Landscape Ecol (2010) 25:1231–1246
DOI 10.1007/s10980-010-9495-9

RESEARCH ARTICLE

Multi-functional landscapes in semi arid environments: implications for biodiversity and ecosystem services

P. J. O'Farrell · B. Reyers · D. C. Le Maitre · S. J. Milton · B. Egoh · A. Maherry · C. Colvin · D. Atkinson · W. De Lange · J. N. Blignaut · R. M. Cowling

Received: 23 September 2009 / Accepted: 27 May 2010 / Published online: 15 June 2010

Abstract Synergies between biodiversity conservation objectives and ecosystem service management were investigated in the Succulent Karoo biome (83,000 km^2) of South Africa, a recognised biodiversity hotspot. Our study complemented a previous biodiversity assessment with an ecosystem service assessment. Stakeholder engagement and expert consultation focussed our investigations on surface water, ground water, grazing and tourism as the key services in this region. The key ecosystem services and service hotspots were modelled and mapped. The congruence between these services, and between biodiversity priorities and ecosystem service priorities, were assessed and considered in relation to known threats. Generally low levels of overlap were found between these ecosystem services, with the exception of surface and ground water which had an 80% overlap. The overlap between ecosystem service hotspots and individual biodiversity priority areas was generally low. Four of the seven priority areas assessed have more than 20% of their areas classified as important for services. In specific cases, particular service levels could be used to justify the management of a specific biodiversity priority area for conservation. Adopting a biome scale hotspot approach to assessing service supply highlighted key management areas. However, it underplayed local level dependence on particular services, not effectively capturing the welfare implications associated with diminishing and limited service provision. We conclude that regional scale (biome level) approaches need to be combined with local level investigations (municipal level). Given the regional heterogeneity and varied nature of the impacts of drivers and threats, diverse approaches are required to steer land management towards sustainable multifunctional landscape strategies.

Electronic supplementary material The online version of this article (doi:10.1007/s10980-010-9495-9) contains supplementary material, which is available to authorized users.

P. J. O'Farrell (✉) · B. Reyers · D. C. Le Maitre · B. Egoh · A. Maherry · C. Colvin · W. De Lange
Natural Resources and the Environment, CSIR, P.O. Box 320, Stellenbosch 7599, South Africa
e-mail: pofarrell@csir.co.za

S. J. Milton
Renu-Karoo Veld Restoration, P.O. Box 47, Prince Albert 6930, South Africa

D. Atkinson
Research Cluster on Sustainable Development and Poverty Reduction, University of the Free State, Bloemfontein, PO Box 139, Philippolis 9970, South Africa

J. N. Blignaut
Department of Economics, University of Pretoria, ASSET Research, and Jabenzi, Pretoria 0001, South Africa

R. M. Cowling
Department of Botany, Nelson Mandela Metropolitan University, P.O. Box 77000, Port Elizabeth 6031, South Africa

Keywords Ecosystem service assessment · Grazing · Water · Tourism · Biodiversity hotspots · Climate change

Introduction

Classic conservation approaches with their narrow focus on species preservation and reserve design have increasingly been supplemented by new strategies in an effort to deal with the unprecedented scale of human impacts and often constrained resources (Fischer et al. 2006; Redford and Adams 2009). These new strategies complement formal protected areas, by focussing on the management of off-reserve areas and working landscapes which include humans and their production activities (Pence et al. 2003; O'Farrell et al. 2009b).

More recently these broader approaches have begun to focus on ecosystem services, the benefits that people derive from ecosystems (MA 2005; Diaz et al. 2006), as a way to include human needs and well-being into conservation strategies. The rationale behind these ecosystem service based approaches for conservation is that by understanding and mitigating the threats posed to ecosystem services one will also conserve the biodiversity that underpins these services, while at the same time increasing the relevance, incentives and funding resources of these conservation efforts (Vira and Adams 2009). Despite concerns around possible unintended negative consequences (McCauley 2006; Redford and Adams 2009; Vira and Adams 2009) and limited congruence between biodiversity and ecosystem services (Chan et al. 2006; Egoh et al. 2009; Reyers et al. 2009), ecosystem based approaches have grown in number and coverage over the past decade and are now a key focus of many conservation organisations and the subject of many research and development projects (Goldman and Tallis 2009; Tallis and Polasky 2009; Tallis et al. 2009).

A recent development, focused at a landscape scale (several thousand hectares), is the notion of landscape multi-functionality, which moves away from the traditional management of a single function landscape manipulated to, for example, either produce food or serve as a recreation area, to a landscape offering multiple environmental, social and economic benefits (de Groot 2006; Wiggering et al. 2006; Carpenter et al. 2009; Daily et al. 2009; Lovell and Johnston 2009a). The design and management of landscapes with multiple goals, including sustainable food production, biodiversity conservation, water production and job creation, holds the potential to improve both production and ecological functions and therefore the longer term resilience or sustainability of the landscape (McNeely and Scherr 2003; Nassauer and Opdam 2008). This is an appealing prospect and will require the consideration of the inherent contributions of various landscape features to multiple goals (Lovell and Johnston 2009a). Furthermore, it requires a thorough understanding of synergies, threats and trade-offs between multiple goals (De Fries et al. 2004; Rodriguez et al. 2006; Carpenter et al. 2009; Daily et al. 2009; Reyers et al. 2009), a good knowledge of the social context in terms of stakeholders, institutions and incentives (Cowling et al. 2008), and the ability to transfer all of this knowledge into the design and establishment of multi-functional landscapes (Nassauer and Opdam 2008).

