CARBON SEQUESTRATION AND RESTORATION: CHALLENGES AND OPPORTUNITIES IN SUBTROPICAL THICKET

[1]M. Powell, [2]A. Mills, and [3]C. Marais
[1] Subtropical Thicket Rehabilitation Project, Patensie
[2] South African National Biodiversity Institute, Claremont, and
Department of Soil Science, University of Stellenbosch
[3] Working for Water Programme, Cape Town

Abstract

The subtropical thicket biome covers approximately 17% of the surface area of the Eastern Cape province. The STEP project has reported that large areas of thicket have been seriously degraded, principally through injudicious stock management practices. A substantial percentage of the STEP's 112 subtropical thicket types has *Portulacaria afra* (spekboom) as a canopy dominant, or major constituent of the aerial plant biomass. *Portulacaria afra*, and other succulents are susceptible to overstocking, often being completely removed from the landscape. This culminates in disrupted nutrient cycles, slow rates of water infiltration, poor water-use efficiency and leads to a state of desertification that is difficult to reverse. Intact subtropical thicket has unusually large stocks of ecosystem carbon, and *P. afra* has a fast growth rate for a semi-arid adapted species. In light of the above and the recent development of carbon sequestration projects worldwide, the Subtropical Thicket Rehabilitation Project was launched in January 2004 with the explicit aim of testing the feasibility of using *P. afra* and other thicket species to sequester carbon under the Clean Development Mechanism of the Kyoto Protocol. Restoration of degraded subtropical thicket would achieve the combined aims of improving rural livelihoods, restoring biodiversity, and replenishing natural capital/ecosystem services. A baseline methodology to assess plant species diversity and carbon stocks at the landscape and patch level is outlined. In addition, preliminary insights into *P. afra* survivorship are presented and the major challenges facing the development of a landscape scale restoration exercise are discussed.

1. Introduction

1.1 Subtropical thicket

The Thicket Biome, and in particular the subtropical thicket component, is centred predominantly within the Eastern Cape province (Low & Rebelo, 1996). In an intact or pristine condition the vegetation is typically a short, evergreen, compact, continuous canopy of short trees, shrubs, succulents, forbs, bulbs and vines (Low & Rebelo, 1996). This dense aggregation of plants supports a relatively high species diversity of browsing mammals (Skead, 1987), suggesting a long period of co-evolution (Kerley *et al.,* 1995), but, somewhat surprisingly, it appears to be ill-equipped to sustain domestic livestock (Stuart-Hill, 1992). Another surprising aspect of subtropical thicket is that ecosystem carbon storage is unusually large for a semi-arid environment (Mills *et al*., 2005). Clues for unravelling these puzzles may lie in the dominance of *Portulacaria afra* (i.e spekboom) across vast areas in many subtropical thicket types (Vlok *et al.,* 2003) and its ability to fluctuate between crassulacean acid metabolism (CAM, whereby plants reduce water losses by absorbing carbon dioxide at night) and C3 photosynthetic pathways (Ting & Hanscom, 1977) which can result in enhanced productivity in semi-arid environments.

1.2 Degradation levels

Despite the fact that subtropical thicket has been shown to have considerable economic value if the vegetation structure remains intact (Sims-Castely, 2002), nearly all forms of subtropical thicket have moderate to severe levels of degradation (Lloyd *et al*., 2002). Succulent thickets (i.e. *P. afra* thickets) are particularly prone to degradation (Lechmere-Oertel *et al.,* 2005), primarily as a result of overstocking with small stock (Stuart-Hill, 1992). Such degradation can result in a loss of 75% total dry biomass due to the replacement of spekboom with ephemeral grasses and forbs. There is also a predictable and major change in species composition, vegetation structure and complexity, with the ultimate loss of the canopy dominants e.g. *Pappea capensis* (Lechmere-Oertel, 2003; Lechmere-Oertel *et al.,* 2005). Considerable reductions in soil quality occur during degradation, with declines in soil carbon stocks, soil nitrogen stocks and an increased tendency of soils to crust (Mills & Fey, 2004). Severely degraded thicket exhibits impaired ecosystem services, and has a very low probability of recovery without intervention (Stuart-Hill & Aucamp, 1993; Turpie *et al*., 2003; Sigwela, 2004). A clear practical understanding of key interventions required to reverse thicket degradation is currently lacking. *Portulacaria afra* can potentially play a role in thicket restoration because it can grow from cuttings and fixes large amounts of carbon in both soils and biomass at the landscape scale (Lechmere-Oertel, 2003; Mills *et al*., 2006). Within the thicket vegetation types, spekboom veld or spekboom thickets, which have *P. afra* as a canopy dominant (Vlok *et al.,* 2003) are largely restricted to the Eastern Cape (Lombard *et al.,* 2003). The scale of degradation and the costs of restoration indicate that considerable financial investment will be required to restore intact thicket (Lechmere-Oertel, 2003).

