40*	*5*	*14*		*93*	*7*
Degraded	outside	18	1	47	*b*		13	1	15	*YZ*	31	2
	under	*25*	*2*	*47*		*q*	*13*	*1*	*15*		*31*	*2*
Old lands	outside	20	3	25	*b*		22	4	10	*Z*	42	4
	under	*28*	*3*	*25*		*q*	*22*	*4*	*10*		*42*	*4*

[*] The different letters indicate significant differences at specified depth, in the open or under the canopy.

South African Journal of Botany 77 (2011) 236 – 240

Short communication

A preliminary assessment of rain throughfall beneath *Portulacaria afra* canopy in subtropical thicket and its implications for soil carbon stocks

R.M. Cowling [a,*], A.J. Mills [b]

4.1. Throughfall patterns

At 49–63% of gross rainfall, throughfall in spekboom thicket is amongst the lowest recorded in the literature. Values from Amazonian rainforest sites range from 74 to 91% (Cuartas et al. 2007), temperate broadleaved forests from 70 to 90% (Herbst et al., 2008; Rowe, 1983; Rutter et al., 1975), and coniferous

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Pereira et al., 2009).

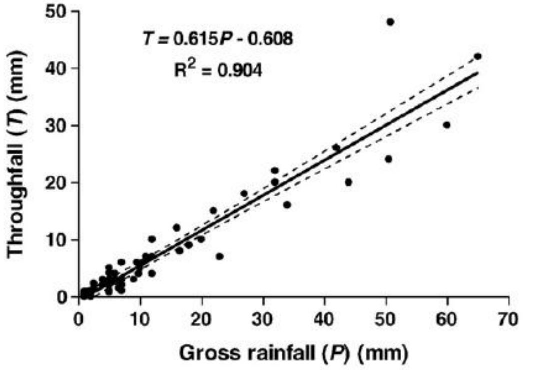


Fig. 2. Relationship between gross rainfall and throughfall (n=69) beneath *Portulacaria afra* canopy in spekboom thicket, measured Jan–Jun 2006. Dashed lines are 95% confidence intervals.

4.2. Implications for soil carbon stocks

The low rates of throughfall recorded in this study support the hypothesis that the extreme accumulation of soil organic carbon in thicket soils is partly due to interception of rainfall and concomitant constraints on soil microbial activity. It should be noted that the thick litter layer also intercepts throughfall and further reduces the amount of rainwater reaching the mineral soil. (cf. Thurow et al., 1987). Indeed, in light rainfall events, it is conceivable that over large areas of the landscape no rainwater will reach the mineral soil, thereby halting the Birch effect (Birch, 1958) completely. The wetting of the litter layer will promote decomposition of the litter, but unless the water moves into the mineral soil, soil carbon stocks will be protected from the stimulating effect of water on rates of mineralization.

It is puzzling that vegetation in a semi-arid climate would have a canopy structure that results in considerable interception and, therefore, loss of water to evaporation. Possible consequences of increasing the aridity of the soil through a high rate of interception for thicket plants are: (i) reduced competition from less xeric-adapted species; (ii) reduced rates of nutrient-leaching from the regolith during large rainfall events (see Milewski and Mills, 2010); and (iii) the accumulation of soil carbon which increases the water holding capacity of the soil and thus may buffer the effects of extended dry spells.

If low rates of throughfall are inextricably linked to soil carbon accumulation in thicket, as we hypothesise, there is one important implication for restoration of degraded thicket: namely, soil organic carbon stocks will only recover once the canopy structure has been restored. It is likely that the establishment of thicket species is highly dependent on soil properties, with organic matter-rich soils promoting germination and growth (Sigwela et al., 2009). Consequently, fast-tracking restoration of thicket biodiversity is likely to depend on fast-tracking canopy development. Fortunately this can be achieved by planting *P. afra* cuttings in close proximity to one another, with the carbon accrued potentially being sold on international carbon markets to fund the restoration costs (Mills and Cowling, 2006; Mills et al., 2007).

Short communication

Portulacaria afra is constrained under extreme soil conditions in the Fish River Reserve, Eastern Cape, South Africa

A.J. Mills [a,*], R.M. Cowling [b], D. Steyn [c], J. Spekreijse [d], D. Van den Broeck [e],
S. Weel [e], C. Boogerd [e]

South African Journal of Botany 77 (2011) 782–786

(Fig. 3). We note that across the thicket biome *P. afra* dominates landscapes in the form of Spekboomveld or Spekboom Thicket (Vlok et al., 2003) across an exceptionally wide range of climatic and soil conditions: from approximately 200 to 800 mm mean annual rainfall, on nutrient-rich, alkaline shale-derived soils as well as nutrient-poor, acidic sandstone-derived soils. This suggests that *P. afra* is tolerant of a wide range of soil conditions and is unlikely to be constrained directly by any of the soil properties analysed. A catenal effect was ruled out as a possible explanation for the patterns of constraint in Fig. 3 because sites with relatively high *P. afra* cover tended to be located on the crest of hills or in flat landscapes, rather than on mid slopes where nutrient content, for example, would be expected to be intermediate. The constraint of *P. afra* in the extreme edaphic environments in the Fish River Reserve is consequently likely to be a function of correlated factors related to position in the landscape (e.g. temperature or frost) and/or competition from other plants. The nature of the constraint and the