This study investigated synergies at a landscape level between biodiversity conservation objectives and ecosystem service use and management as a first step towards understanding the potential for multi-functional landscapes and the fostering of sustainable agricultural practices. It was by no means a comprehensive assessment of all of the issues listed in the previous paragraph, rather it focused on the contribution of landscape features to ecosystem services, the beneficiaries of these services, their relationship with biodiversity priorities, and threats facing these services. By so doing the study aimed to identify possible synergies and trade-offs in the achievement of multiple goals.

The Succulent Karoo biome in western South Africa provides a suitable case study to apply the concept of multi-functional landscapes in semi-arid environments. The biodiversity of this region has received considerable research attention and is well documented (Cowling and Pierce 1999; Cowling et al. 1999a, b; Joubert and Ryan 1999; Seymour and Dean 1999; Todd and Hoffman 1999; Cowling et al. 2003; Anderson and Hoffman 2007; Cousins et al. 2007; Desmet 2007; Hoffman and Rohde 2007; Hoffman et al. 2007). The global significance of this biome, one of only two semi-arid global biodiversity hotspots or areas of extreme biological richness

(Mittermeier et al. 2005), has resulted in substantial investments in the assessment and management of the region's biodiversity through the Succulent Karoo Ecosystem Program (SKEP) (SKEP 2003b). Using a combination of technical expertise and stakeholder involvement, SKEP undertook a detailed conservation assessment. Here they identified both biodiversity priority areas for conservation (Fig. 1) and those areas that also contributed to the creation of living landscapes able to support all forms of life now and in the future (SKEP 2003b). SKEP did not explicitly assess the benefits humans get from these landscapes.

Our study complemented this SKEP biodiversity assessment with an ecosystem service assessment (MA 2003; Carpenter et al. 2009; Daily et al. 2009). The key ecosystem services and service hotspots were investigated, modelled and mapped. The congruence between these services, and between biodiversity priorities and ecosystem service priorities, was assessed and considered in relation to known threats to this area, in particular climate change. We conclude with some lessons learnt during the study on the opportunities and constraints offered by these broader approaches to the conservation of the region's biodiversity and ecosystem services through the adoption of a multi-functional landscape approach.

Methods

Study area

The Succulent Karoo is an arid to semi-arid biome in western South Africa. This biome is noted for its exceptional succulent and bulbous plant species richness, high reptile and invertebrate diversity, rich bird and mammal life, which make it the most diverse arid environment in the world (CEPF 2003; Desmet 2007; SKEP 2008). This globally important biodiversity hotspot is under significant pressure from a range of human impacts including mining, crop agriculture and overgrazing, inappropriate developments and projected climate change (Hoffman and Ashwell 2001; Hewitson and Crane 2006; Keay-Bright and Boardman 2006; Rouget et al. 2006; MacKellar et al. 2007; Thompson et al. 2009). These threats also place the social and economic systems here at risk. Agriculture is the primary land use activity in the biome, and while dominant activities vary from region to region within the biome, extensive livestock farming is the primary pursuit. Irrigated crop production, which generates relatively higher levels of income, is confined to those areas with reliable supplies of large volumes of water, and limited to the main river systems. The headwater catchments that provide the water for farming are all

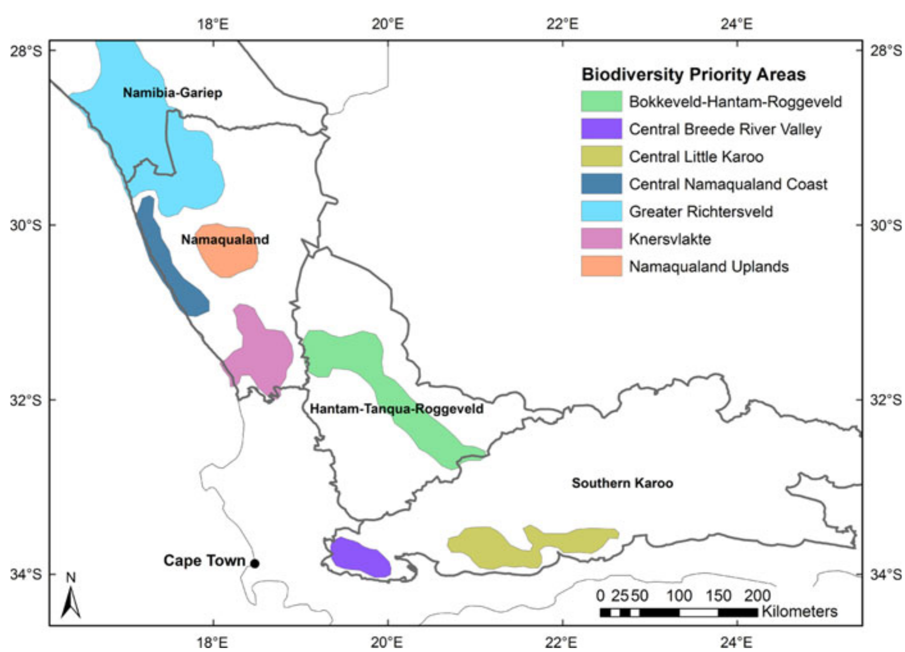

Fig. 1 The SKEP planning domain and the biodiversity priority areas for conservation. Based on SKEP data downloaded from the BGIS website (http://bgis.sanbi.org/skep/project.asp) in October 2008

found in the mountain areas outside of the Succulent Karoo biome. Copper and dimond mining have been historically important, but are now largely confined to the northern region (Carrick and Kruger 2007). Tourism has recently displaced mining and agriculture in certain regions (Hoffman and Rohde 2007), providing financial relief. The Succulent Karoo, like other semi-arid parts of the world, is home to some of the most vulnerable people and places in the country, and people depend on a variety of natural resources for their survival (James et al. 2005).