1.3 Global warming and carbon sequestration

The current level of atmospheric carbon dioxide exceeds levels not reached for the past four hundred and twenty thousand years. The main factor driving the change in atmospheric carbon dioxide levels is anthropogenic activities, mainly the burning of fossil fuels and land use change (Prentice *et al*., 2001; Watson *et al*., 2000). This increase in atmospheric carbon dioxide in turn is changing the world's climate (Houghton *et al*., 2001). Van Jaarsveld & Chown (2001) predicted that impacts of global change for South Africa could have dire consequences for SA's biodiversity, most likely in the form of range contractions and species compositional changes, including extinctions. The authors warn that transformed habitats are likely to be most affected, with subtropical thicket being a potential case in point. To abate a continued increase in atmospheric carbon dioxide levels, the United Nations Framework Convention on Climate Change (UNFCCC) has been established and requires that developed countries reduce their emissions.

To facilitate a reduction in overall emissions, an allowance is made under Article 12 of the Kyoto Protocol for the establishment of carbon sequestration projects in developing countries. The carbon sequestered through such a project, seen as a carbon credit, can be offset against the carbon budget of the country or can be traded for a fee. This process is known as the Clean Development Mechanism (CDM). For developing countries, it provides a source of funding for land restoration projects. The complicated market forces within the global carbon market are, however, far from understood (Williams *et al*., 2005) which makes financial feasibility studies difficult

Portulacaria afra is an appropriate species for thicket restoration (Swart & Hobson, 1994), and has an unusual ability to rapidly fix carbon in semi-arid environments: up to 0.42 kg C m^{-1} yr^{-1} (Mills & Cowling, 2006). Carbon storage within intact subtropical thicket can exceed 200 t C ha^{-1} (Mills *et al*., 2003; 2005; Skowno, 2003) and is possibly linked to the dominance of *P. afra* in some areas. An interesting aspect of carbon storage in subtropical thicket is its distribution in the landscape. In a study near Kirkwood, the bulk of carbon was stored in the soil (an average value of 168 t C ha^{-1}), with root carbon contributing a further 25 t C ha^{-1}, and above-ground carbon a further 52 t C ha^{-1}, totalling 245 t C ha^{-1} (Mills *et al*., 2005).

Furthermore, trial work by Swart and Hobson (1994) suggests that *P. afra* could be the most cost effective method of rehabilitating large areas of the subtropical thicket biome. Despite the high rates of carbon sequestration reported by Mills and Cowling (2006), initial assessments by Turpie *et al*. (2003), using conventional approaches and discount rates, indicate that [at] the rate of recovery for subtropical thicket the wide-scale employment of carbon sinking would not be a financially viable land use practice.

2. The Subtropical Thicket Rehabilitation Project

The Department of Water Affairs and Forestry has initiated a pilot project to assess the viability of using primarily *P. afra* to restore large areas of subtropical thicket. A strong initial focus will be on the potential role of carbon sequestration as a funding source. However, the growing interest worldwide in payments for ecosystem services (PES), has lead to investigation of other funding streams within the project. The Subtropical Thicket Rehabilitation Project aims to provide several key deliverables, namely improved water retention and quality, restoration of biodiversity, sequestration of carbon, containment of cactus (*Opuntia* spp.) and reversal of desertification, with the ultimate aim of kickstarting a larger restoration project across the entire biome.

2.1 General strategy

Areas of degraded subtropical thicket were surveyed to determine baselines for plant species diversity and ecosystem carbon stocks (including above ground biomass, litter, roots and soil carbon). Adjacent intact areas were surveyed to assess targets for plant species and carbon stocks. The difference between degraded and intact sites gives an indication of the potential carbon and biodiversity credits that could be attained following successful restoration. Using the generally accepted model of capacity building and empowerment employed by the Working for Water Programme, contractor teams have been employed to harvest *P. afra* truncheons and to plant them in degraded sites. (Working for Water is aimed at controlling alien invasive weeds to improve water security, ecological integrity and the productive potential of the land through an empowerment programme). A propagation nursery has been established at the Kouga Dam to cultivate large volumes of woody plant species (creating further skills and capacity). These plants once hardened will be planted into the established spekboom matrix within the rehabilitated areas. A strong theme throughout the lifespan of the project is skills transfer, capacity building and striving towards economic independence for small contractor teams.

2.2 Scientific methods

The study area was divided into three nodes to cover the abiotic and environmental gradients. The nodes are located in the east, west and central areas of the Baviaanskloof Megareserve. At each node, plots were randomly selected using GIS software (ARCVEW 3.2). A minimum of 25 plots were laid out in both intact subtropical thicket vegetation and in degraded areas. All plots were surveyed using sub-meter (x, y coordinates) DGPS (Trimble) and marked in the field with steel pegs, and were designed in a nested manner. The 15m by 15m plot serves as a vegetation control block. Nested within this is a 5m by 5m plot (species diversity and allometry). Within the 5m by 5m is a 2m by 2m plot that is used to estimate non-woody plant biomass. Within the 2m by 2m is a 0.5m by 0.5m that is used to collect surface litter. In old lands allometry estimates were conducted in 25m by 25m plots. Fixed-point photography has been employed at all three nodes.