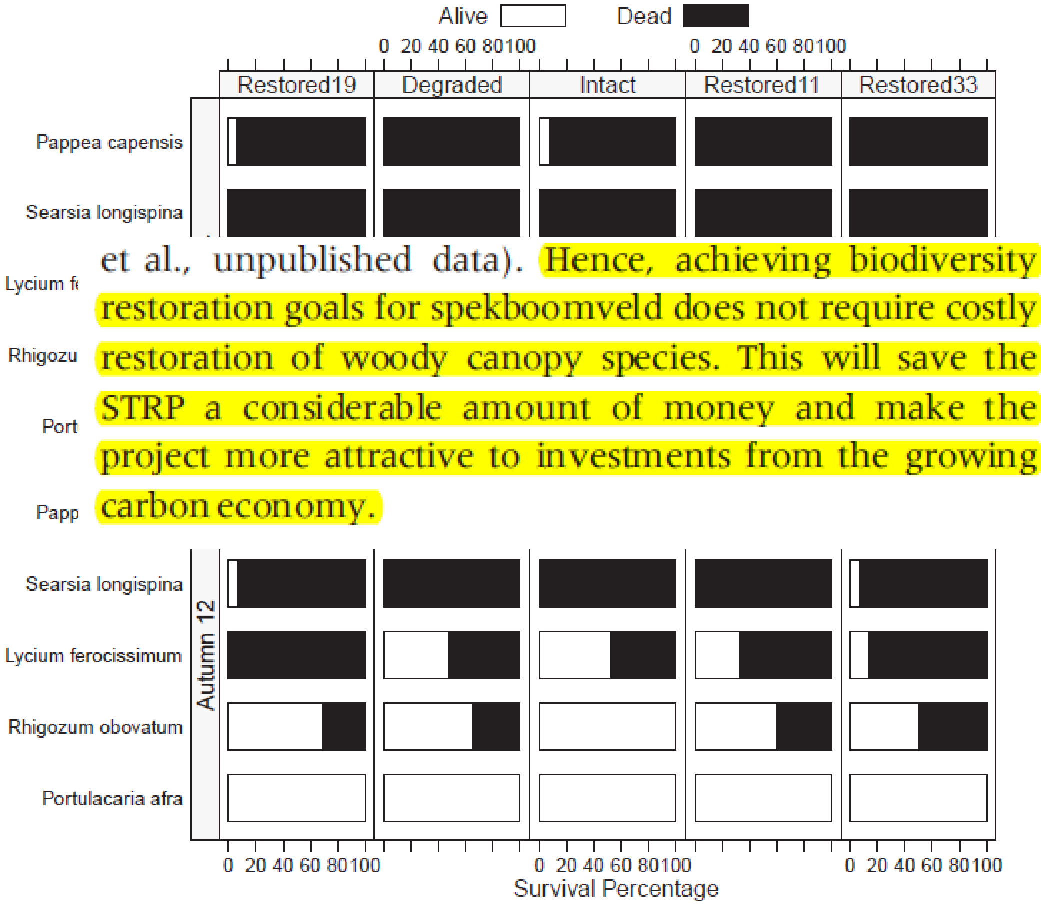
Fig. 3. The relationship
points identified using

circles depict boundary
r of boundary points.

Applied Vegetation Science **15** (2012) 26–34

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

Marius L.van der Vyver, Richard M. Cowling, Eileen E. Campbell & Mark Difford

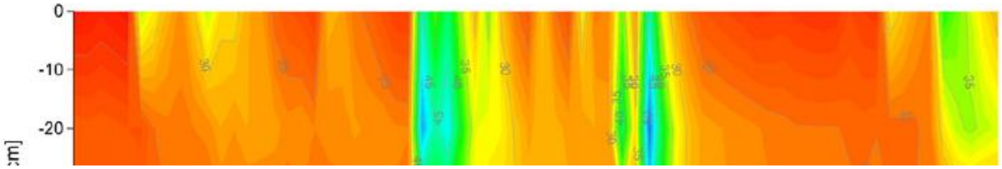


et al., unpublished data). Hence, achieving biodiversity restoration goals for spekboomveld does not require costly restoration of woody canopy species. This will save the STRP a considerable amount of money and make the project more attractive to investments from the growing carbon economy.

Hydrological implications of desertification: Degradation of South African semi-arid subtropical thicket

G. van Luijk[a,b], R.M. Cowling[c], M.J.P.M. Riksen[a,*], J. Glenday[b,d]

Journal of Arid Environments 91 (2013) 14–21



relatively intact thicket. The results showed clear trends in the impacts of spekboom thicket degradation on hydrological processes. The more than hundred-fold lower infiltration in soils associated with degraded thicket relative to the soils beneath the intact, spekboom canopy, resulted in lower levels and less retention of soil moisture, almost double the amount of runoff, and an almost six-fold increase in sediment load. Thus, restoring degraded thicket will reduce erosion and likely improve baseflows, in addition to sequestering carbon.