Identifying services

An extensive literature review focussed on all aspects of the Succulent Karoo was undertaken, and stakeholders and experts consulted, to identify the beneficiaries and the ecosystem services present in this biome. Eighteen different beneficiary groups were identified who collectively relied on 41 associated ecosystem services (Appendix 1, 2 in Supplementary material). The provision of three key services, namely: water supply, grazing provision, and tourism, which were directly linked to the 41 identified services, formed the focus of our analysis.

The Succulent Karoo biome boundary as defined by the national vegetation map was used in assessing grazing provision and tourism (Mucina et al. 2006). In the case of the water provision service, it was necessary to extend the service area boundary beyond that of the vegetation to align with the most basic hydrological units, these being the headwater catchments of the river systems of the Succulent Karoo (Midgley et al. 1994b). Within each of these defined areas the key services were modelled and the major threats discussed. Our approaches are discussed below.

Water

The assessment of water services drew on a variety of previous studies (Braune and Wessels 1980; Görgens and Hughes 1982, 1986; Midgley et al. 1994b; DWAF 2003a, b, 2004a, b, 2005; DWAF GRA2 2005). Both the water supply function and the flow regulation role that ecosystems play in the service of water provision were focussed on. The mean annual runoff according to catchments, and the mean annual groundwater recharge for the hydrological domain were mapped. Groundwater recharge is an important parameter for estimating how much groundwater is potentially available for use. The recharge was estimated from the rainfall and factored in underlying aquifer types (lithology) and long-term mean recharge estimated from sample points spread across the country (DWAF GRA2 2005).

Grazing

The grazing service spatial data were derived from the national vegetation map of South Africa (Mucina and Rutherford 2006) and the South African 1:250,000 maps of areas of homogeneous grazing potential (Scholes 1998). Scholes's (1998) approach to estimating grazing potential was adopted because it explicitly incorporates climate, soil type and vegetation and is been calibrated with long-term observations of stocking rates of wildlife and livestock systems that have not caused irreversible degradation. This approach estimates the potential mean carrying capacity of the land, not the actual available grazing, and therefore does not take the impacts of historical overgrazing into account.

Tourism

Understanding tourism as an ecosystem service requires the identification of the biodiversity, ecosystem and landscape features or assets that drive tourism, as well as the socio-economic features that drive its promotion and development. This has been recognised as being extremely difficult to achieve (European Communities 2008; Shackleton et al. 2008). In the case of the Succulent Karoo the best and most widely known tourism attractions are the diverse spring flowers (Turpie and Joubert 2001; James et al. 2007) and the relatively undeveloped landscapes with little (apparent) evidence of human impact (Reyers et al. 2009). To determine the travel routes followed by tourists, we examined tourist brochures and travel guides, contacted tourism associations, examined the Automobile Association's accommodation database (AA 2005) to determine where accommodation was located, and identified tourism features, including protected areas, heritage sites, and cultural features from the Environmental Potential Atlas database for South Africa (DEAT 2001). Tourism viewsheds, or areas visible to tourists (i.e., up to 10 km) travelling by road along the identified tourist routes, were then created. This line of sight analysis was corrected for changes in elevation, using the SRTM 90-m digital elevation model. Other landscape features considered to be tourist attractions were mapped as conservation areas (CSIR 2007). Therefore, we mapped this tourism service as a combination of tourism routes and their viewsheds, together with landscape features known to attract tourists.

Mapping hotspots and assessing congruence

The maps of ecosystem services were evaluated in terms of their area of production and overlap with one another. For the purposes of comparison, each map of ecosystem services was classified into high, medium, and low production classes. For the continuous variable maps of grazing production and water provision, these classes were determined using a Jenks natural breaks classification in ArcGIS® 9.2 (Environmental Systems Research Institute 2008). For the tourism map all areas of a viewshed were included as high production areas (Prendergast et al. 1993, 2008).

Following Egoh et al. (2008), overlap was assessed between high production areas, hereafter referred to as "ecosystem service hotspots", by assessing the proportional area of overlap as a percentage of the smallest hotspot (Prendergast et al. 1993). These hotspots are the key areas of service delivery requiring specific management, understanding and assessing threats.

We were specifically interested in the levels of congruence between ecosystem service hotspots and previously identified biodiversity priorities produced through the SKEP study (SKEP 2003a). How much of each priority area is covered by ecosystem service hotspots, and how much of the ecosystem service hotspots fell into priority areas was examined. The levels of overlap between all ecosystem service hotspots combined and the biodiversity priority areas were also considered. This was done to assess the utility of an ecosystem service approach in justifying the selection of the biodiversity priority areas and also to assess the value of the biodiversity priority areas for managing ecosystem services.