2.2.1 Species diversity baselines

Plant diversity was determined in 25 m^2 plots. Percentage cover was used as a surrogate for abundance and voucher specimens have been logged at the Schonland Herbarium in Grahamstown.

2.2.2 Allometry

The use of indirect methods to estimate standing carbon stocks (aerial plant biomass) closely follows recommendations made by Scholes (2004). A minimum number of trees/shrubs (n = 30) per species were sampled across a wide size range. Stem number, plant height and mean canopy diameter were recorded prior to plants being destructively harvested. Each plant was systematically separated into leaves, branches, thorns, flowers, fruit and main stem for carbon partitioning estimates. Sub-samples were dried using a modified fruit-drying oven at 60^{o}C to constant weight. Species were chosen to represent a number of guilds, with at least 3 species selected per guild. The guilds included: canopy dominant trees (e.g. *Pappea capensis*), woody shrubs (e.g. *Grewia robusta*), multiple-stemmed shrubs (e.g. *Putterlickia pyracantha)*, succulent shrubs (e.g. *Crassula ovata*) and succulent trees (e.g. *Aloe speciosa* and *Euphorbia grandidens*). Later the guilds of megastems (i.e. plants with exceptionally large numbers of thin stems) and small bushes were included (e.g. *Plumbago auriculata* and *Pteronia incana*, respectively). All plant material has been catalogued and stored for carbon auditing purposes. The measurements for each species/guild will be used to establish reliable relationships for total aerial plant carbon.

2.2.3 Carbon

Woody aerial plant carbon will be estimated using allometric equations derived from destructive harvesting. Herbaceous aerial carbon was estimated by harvesting all non-woody plants within 2m by 2m plots. Surface litter was sampled from the 0.5m by 0.5m plots and root carbon was estimated from samples taken at 3 depths (1-3cm, 3-10cm and 10-25cm). At each depth, roots were extracted by wet-sieving using a 2mm sieve. Roots finer than 2mm were deemed “soil organic matter”. All biomass samples (above-ground, litter and roots) were dried at 60^{o}C. Rock mass and volume were determined at each site and each depth. Bulk density estimates were made at each site at all depths by volume replacement (using sand of a known particle size distribution). Soil samples were taken for laboratory analysis (Walkley-Black soil carbon) at all sites at all depths. All samples have been catalogued and stored for carbon auditing purposes.

2.2.4 Paddock planting trials

Using digital aerial photography from 2004, a number of sites across the Baviaanskloof Megareserve were identified as degraded. Contractor teams of 10 people were employed to harvest spekboom truncheons, prepare holes and plant truncheons. Mortality assessments were made for each planting trial, six months after planting. Truncheon planting size and spacing were varied to ascertain best practice.

2.3 Preliminary results

Portulacaria afra mortality in the field plantings (paddock size contracts) have been providing mixed results. Mortality for newly planted spekboom truncheons is highly variable. Desiccation prior to root establishment is suspected to be a major factor behind mortalities in some areas. Unexpected mortalities have arisen from a host of other sources, often operating in concert. Damage in the form of browsing from donkeys, baboons and kudu has been the single most disruptive factor. Winter 2005 reportedly brought the most severe frost event in more than two decades. Accidental runaway fires, rodents ring-barking stems, grass competition and fungal attack have all contributed to high mortalities in some areas. A high soil moisture content immediately prior to planting appears to promote fungal attacks and is thought to be a factor behind some mortality. Where the above factors have been avoided, mortality is negligible. The present challenge is thus to devise methodologies that will minimise risks such as excessive herbivory, fires, grass competition and fungal attacks.

3. Major challenges

3.1 Looking for attention – subtropical thickets

The thicket biome has only been formally recognised for a decade (Low & Rebelo, 1996). This may help to explain the lack of high profile attention for **thickets** in national woodland policy (Grundy & Wynberg, 2001) and woodland symposia (Seydack *et al*., 2002). Given the extent of degradation, the value of the lost natural capital and the potential spin-offs from restoration, we suggest that DEAT and Department of Agriculture should become co-custodians of the restoration effort.

3.2 Research generalisations

The botanical diversity, community composition and structural complexity between the 112 thicket types (Vlok & Euston-Brown, 2002) challenges the research generalisations drawn from highly localised studies, and sweeping statements regarding the behaviour and traits of subtropical thicket in general. A real need exists to qualify and quantify findings, relative to the specific thicket subtype as defined by Vlok and Euston Brown (2002). For example, the possible relationship between *P. afra* abundance (percentage canopy cover/volume) and the rate of ecosystem carbon accrual for degraded sites following **restoration** intervention in different thicket types warrants investigation.