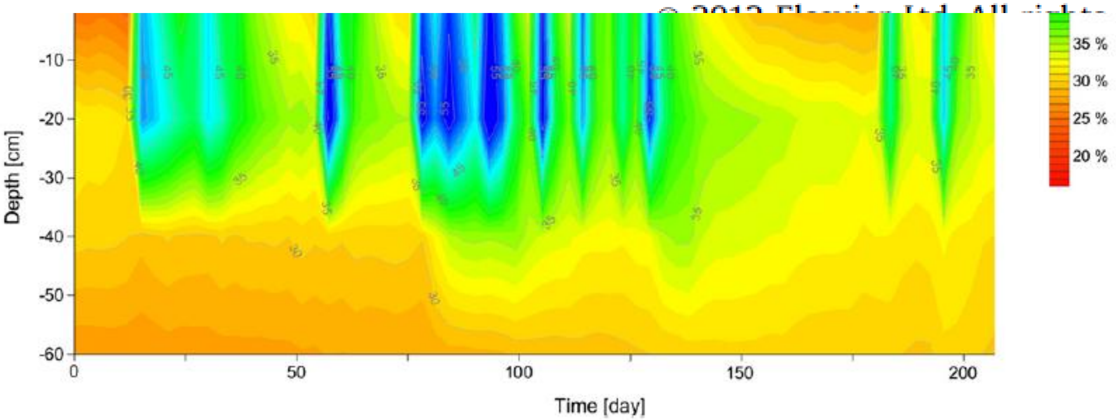


Fig. 3. Depth–time plots of the moisture in the soil profile in degraded thicket (top) and beneath the spekboom canopy (bottom). Data were collected between October 2010 ar April 2011 in the Baviaanskloof, South Africa.

Spontaneous Return of Biodiversity in Restored Subtropical Thicket: *Portulacaria afra* as an Ecosystem Engineer

Marius L. van der Vyver,[1,2] Richard M. Cowling,[1] Anthony J. Mills,[3] and Mark Difford[1]

observed a concomitant increase in the abundance of woody canopy recruits, a major functional group in intact Sundays spekboomveld (Vlok et al. 2003) and a general increase in phylogenetic α-diversity and turnover (β-diversity). This trend appeared to be stronger at Rhinosterhoek. The presence of woody canopy recruits suggests that abiotic and biotic conditions on 35-year-old and older restoration treatments are conducive to the spontaneous establishment of these species.

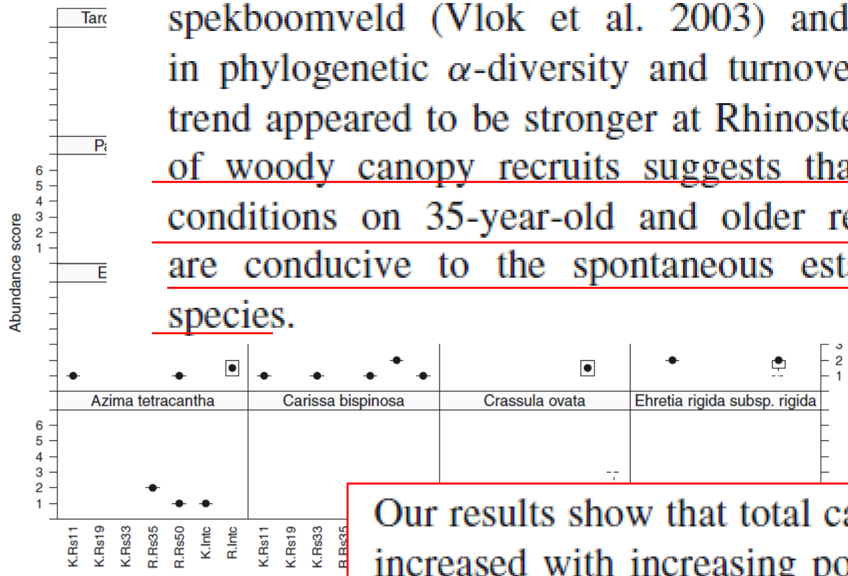
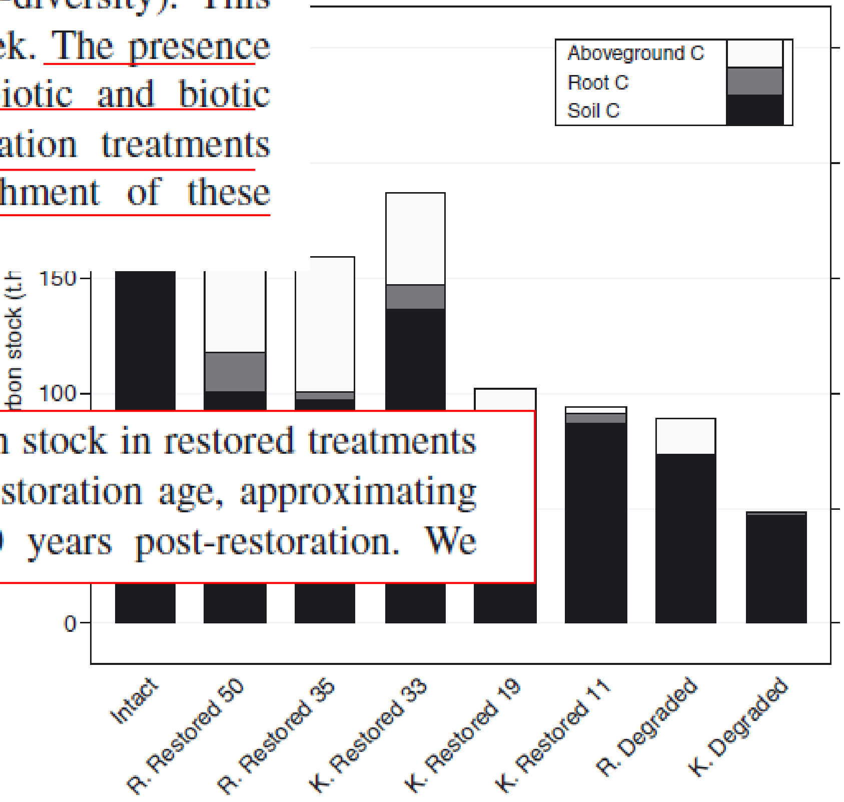