Results and discussion

Water

High regional variation in rainfall is responsible for the wide range in mean annual runoff rates (Fig. 2). All of the catchments to the north and west have less than 2.5 mm of runoff per year. The inhabitants of those areas are completely dependent on groundwater recharge from periodic heavy rainfalls, and ephemeral surface flows in the rivers which recharge alluvial aquifers. The south and central region (south of Nieuwoudtville, Fig. 2) has slightly higher runoff (>10 mm/year) compared with areas to the north, and the rivers in this region generally have a seasonal flow. The southern and eastern parts of the hydrological domain have relatively high levels of surface water runoff (>10 mm), the rain shadow areas in the interior being the exception.

The overall pattern of ground water recharge is dominated by the distribution of the rainfall but it is also strongly influenced by the higher recharge potential of the underlying geology in the mountain ranges (Fig. 3). The south western and central eastern regions are of key importance in ground water recharge. The amounts given (Fig. 3) are the mean recharge rates, the actual amounts will vary depending on the recent rainfall regime and, particularly in arid areas, the periodic occurrence of rainfall events that are large enough for the water to pass through the unsaturated zone and recharge the aquifer.

Arguably the greatest threat facing the Succulent Karoo biome and its inhabitants is climate change. Increases in air temperatures and declines in rainfall, particularly winter rainfall, are expected for most of this region (Hannah et al. 2002; Hewitson and Crane 2006; MacKellar et al. 2007). The reduction in rainfall will result in a greater reduction in surface and ground water availability, as relationships between rainfall and runoff are non-linear (i.e., the rainfall:runoff and rainfall:recharge ratios decline as rainfall decreases) (Midgley et al. 1994a; Zhang et al. 2001). Southern African data indicate a non-linear relationship between mean annual rainfall and mean recharge, with a steep decline in recharge once annual rainfall drops below 400 mm (Cavé et al. 2003). Furthermore, higher air temperatures will increase evaporative demand which will further increase soil moisture losses. The northern catchments are expected to be the most severely affected, moving towards a more extreme desert climate. In addition to climate change impacts, increased demand for water, wasteful use, and the depletion of fossil groundwater resources present further challenges.

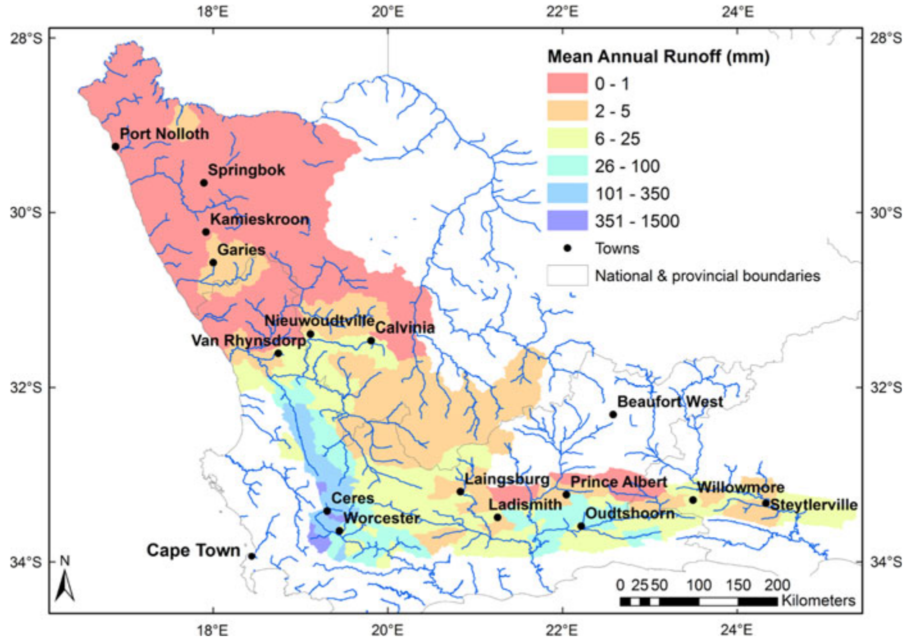

Fig. 2 Mean annual runoff per quaternary catchment, which ranges from 0.2 to 2.5 mm (for most of the north and interior) to 1,500 mm on the southwest

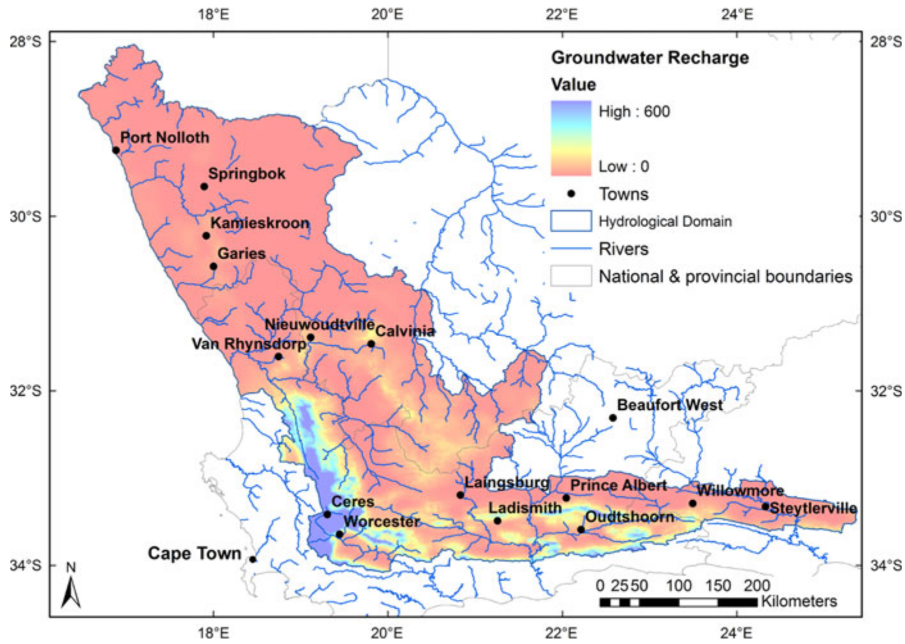

Fig. 3 Mean annual groundwater recharge (mm) in the hydrological domain of the Succulent Karoo (DWAF GRA2 2005)