3.3 Holistic land use planning and Integrated conservation planning

Cowling *et al.* (2006) have provided us with timely warning as to the dangers of proceeding with large-scale restoration projects without the appropriate forethought and planning. They argue convincingly that without a conceptual framework, any initiative is likely to fail. This would entail comprehensive stakeholder engagement and endorsement as well as clear targets. South Africa has not yet risen to the challenge of attempting restoration of degraded landscapes on a regional scale (Milton *et al.,* 2003). The scale of the degradation in subtropical thicket could arguably place subtropical thicket restoration as the biggest restoration challenge facing the country at the moment. The fruits of recent and comprehensive bioregional conservation planning initiatives (as applied to local authorities) are available (Pierce, 2003; Pierce *et al*., 2005). In the likely event of limited funding, the challenge would be to align restoration spatial plans with spatial targets already recommended (Roguet *et al*., 2005). The concept of “emerging ecosystems” in a South African context is relatively novel (Milton, 2003). The pseudo-savannah state of degraded subtropical thicket (Lechmere-Oertel, 2003) is one such emerging ecosystem. Milton *et al.,* (2003) suggest that society will need to make decisions regarding the most appropriate management options (ranging from neglect to restoration) for these anthropogenically altered states, but critically employing a multidisciplinary cost-benefit analysis – for present and future users. Mills *et al*., (2006) suggest that there is potential in degraded thickets to create "hyper-beneficial" thickets, with an increased abundance of beneficial species. This approach requires testing and considerable amounts of planning and thought. A major provincial and national interdepartmental responsibility will be to manage the needs and aspirations of potential beneficiaries of carbon trading, and to ensure wise and sustainable development. Carbon investors may require cessation of pastoralism for a number of years, and this needs to be balanced with farmer needs and creation of alternative income streams.

3.4 Inter-departmental cooperation

The Department of Agriculture (2003) in the Western Cape have demonstrated considerable leadership in the field of integrated land use planning – through Land Care Area Wide Planning. The fundamental premise of the approach is to conduct resource problem solving, by integrating social, economic and ecological concerns beyond the individual land parcel. The concept needs to be rapidly expanded to the rest of the country, especially in the subtropical thicket biome. Subtropical thicket restoration across the region will undoubtedly fail if this does not happen. There has been a history of unsustainable land use practice bordering on subsidised desertification, within the Eastern Cape (see Figures 1 and 2 below).

Figure 1. Fence line contrast showing high levels of degradation in the Kirkwood area.

The full restoration of degraded subtropical thicket is going to require considerable financial and institutional resources, as well as a significantly long time line (with no guarantee of full ecosystem recovery). Society cannot allow the continued mining of natural capital through overstocking of livestock. The relevant authorities urgently need to start monitoring and controlling the unsustainable harvesting of agricultural resources in order to make land users accountable for their actions.

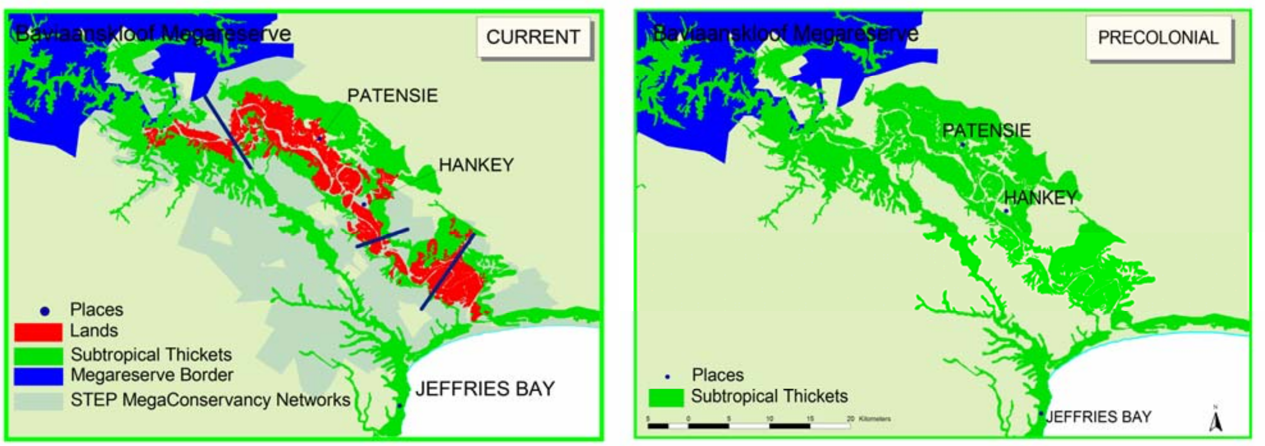

Figure 2. Pre-colonial Gamtoos Valley Subtropical Thicket and current degradation showing areas at risk of losing corridor connectivity.