Figure 3. Box plots showing abundance scores of recruits (indi
explanation of score categories. Prefix "R." denotes stands at R
number appended indicates the number of years under restorati

Our results show that total carbon stock in restored treatments increased with increasing post-restoration age, approximating that of intact spekboomveld 50 years post-restoration. We



The Influence of Soil Properties on the Growth and Distribution of *Portulacaria afra* in Subtropical Thicket, South Africa

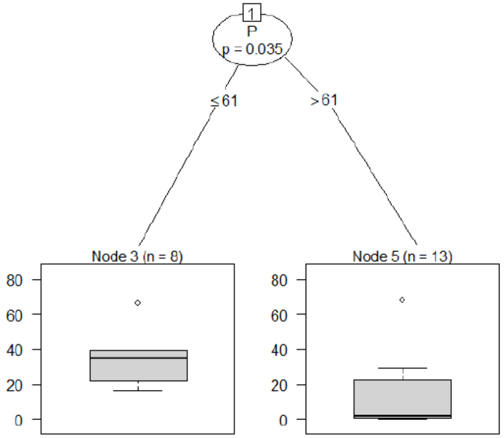


Figure 4.10: Results from the conditional inference tree analysis of active spekboom growth in restoration plots in Addo, Baviaanskloof and Calitzdorp, considering only soil characteristics. The bottom boxes/ nodes express active growth percentages as box plots.

January 2013

Supervisor: Dr. C. Coetsee
Co-Supervisor: Prof. R.M. Cowling

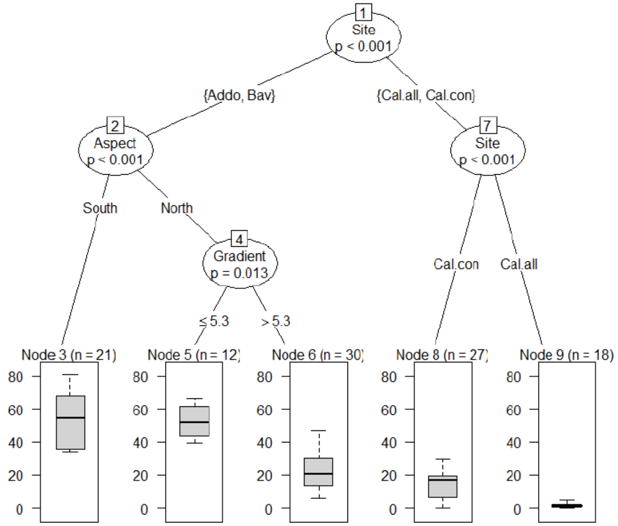


Figure 4.8: Results from the conditional inference tree analysis of active spekboom growth in restoration plots in Addo, Baviaanskloof and Calitzdorp, taking into account all explanatory variables. Addo, Bav, Cal.all and Cal.con are abbreviations for the different restoration sites, where Bav = Baviaanskloof, Cal = Calitzdorp, al = alluvium type soils, con = conglomerate type soils, the latter two seen in close proximity to each other at Calitzdorp. The bottom boxes/ nodes express the percentage of actively growing plants as box plots.

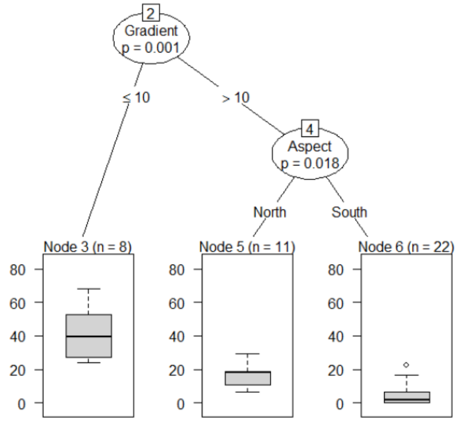


Figure 4.9: Results from the conditional inference tree analysis of active spekboom growth in restoration plots in Addo, Baviaanskloof and Calitzdorp, taking into account all explanatory variables apart from site. The bottom boxes/ nodes express the percentage of actively growing plants as box plots.

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rson[1], Janet Franklin[2]