Grazing capacity

The grazing capacity of the Succulent Karoo study area was found to be spatially heterogeneous (Fig. 4), largely following rainfall patterns and soil types. The grazing potential ranges from 18 to 22 LSU/km^2 right down to 0 to 1 LSU/km^2. Areas with the highest grazing potential are situated in the south of the region. Areas with moderate grazing potential are closely associated with areas of high potential, but also occur further north as well. Low potential grazing areas occur in all of the above locations, but are dominant in the west and far north. Most of the far northern region (Namaqualand) is in the 0–1 LSU/km^2 range and this is also the area where most of the non-commercial, subsistence livestock farming

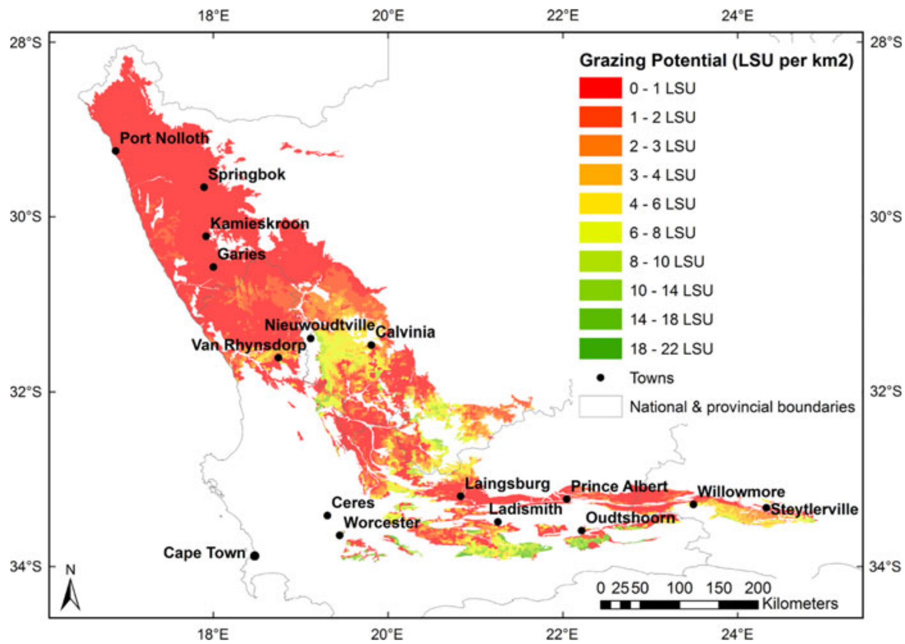

Fig. 4 Potential grazing capacity of the Succulent Karoo vegetation showing the homogenous areas that have the same large stock unit (LSU) capacity (based on Scholes 1998). Biome boundaries as defined by Mucina et al. (2006)

is practiced. This finding highlights the marginal nature and fragility of the grazing service in these areas where it is an important factor in peoples' livelihood security and value systems.

With soil moisture as the key driver of grazing production, reductions in rainfall will result in concomitant decreases in this service. However, more research is needed to address key uncertainties in assessing the magnitude of the impacts (Tietjen and Jeltsch 2007). The increase in the concentration of CO_2 in the atmosphere may increase the water-use efficiency, particularly of plants with C_3 photosynthetic pathways (Farquhar 1997). Biological soil crusts play an important role in soil stabilisation and in vegetation productivity through nitrogen fixation and, at least in some cases, increased water infiltration (Belnap and Lange 2003; Le Maitre et al. 2007a). Cover of biological crust is broken and reduced by livestock trampling making fine-textured soils vulnerable to erosion by wind and water (Esler et al. 2006). These crusts are also known to be sensitive to increases in temperature and decreases in rainfall which, combined with their sensitivity to ultraviolet radiation, makes them vulnerable to climate change (Belnap et al. 2004, 2008). Therefore, the utilisation of grazing services into the future may compromise service production under conditions of climate change.

The grazing services of the Succulent Karoo biome have been utilized for livestock production for around 2000 years (Deacon et al. 1978; Smith 1983). The indigenous Khoikhoi pastoralists followed a transhumance lifestyle moving livestock between different vegetation types according to seasons (Smith 1983), allowing them to access both water and grazing throughout the year (Penn 1986). These strategies were adopted by settlers to the region and continue being practiced today to a much lesser degree and in specific areas. This is largely due to political and economic development, and private land ownership, that has constrained movements to within specific areas, or between two farms with one being outside of the Succulent Karoo biome. Whilst movements are constrained, farmers perceive seasonal differences in vegetation types and move stock on a seasonal basis between these within one farm (O'Farrell et al. 2007). Transhumance movements between the Succulent Karoo and adjacent biomes historically stabilized subsistence economies, but changes in land tenure in the past century have led to sedentary grazing and damage to the resource base (Archer 2000; Beinart 2003; Hoffman and Rohde 2007). Additional damage to this grazing service was caused by ploughing of alluvial deposits for subsistence crops (Macdonald 1989; Thompson et al. 2009), and by overstocking, particularly with ostriches at high density on natural veld by supplementing the grazing with food purchased from outside the biome (Dean and Macdonald 1994; Herling et al. 2009).