3.5 Cracking the code to facilitated subtropical thicket regeneration

Although a matrix of *P. afra* may be returned to the spekboom-dominated thicket types by planting *P. afra* cuttings, the challenge of returning the full complement of species will be immense. Conventional restoration techniques have been shown to deliver poor results in degraded subtropical thickets (Todkill, 2001). Not only are many thicket plant species relatively slow growing relative to *P. afra,* but there is also very little evidence of natural recovery – probably as a result of poor seedling survival and lack of canopy recruitment (Sigwela, 2004). Frugivorous birds may play an important role in seed dispersal within subtropical thicket (Dean, 2002), explaining the high number of plant species with fleshy fruits (Vlok & Euston Brown, 2002). Vervet monkeys (Foord *et al.,* 1994) could also contribute to restoration programmes. Watson (2001) recognised mistletoes as keystone species in many parts of the world, often impacting on alpha diversity. Subtropical thickets have been shown to exhibit high levels of mistletoe species richness with a relatively wide variety of hosts (Dean *et al.,* 1994). The critical aspect of mistletoes with regard to subtropical thicket restoration is the strong association of *Viscum crassulae* with *P. afra* (Midgley & Joubert, 1991). Powell *et al*. (2004) advocated a combined approach of rehabilitating with *P. afra* truncheons (some infected with *V. crassulae*), and large specimens of *Aloe*, *Euphorbia*, *Crassula* and other succulent species, effectively creating instant bush structure. In so doing, the catalyst will be created for an accelerated increase in biodiversity (via zoochorous seed dispersal). This could effectively convert pseudo-savannah and old lands, through the initiation and growth of bush clumps, back to intact subtropical thicket. A significant need exists for more research trials into a number of aspects within subtropical thicket restoration, similar to those reported by Beukes & Cowling (2003) for succulent karoo.

3.6 Biodiversity offsets

Although biodiversity offset trading is considerably less developed than carbon trading, the possibility of future financial benefits to conserve biodiversity should be considered. A review by Ferraro & Kiss (2002) demonstrated that in many cases it was more cost-effective for conservationists to make direct payments, as opposed to incentive schemes. The Kyoto Protocol has provided strong financial incentives, while the Convention on Biodiversity less so. This could skew the balance in trade-offs between carbon storage and biodiversity (Capparos & Jacquemont, 2003). A clear national policy directive is required to guide this issue.

3.7 Mainstreaming and stakeholder participation

Biodiversity loss should receive as much priority as ecosystem functions in the policy making process for sustainable development (Milton *et al*., 2003). Furthermore, the prevention of further degradation will be more cost effective than trying to restore degraded landscapes. Where restoration is required the main challenge is to make it cost effective and to catalyse natural ecosystem recovery. Hobbs & Norton (2004) remind restoration practitioners that any ecosystem is complex and has the ability to reside at a number of altered states along an ecosystem trajectory. The position of these states is a function of a number of factors (such as the original natural state, the severity and nature of disturbance, and the nature and extent of restoration intervention).

To achieve large-scale restoration, it is critical that “mainstreaming” is adopted. Petersen & Huntley (2005) define mainstreaming as securing the goals (restoration or conservation) into the economic landscape, which would include development models, policies and programmes of the broader community. In a recent review of successful mainstreaming projects in South Africa (Pierce *et al*., 2002) “effective communication with key stakeholders” was often cited as a common denominator. Pro-poor development programmes in the developing world, for example in Africa and South America, can be used as vehicles to restore natural capital while mainstreaming it by placing job creation and economic empowerment on the social agendas of countries and international agencies.

4. The way forward

The Subtropical Thicket Rehabilitation Project complies with practically all the goals set out in the Forestry White Paper on Sustainable Forestry Development in SA (DWAF, 1997). These include *inter alia*:

- Fostering a spirit and ethic for stewardship for natural resources in the broader community
- Addressing rural poverty issues
- Encouraging local economic development

- Recognising the special value of woodlands and forest resources
- The need to halt and reverse desertification
- Sustainable land use management
- Inter-departmental cooperation and cooperative governance
- Promoting restoration of degraded forests and woodlands
- Providing incentives and small scale funding for conservation and restoration

Similarly the White Paper on Conservation and Sustainable use of South Africa's Biological Diversity (DEAT, 1997 cited in Grundy & Wynberg, 2001) sets goals that subtropical thicket restoration will assist in meeting. Furthermore, the Subtropical Thicket Rehabilitation Project is custom made to meet the multiple and cross-sectoral goals and objectives for the STEP Project as outlined in Knight *et al.* (2003).

At this early stage in the growth of the project (a subset of Working for Woodlands), a number of key interventions are urgently required to ensure sustainability and cooperative governance:

- Interdepartmental co-envisioning and co-operation as well as cross departmental policy coordination
- Increased NGO awareness and more vociferous ecological watchdogs
- Clear and unambiguous policy with regards to forest definitions relating to Kyoto and CDM
- Continued research into key aspects of horticultural, ecological, biogeographic, social and economic aspects of the subtropical thicket restoration
- Active and well-coordinated stakeholder engagement and a funded public awareness campaign
- Comprehensive (multi-tier) performance monitoring and accountability for state officials charged with safeguarding agricultural resources, biodiversity and natural capital.