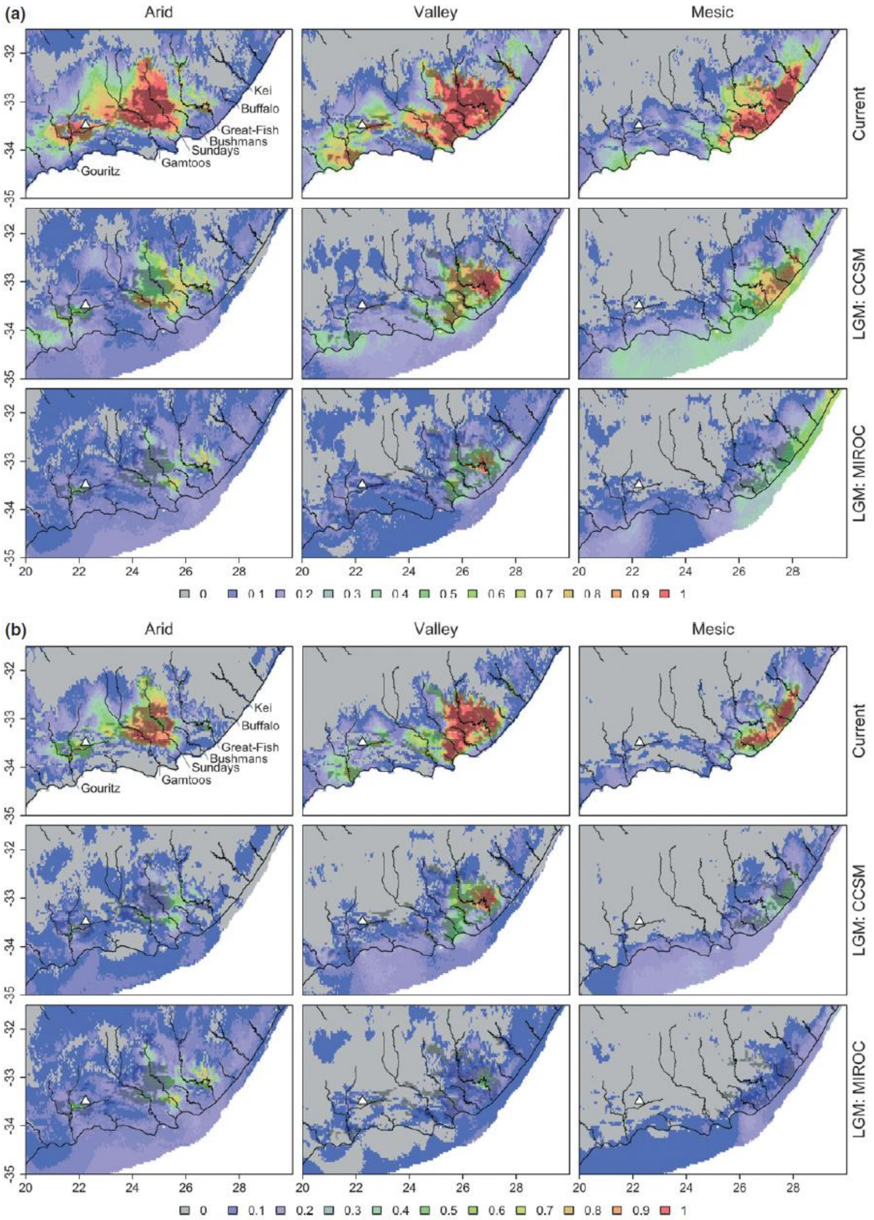
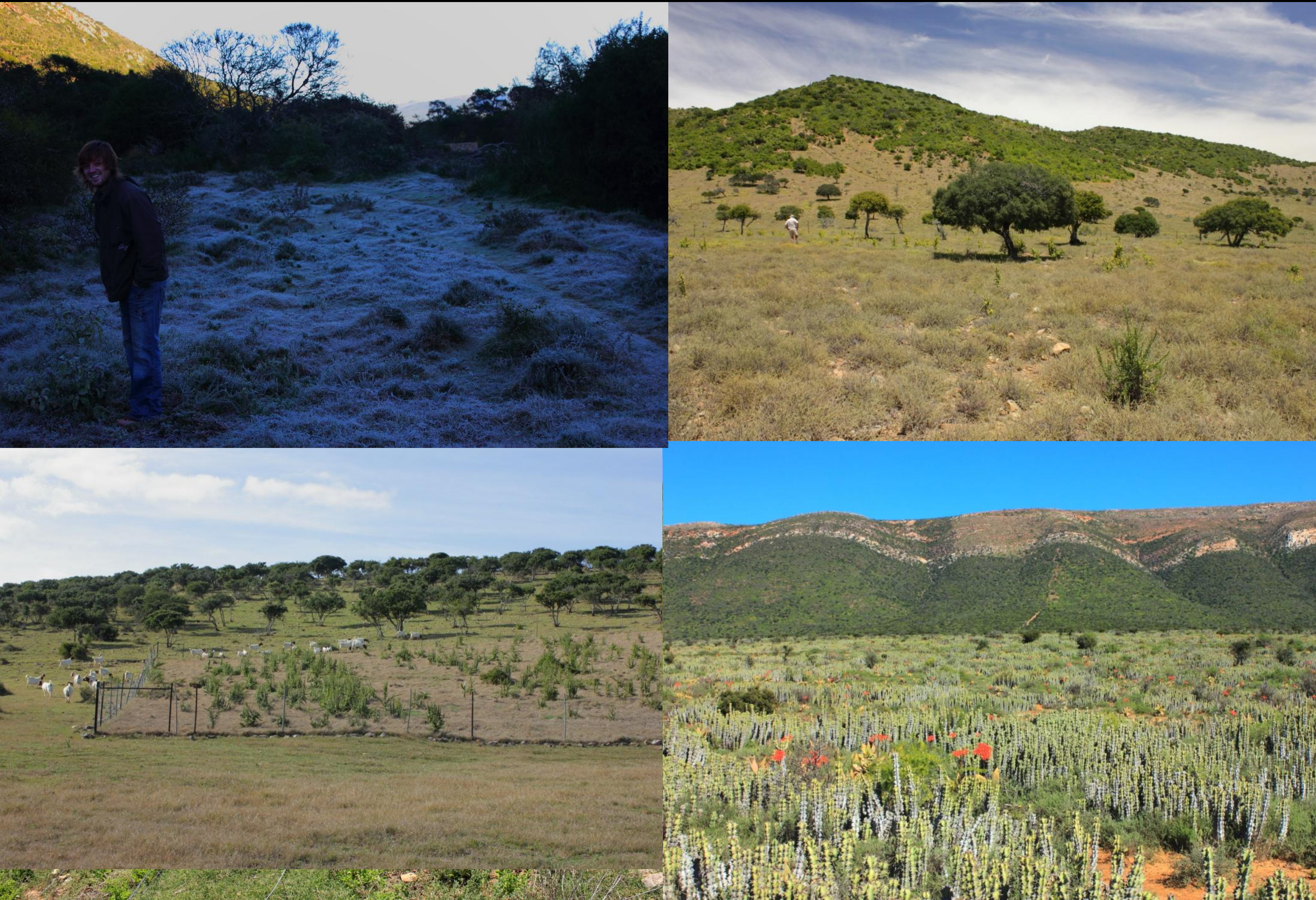