Intensive heavy grazing resulting from a lack of mobility and access to sufficiently different grazing resources has resulted in changes in plant community composition within this biome (Todd and Hoffman 1999; Anderson and Hoffman 2007). Natural plant communities in valley bottoms have been demonstrated to have reduced cover and dominance of palatable species, and an increased dominance of unpalatable species under sustained heavy grazing (Allsopp et al. 2007). Anderson and Hoffman (2007) found that sustained heavy grazing results in a reduction in leaf succulent and woody plant cover, increases in dwarf shrub cover, and plant community functional composition shifts towards more ephemeral communities. These changes are a major cause for concern as grazing services become more tightly coupled to rainfall. Changes in rainfall will result in less grazing and poorer quality livestock with lower growth rates and, thus, decreased production of secondary goods such as meat and milk (Richardson et al. 2007), and increased livestock mortalities during drought periods (Anderson and Hoffman 2007).

Tourism

Our spatial analysis indicates that identified tourism service features varied across the Succulent Karoo biome. The north–south section (Namaqualand and Bokkeveld–Hantam–Roggeveld—Fig. 1) is characterised by its spring flower displays, and the east–west section (Southern Karoo—Fig. 1) is associated with scenic landscapes. We recognise that this represents only part of the tourism picture and excludes, for example, tourists who come on specialist birding or plant trips. However, to keep this assessment manageable we focused on the areas visited to view flowers, and on the routes which are advertised for their scenic attractions.

In the Namaqualand and the Bokkeveld–Hantam–Roggeveld regions, flower displays on transformed or previously ploughed lands, and protected areas, are key attractions (Fig. 5). Based on the numbers of AA rated tourist accommodation facilities, the urban centres of Oudtshoorn, Clanwilliam, and Springbok all feature as important tourism destinations, but accommodation is available even in small settlements. The important cultural and heritage features such as the Cederberg (east of Clanwilliam) and the Swartberg mountains north of De Rust (Fig. 5), both renowned for their San rock art, are on the margins of

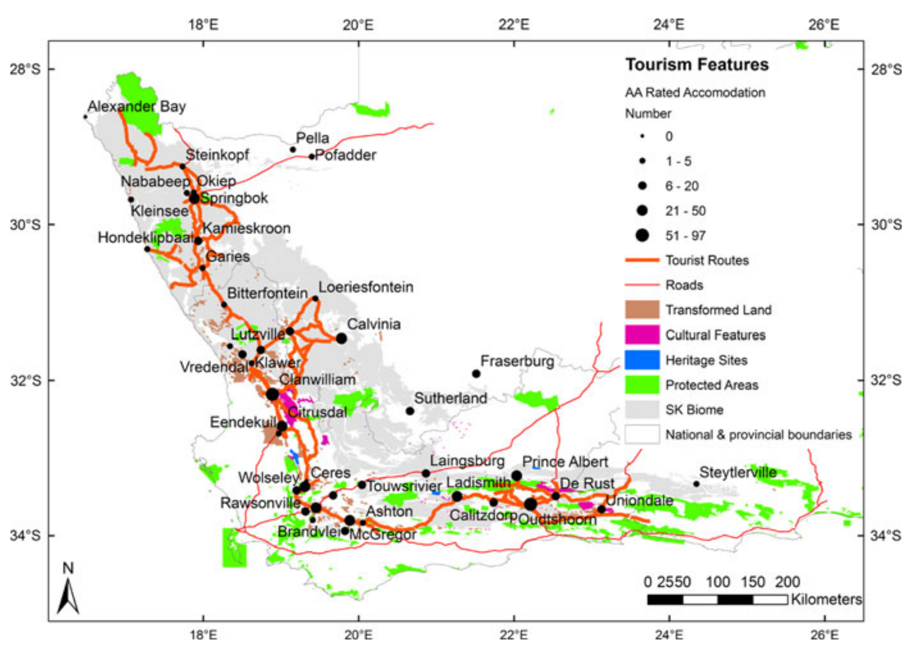

Fig. 5 Tourism features and tourist facilities in the Succulent Karoo based on data from the Environmental Potential Atlas (DEAT 2001) supplemented with accommodation data from the AA database (AA 2005). Tourism routes selected for this study

the Succulent Karoo biome. The major tourism routes within the south eastern region of the Succulent Karoo are popular for their scenery and the vistas characterised by wide open spaces with little obvious evidence of human impacts (Fig. 6). The analysis highlights the limited areas that tourists encounter and, unlike grazing, the viewshed is typically not a landscape or area-wide feature. There are many vantage points which provide extensive vistas over the Succulent Karoo, but because these are not situated in the biome itself, they were excluded from the assessment.

Climate change is also expected to have two major implications for tourism in this region, affecting both the biological attractions and constraining developments through water supply issues. Annual plant species which typify spring in the Namaqualand and Bokkeveld–Hantam–Roggeveld regions (Fig. 1) are directly cued by rainfall (Van Rooyen et al. 1990) and decreases in the size and probability of flower displays are highly likely to result in a decrease in flower tourism to the region (James et al. 2007). If temperatures increase beyond the optimal range then certain succulent species, for which this region is acclaimed, are likely to experience severe mortality and even become extinct (Musil et al. 2005; Midgley and Thuiller 2007). In addition, current tourism developments in this region are water intensive; thus water-use efficiency and equitable allocation would need to be considered if tourism is to continue as a growth industry. A change in mindset of both tourists and the tourism service industry, as well as the development and use of water efficient technologies are required.