5. Conclusion

The great vision by DWAF to initiate the project should be applauded. The initiative makes tangible contributions towards honouring national commitments to the Convention of Biodiversity, Kyoto Protocol and the Convention on Combating Desertification. Furthermore the project will restore natural capital, improve ecosystem functioning and rate of supply for ecosystem services, while provide employment and capacity building in rural areas. There can be little doubt that the Working for Water Programme is one of world's leading natural resource protection and restoration programmes. Any endeavour that annually mobilises thirty thousand un-employed and unskilled workers is likely to suffer growing pains. The Subtropical Thicket Rehabilitation Project (Working for Woodlands) aims to slipstream the ground breaking Working for Water initiative, distilling valuable lessons and avoiding painful ones.

Acknowledgements

Valuable comments were provided by Richard Cowling and Shirley Pierce. Data for agricultural development in the Gamtoos Valley, as well as the use of DGPS were provided by the Gamtoos Irrigation Board. GIS data for vegetation and degradation assessment were provided courtesy of the STEP Project. Colour digital photography was provided by the DWAF.

References

BEUKES, P.C. & COWLING, R.M. (2003). Evaluation of restoration techniques for the succulent karoo, South Africa. *Restoration Ecology* 11(3): 308-316.

CAPARROS, A. & JACQUEMONT, F. (2003). Conflicts between biodiversity and carbon sequestration programs: economic and legal implications. *Ecological Economics* 46(1): 143-157.

COWLING, R.M., PIERCE, S.M. & SIGWELA, A. (2006). Mainstreaming restoration: a conceptual and operational framework. In: ARONSON, J. MILTON, S. & BLIGNAUT, J. (eds.). *Restoring Natural Capital – Science, Business, and Practice*. Island Press, Washington (in press).

DEAN, W.R.J. (1994). The distribution of mistletoes in South Africa: patterns and species richness and host choice. *Journal of Biogeography* 21: 503-510.

DEAN, W.R.J. (2002). *Distribution patterns and habitat of avifauna in the thicket biome*. TERU report no. 41. University of Port Elizabeth. 32pp.
DEAT (1997). *White Paper on Conservation and Sustainable Use of South Africa's Biodiversity*. Department of Environment and Tourism, Government Printer, Pretoria.
Department of Agriculture (2003). Landcare areawide planning. Resource Conservation Division, Department of Agriculture Western Cape, Elsenberg.
DWAF (1997). *White Paper on Sustainable Forestry Development in South Africa*. Department of Water Affairs and Forestry Government Printer, Pretoria.
FERRARO, P.J. & KISS, A. (2002). Direct payments to conserve biodiversity. *Science* 298: 1718-1719.
FOORD, S.H., VAN AARDE, R.J. & FERRIERA, S.M. (1994). Seed dispersal by vervet monkeys in rehabilitating coastal dune forests at Richards Bay. *South African Journal Wildlife Research* 24 (3): 56-59.
GRUNDY, I. & WYNBERG,R. (2001). Integration of biodiversity into national forest planning programmes: The case of South Africa. CIFOR, Bogor. Indonesia.
HOBBS, R.J. & NORTON, D.A. (2004). Ecological filters, thresholds and gradients in resistance to ecosystem reassembly. In: TEMPERTON, V.M., HOBBS, R.J., NUTTLE, T. & HALLE, S. (eds.). *Assembly Rules and Restoration Ecology: Bridging the Gap Between Theory and Practice*. Society for Ecological Restoration International, Island Press. Washington.
HOUGHTON, J.T., DING, Y., GRIGGS, D.G., NOGUER, M., VAN DER LINDEN, P.J., DAI, X., MASKELL, K. & JOHNSON, C.A. (2001). *Climate Change: The Scientific Basis*. The Intergovernmental Panel on Climate Change Third Assessment Report. Cambridge University Press, Cambridge.
KERLEY, G.I.H., KNIGHT, M.H. & DE KOCK, M. (1995). Desertification of subtropical thicket in the Eastern Cape, South Africa: are there alternatives? *Environmental Monitoring and Assessment* 37: 211-230.
KNIGHT, A.T., BOSHOFF, A.F., COWLING, R.M. & WILSON, S.L. (2003). *Keeping People on the Land in Living Landscapes: A Co-operative Strategy for Conserving Landscapes and Enhancing Livelihoods in the Subtropical Thicket Biome, South Africa*. TERU Report No. 46. University of Port Elizabeth, Port Elizabeth, South Africa.
LECHMERE-OERTEL, R.G. (2003). The effects of goat browsing on ecosystem patterns and processes in succulent thicket, South Africa. Ph.D thesis. University of Port Elizabeth. Port Elizabeth, South Africa.
LECHMERE-OERTEL, R.G, KERLEY, G.I.H. & COWLING, R.M. (2005). Patterns and implications of transformation in semi-arid succulent thicket, South Africa. *Journal of. Arid Environments* 62: 459-474.
LOMBARD, A.T., WOLF, T. & COLE, N. (2003). *GIS coverages and spatial analysis for the Subtropical Thicket Ecosystem Planning* (STEP) Project. TERU Report 42: 78pp. University of Port Elizabeth. Port Elizabeth, South Africa.
LOW, A.B. & REBELO, A.G. (1996). *The Vegetation of South Africa, Lesotho and Swaziland*. Department of Environmental Affairs and Tourism, Government Printer, South Africa.
LLOYD, J.W., VAN DEN BERG, E.C. & PALMER, A.R. (2002). *Patterns of transformation and degradation in the thicket biome, South Africa*. TERU report no: 39. University of Port Elizabeth, Port Elizabeth. 88pp.
MIDGLEY, J.J. & JOUBERT, D. (1991). Mistletoes, their host plants and effects of browsing by large mammals in Addo Elephant National Park. *Koedoe* 34 (2): 149-152.
MILLS, A.J. & COWLING, R.M. (2006). Rate of carbon sequestration at two thicket restoration sites in the Eastern Cape, South Africa. *Restoration Ecology* 14 (1): 38-49.
MILLS, A.J., O'CONNOR, T.M., BOSENBERG, D.W., DONALDSON, J., LECHMERE-OERTEL, R.G., FEY, M.V., & SIGWELA, A. (2003). Farming for carbon credits: implications for land use decisions in South African rangelands. In: ALLSOPP, N., PALMER, A.R. MILTON, S.J., KIRKMAN, K.P. KERLEY, G.I.H., HURT, C.R. & BROWN, C.J. (eds.). *Seventh International Rangeland Congress*. Durban, South Africa. pp1458 – 1554.
MILLS, A.J. & FEY, M.V. (2004). Transformation of thicket to savanna reduces soil quality in the Eastern Cape, South Africa. *Plant and Soil* 265: 153-163.