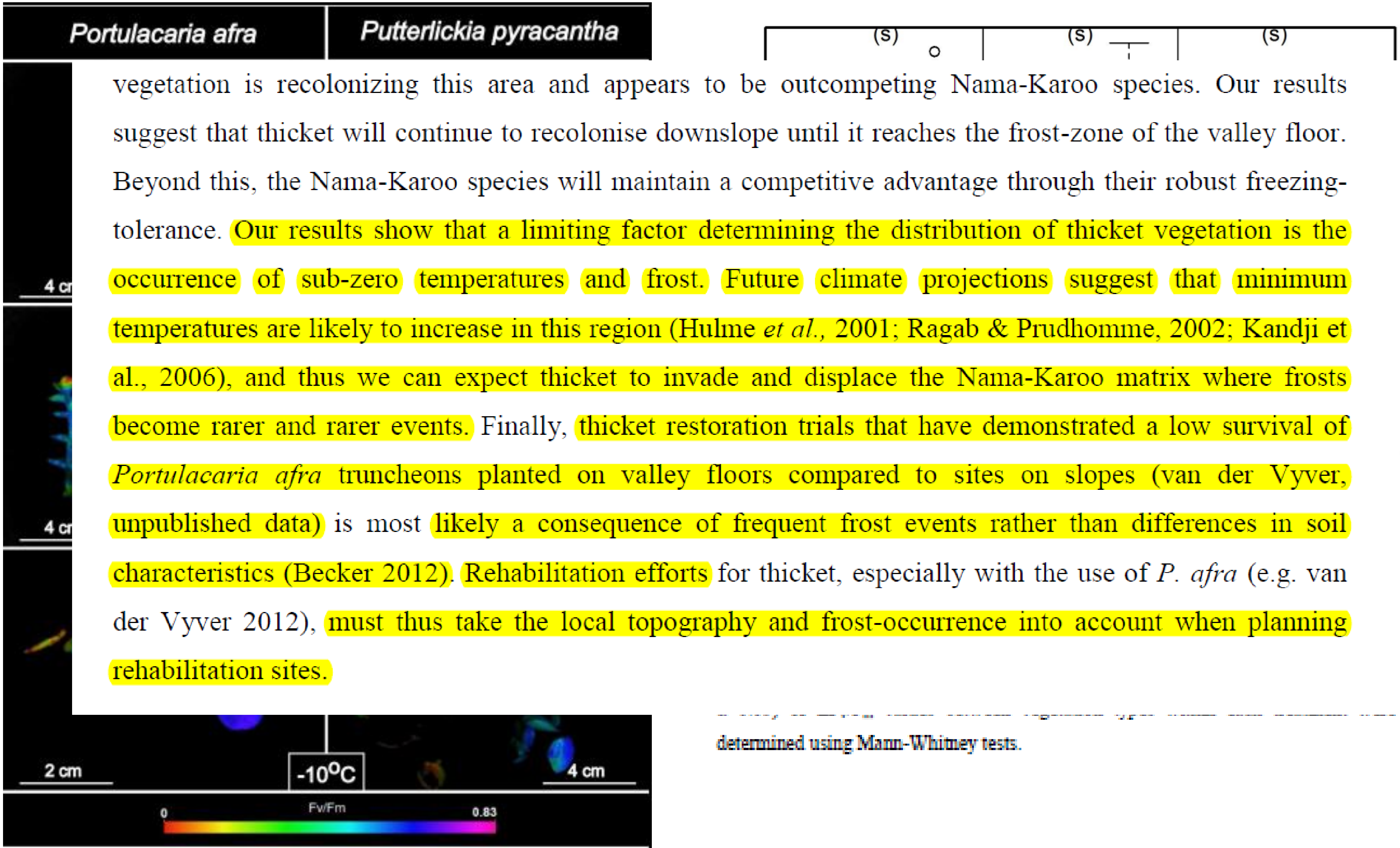
Figure 4 Maps showing the percentage agreement of Albany subtropical thicket (AST) subtypes for the 216 maps of current and Last Glacial Maximum (LGM) climate conditions using (a) low and (b) high threshold criteria (maximum sensitivity plus specificity and maximum kappa, respectively). Shadowed areas indicate the current distribution of the respective AST subtype. LGM conditions are generated from two global climate models [Community Climate System Model (CCSM) and Model for Interdisciplinary Research on Climate (MIROC)]. Grey indicates absence in all maps, red indicates greater certainty of presence, blue indicates greater certainty of absence, and green indicates areas of greatest uncertainty. The 216 maps are generated using six unique locality data sets per subtype, six environmental parameter sets and six different modelling algorithms (generalized linear models, generalized additive models, Domain, Bioclim, random forests and Maxent). The location of Boomplaas Cave (discussed in text) is shown (white triangle).