Ecosystem services distribution and hotspots

There are generally low levels of overlap between the various ecosystem service hotspots, implying that areas important for one ecosystem service are rarely important for another (Table 1). An exception is the 80% overlap between groundwater recharge and surface water hotspots, largely because they are both directly related to rainfall.

The overlap between the area of the ecosystem service hotspots and the individual biodiversity priority areas is generally low (Fig. 7; Table 2). All priority areas have at least 15% of their area classified as important for a particular ecosystem service (usually tourism), with four of these (Central Breede River Valley, Central Little Karoo, Knersvlakte and Namaqualand Uplands) comprising more than 20%. Tourism viewsheds occupy most of the priority areas, with the exception of surface water supply, where this service's hotspot covers more than 50% of the Central Breede River Valley. The remaining

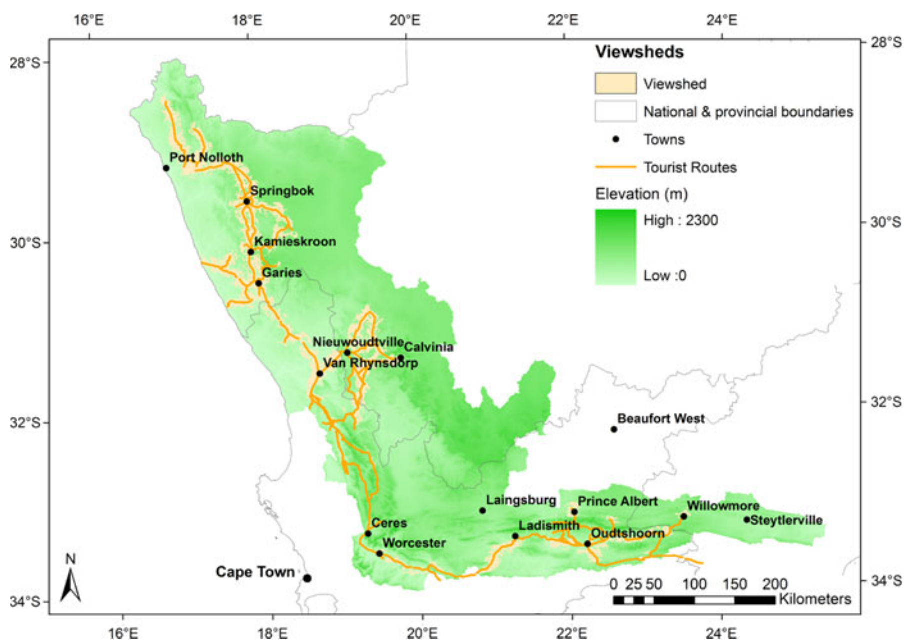

Fig. 6 Tourism viewsheds for the Succulent Karoo generated from identified tourist routes and the SRTM 90-m digital elevation model

ecosystem service hotspots do not occupy a large proportion of the SKEP priority areas. It is, however, important to differentiate between area of congruence and the quantity of each ecosystem service provided. Although ecosystem service hotspots may not occupy much area of a priority area, the priority areas still supply quantities of ecosystem services in an area of overall ecosystem service scarcity.

Table 1 Proportional overlap of ecosystem service hotspots

Ecosystem service	Proportional overlap (%)			
	Surface water	Groundwater recharge	Grazing	Tourism
Surface water	–			
Groundwater recharge	80.5	–		
Grazing	15.4	3.1	–	
Tourism	3.8	0.9	26.9	–

Proportional overlap measures the area of overlap as a percentage of the smaller hotspot to correct for the area differences between service hotspots

The findings point to the potential for surface water management to help promote the conservation of the Central Breede River Valley and parts of the Central Little Karoo priority areas, while tourism and the maintenance of attractive viewsheds may help the cases of these and the other priority areas. When the overlap of all ecosystem service hotspots combined with the priority areas are assessed, there is good support for the Central Breede River Valley and Central Little Karoo as being important for a few ecosystem services.