MILLS, A.J., COWLING, R.M., FEY, M.V., KERLEY, G.I.H., DONLADSON J.S., LECHMERE-OERTEL,R.G., SIGWELA, A., & SKOWNO, A.L., A.L. & RUNDEL,, P. (2005). Effects of goat pastoralism on ecosystem carbon storage in semi-arid thicket, Eastern Cape, South Africa. *Austral Ecology* 30: 797-804.

MILLS, A.J., TURPIE, J.K, COWLING,R.M., MARAIS C, KERLEY, G.I.H., LECHMERE-OERTEL,R.G., SIGWELA, A. & POWELL, M.J. (2006). Assessing the costs, benefits and feasibility of subtropical thicket restoration in the Eastern Cape, South Africa. In: ARONSON, J., MILTON, S.J. & BLIGNAUT, J. (eds.). *Restoring Natural Capital – Science, Business, Practice.* Island Press, Washington (in press).

MILTON, S.J. (2003). 'Emerging ecosystems' – a washing-stone for ecologists, economists and sociologists. *South African Journal of Science* 99:404-406.

MILTON, S.J., DEAN, W.R.J., & RICHARDSON, D.M. (2003). Economic incentives for restoring natural capital in southern African rangelands. *Frontiers Ecology & Environment* 1(5): 247-254.

PETERSEN,C. & HUNTLEY, B.J. (2005). What is mainstreaming biodiversity? In: PETERSEN, C. & HUNTLEY, B.J. (eds.). *Mainstreaming Biodiversity in Production Landscapes*, Global Environment Facility. Washington, D.C. pp. 2-11.

PIERCE, S.M., COWLING, R.M., SANDWITH, T. & MACKINNON,K. (eds.) (2002). *Mainstreaming Biodiversity in Development : Case studies from South Africa*. World Bank, Washington D.C.

PIERCE, S.M. (2003). *The STEP Handbook. Integrating the natural environment into land use decisions at the municipal level: towards sustainable development*. TERU Report No. 47. University of Port Elizabeth, Port Elizabeth.

PIERCE, S.M., COWLING, R.M., KNIGHT, A.T., LOMBARD,A.T, ROUGET, M. & WOLF, T. (2005). Systematic conservation planning products for land-use planning: interpretation for implementation. *Biological Conservation* 125: 441-458.

POWELL, M.J., SKOWNO, A.L., MILLS, A.J. & KNOWLES, T. (2004). Providing a context for the rehabilitation of subtropical thicket. Proceedings of the Inaugural Thicket Forum. Zuurberg Inn. (unpublished).

PRENTICE, I.C., FARQUHAR, G.D. FASHAM, M.J.R., HEIMANN, G.M.L., JARAMILLO, V.J., KHESHGI, H.S., LE QUÉRÉ, C., SCHOLES, R.J. AND WALLACE. D.W.R. (2001). The Carbon Cycle and Atmospheric Carbon Dioxide In: HOUGHTON, J.T., DING, Y., GRISS, D.J., NOGUER, M. VANN DER LINDEN, P.J. DAI,X., MASKELL, K. & JOHNSON, C. A (eds.). *Climate Change 2001: The Scientific Basis.* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, United Kingdom and New York, USA. pp.183-237.