Current Research:



The effects of frost on subtropical thicket and Nama-karoo shrubland: – ecophysiological control of a biome boundary

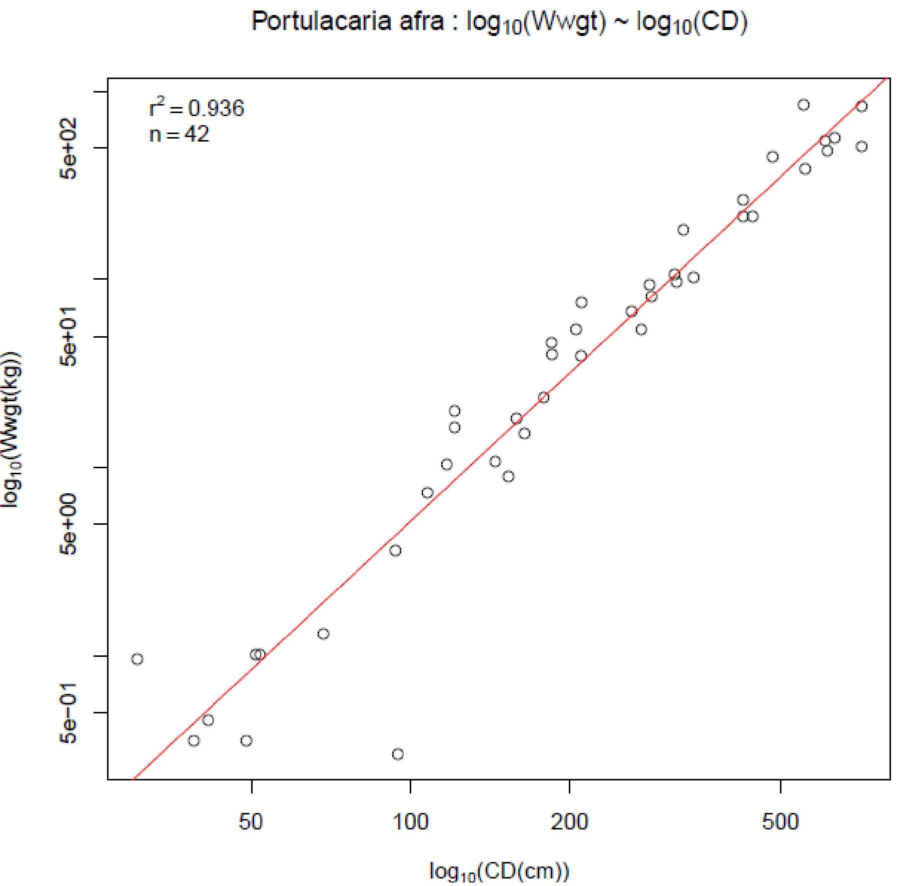
Robbert Duker, Richard M. Cowling, Derek R. du Preez, Marius L. van der Vyver, Clayton R. Weatherall-Thomas, and Ian T. Ritchie, Alastair J. Potts.



vegetation is recolonizing this area and appears to be outcompeting Nama-Karoo species. Our results suggest that thicket will continue to recolonise downslope until it reaches the frost-zone of the valley floor. Beyond this, the Nama-Karoo species will maintain a competitive advantage through their robust freezing-tolerance. Our results show that a limiting factor determining the distribution of thicket vegetation is the occurrence of sub-zero temperatures and frost. Future climate projections suggest that minimum temperatures are likely to increase in this region (Hulme *et al.*, 2001; Ragab & Prudhomme, 2002; Kandji et al., 2006), and thus we can expect thicket to invade and displace the Nama-Karoo matrix where frosts become rarer and rarer events. Finally, thicket restoration trials that have demonstrated a low survival of *Portulacaria afra* truncheons planted on valley floors compared to sites on slopes (van der Vyver, unpublished data) is most likely a consequence of frequent frost events rather than differences in soil characteristics (Becker 2012). Rehabilitation efforts for thicket, especially with the use of *P. afra* (e.g. van der Vyver 2012), must thus take the local topography and frost-occurrence into account when planning rehabilitation sites.

determined using Mann-Whitney tests.

300 Thicket-wide Plots (0.25 ha) Experiment


Portulacaria afra : $\log_{10}$(Wwgt) ~ $\log_{10}$(CD)
$r^2 = 0.936$
n = 42
$\log_{10}$(Wwgt(kg))
5e+02
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5e-01
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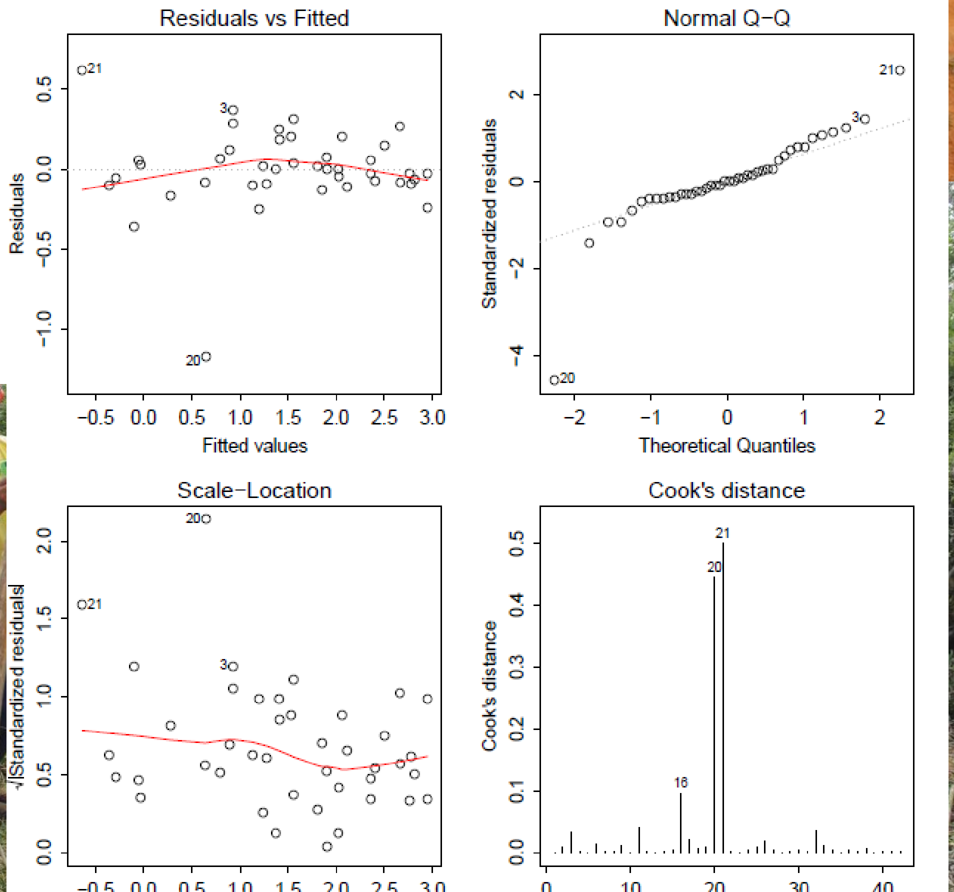
$\log_{10}$(CD(cm))