ROUGET, M., COWLING, R.M., LOMBARD, A.T., KNIGHT, A.T. & KERLEY, G.I.H. (2005). Designing large-scale conservation corridors for pattern and process. *Conservation Biology* 20 (2): 549-561.

SCOLES, R.J. (2004). Carbon storage in Southern African Woodlands. In: LAWES, M.J., EELEY, H.A.C., SHACKLETON, C.M. & GEACH, B.G.S. (eds.). *Indigenous Forests and Woodlands in South Africa: Policy, People and Practice*. University of KwaZulu-Natal Press, Pietermaritzburg, pp. 797-813.

SKEAD, C.J. (1987). *Historical mammal incidence in the Cape Province. Volume 2. The eastern half of the Cape Province, including Ciskei, Transkei and Griqualand*. The Chief Directorate Nature and Environmental Conservation of the Cape of Good Hope, Cape Town,

SEYDACK, A.H.W., VORSTER,T., VERMEULEN,W.J. & VAN DER MERWE,I.J. (eds.).(2002). *Multiple Use Management of Natural Forests & Woodlands: Policy Refinements & Scientific Progress.* Natural Forests & Savanna Woodlands Symposium III. Indigenous Forest Management -DWAF, Pretoria. 444pp.

SIGWELA, A.M. (2004). The impacts of land use on vertebrate diversity and vertebrate mediated processes in the Thicket Biome, Eastern Cape. Ph.D thesis, University of Port Elizabeth. Port Elizabeth.

SIMS-CASTLEY R. (2002). *A preliminary review of gross financial incomes generated by industries dependent on thicket vegetation*. TERU report no. 37. University of Port Elizabeth, Port Elizabeth.

SKOWNO, A.L. (2003). Indirect biomass estimation in subtropical thicket vegetation in the Eastern Cape Province, South Africa. Report for the Conservation farming Project. National Botanical Institute, Cape Town.

STUART-HILL, G. (1992). Effects of elephants and goats on the Kaffrarian succulent thicket, of the Eastern Cape, South Africa. *Journal of Applied Ecology* 29: 699-710.

STUART-HILL, G.C. & AUCAMP, A.J. (1993). Carrying capacity of the succulent valley bushveld of the eastern Cape. *African Journal of Range and Forage Science* 10 (1): 1-10.

SWART, M.L. & HOBSON, F.O. (1994). *Establishment of Spekboom*. Dohne Bulletin 3: Dohne Research Station, Stutterheim. pp. 10-13.

TING, I.P. & HANSCOM, Z. (1977). Induction of acid metabolism in *Portulacaria afra. Plant Physiology* 59: 511-514.

TODKILL, W.B. (2001). Towards the rehabilitation of degraded Subtropical Thicket in the Addo Elephant National Park. M.Sc. thesis, University of Port Elizabeth, Port Elizabeth.

TURPIE, J.K., LECHMERE-OERTEL, R., SIGWELA, A.M., ANTROBUS, G., DONLADSON, J., ROBERTSON, H., SKOWNO, A., KNIGHT, A., KOELLE, B., MILLS, A., KERLEY, G., LEIMAN, A. & VAN ZYL,H. (2003). The ecological and economic implications of conversion to game farming in the xeric succulent thicket of the Eastern Cape, South Africa. In: TURPIE, J.K. (ed.). *An Ecological-economic Appraisal of Conservation on Commercial Farmland in Four Areas of South Africa.* National Botanical Institute, Cape Town.

VLOK, J.H.J. & EUSTON-BROWN, D. (2002). *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*. TERU report no. 40. University of Port Elizabeth, Port Elizabeth.

VLOK, J.H.J., EUSTON-BROWN, D.I.W., & COWLING, R.M. (2003). Acock's Valley Bushveld 50 years on: new perspectives on the delimitation characterisation and origin of subtropical thicket vegetation. *South African Journal of Botany* 69: 27-51.

VAN JAARSVELD, A. & CHOWN, S.L. (2001). Climate change and its impacts in South Africa. Trends in *Ecology and Evolution* 16 (1): 13-14.

WATSON, R.T., NOBLE, I. R., BOLIN, B., RAVINDRANATH, N. H., VERADO, D. J. & DOKKEN, D. J. (2000). *Special Report on Land Use, Land-Use Change and Forestry*. Cambridge University Press, Cambridge.

WATSON, D.M. (2001). Mistletoe – a keystone resource in forests and woodlands worldwide. *Annual Review of Ecology and Systematics* 32: 219-249.

WILLIAMS, J.R. & PETERSON, J.M. & MOONEY, S. (2005). The value of carbon credits: is there a final answer? *Journal of Soil and Water Conservation* 60(2): 36-40.