Residuals vs Fitted
Residuals
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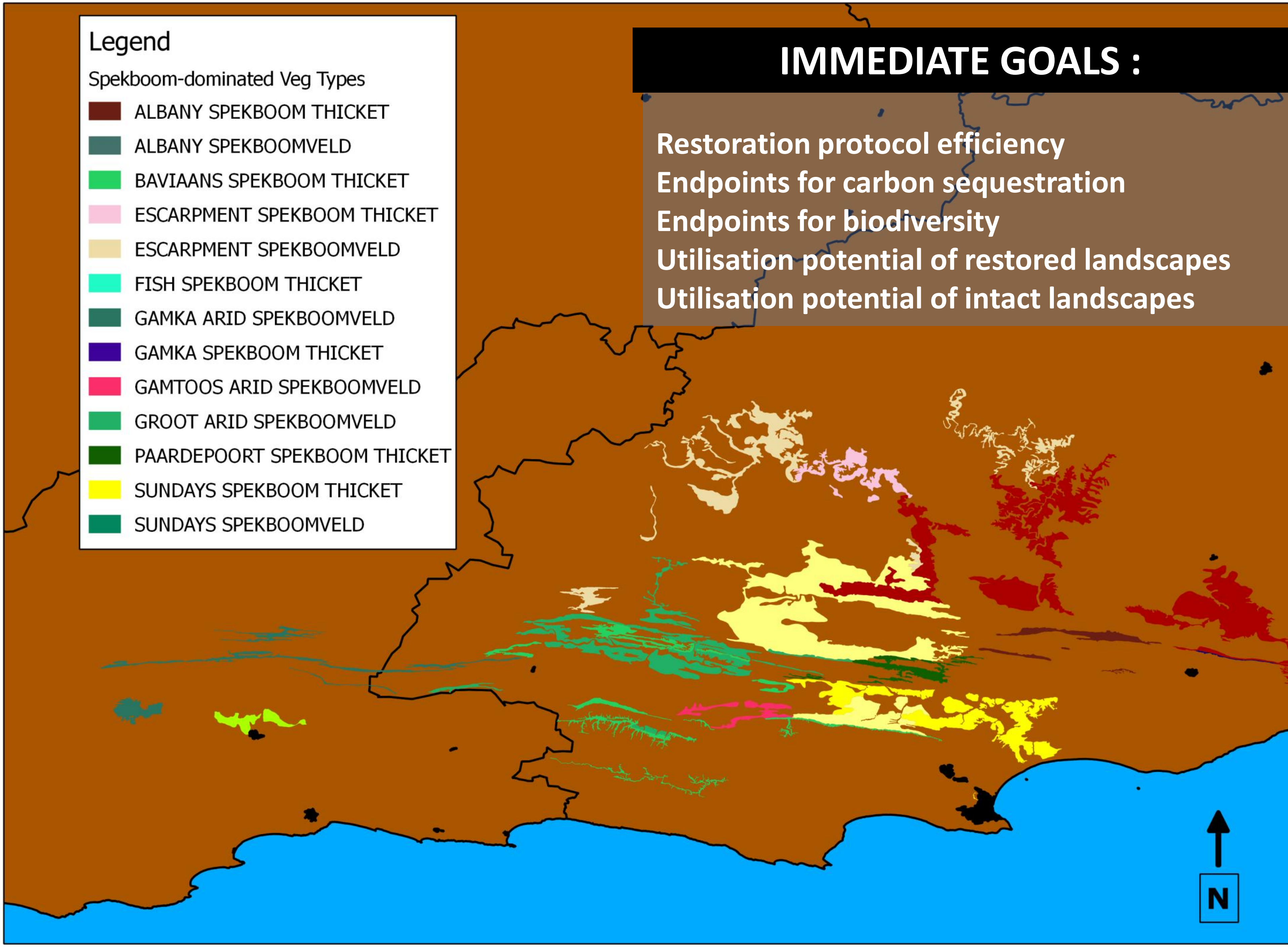
IMMEDIATE GOALS :



Restoration protocol efficiency
Endpoints for carbon sequestration
Endpoints for biodiversity
Utilisation potential of restored landscapes
Utilisation potential of intact landscapes

Contact Details:
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NRF