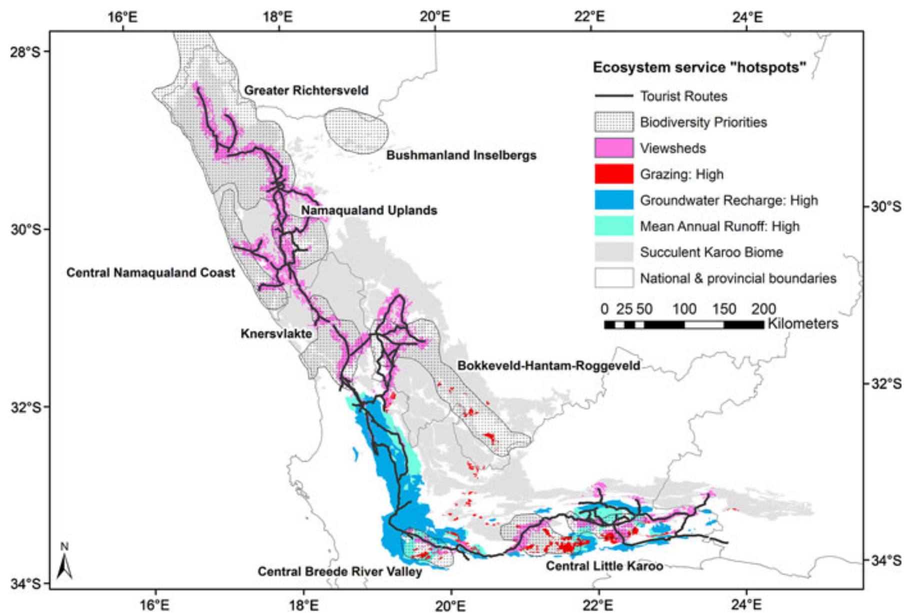

Fig. 7 The distribution of the ecosystem service hotspots for surface water (mean annual runoff), groundwater recharge, grazing and tourism (viewsheds). These have been overlaid with the SKEP biodiversity priority areas (stippled). Biodiversity priority area data downloaded from the BGIS website (http://bgis.sanbi.org/skep/project.asp)

Table 2 Percentage of each biodiversity priority area which is contained within each ecosystem service hotspot

Biodiversity priority area	Surface water	Ground-water recharge	Grazing	Tourism	All service hotspots
Bokkeveld Hantam Roggeveld			1.8	15.4	16.9
Central Breede River Valley	51.4	7.9	7.5	14.4	60.1
Central Little Karoo	18.2	0.9	12.5	23.7	47.0
Central Namaqualand Coast				15.7	15.7
Greater Richtersveld				19.3	19.3
Knersvlakte				29.9	29.9
Namaqualand Uplands				37.4	37.4

Table 3 Percentage of the area of ecosystem service hotspots that falls within SKEP biodiversity priority areas

Biodiversity priority area	Surface water	Ground-water recharge	Grazing	Tourism	All services
Bokkeveld Hantam Roggeveld			9.5	8.7	4.9
Central Breede River Valley	8.1	1.7	9.1	1.8	3.9
Central Little Karoo	7.6	0.5	40.2	7.9	8.0
Central Namaqualand Coast				3.5	1.8
Greater Richtersveld				24.1	12.5
Knersvlakte				9.4	4.9
Namaqualand Uplands				8.1	4.2

When assessing how well the priority areas incorporate ecosystem service hotspots it was found that, with the exception of the Central Little Karoo and the Greater Richtersveld, there is a low level of overlap between ecosystem service hotspots and biodiversity priority areas (Table 3). The Central Little Karoo contains more than 40% of the areas important to grazing services, while the Greater Richtersveld contains more than 20% of the tourism viewshed.

The total contribution of all the priority areas to the ecosystem service hotspots is shown in Fig. 7. A high proportion of the ecosystem service hotspots for tourism (63.44%) and grazing (58.76%) are contained within the SKEP priority areas. However, once again the priority areas only contain limited areas of land which are important to the management of either surface (15.61%) or ground water services (2.17%). A total of 40.13% of service hotspots are contained within the SKEP biodiversity priority areas.

Unlike the other biomes that have been investigated from an ecosystem services perspective (e.g. Savannas and Grasslands), the Succulent Karoo biome is characterized by both the lack of dominance by a single service and a general scarcity of services in this region (van Jaarsveld et al. 2005; Le Maitre et al. 2007b; Egoh et al. 2008). Whilst the semi-arid regions have been poorly researched from an ecosystem services perspective, these findings reflect the environmental constraint of low rainfall and low productivity that typify semi-arid systems.

The low levels of overlap found between services is in line with similar studies (Egoh et al. 2008; Reyers et al. 2009) that demonstrated variable and often low congruence between certain services. These studies highlight the resource and area intensive requirements of managing multiple ecosystem services. The lack of congruence between ecosystem services and biodiversity priorities evident in our study concurs with similar studies (Chan et al. 2006; Anderson et al. 2009; Egoh et al. 2009), which show that ecosystem services approaches will not ensure complete biodiversity protection. Turner et al. (2007) also notes the importance of considering regional variation when developing these approaches for protecting biodiversity. The implication here is that a comprehensive multi-functional landscape analysis is required when assessing both biodiversity and ecosystem services, and ecosystem services analysis alone cannot be relied on as an approach for conserving all biodiversity. The selection of the SKEP conservation priorities regions was driven by endemism criteria rather than biological production which often drives ecosystem services (Costanza et al. 2007). A lack of congruence here may have been anticipated. However, any analysis of this nature is valuable as it highlights where gains and synergies are possible. Santelmann et al. (2004) provide a very similar demonstration of how innovative agricultural practices can both benefit biodiversity and ecosystem services and be acceptable to farmers.

Conclusions and recommendations

Multi-functional landscapes: conceptual relevance and the value of local-scale benefits

The Succulent Karoo, like many other parts of the world, displays heterogeneity in the distribution of ecosystem services and biodiversity. This means that a small number of spatially distinct areas house most of the region's biodiversity and ecosystem services. A multi-functional landscape approach highlights the importance of all of these areas to meeting multiple objectives associated with biodiversity conservation, agricultural activities and human wellbeing, while pointing to the potential trade offs between these objectives. In this study, taking a multi-functional landscape approach, as opposed to single objective approach, proved a useful tool for highlighting the multiple functions associated with the Succulent Karoo and the need to manage the landscape with broader sustainability objectives in mind: balancing short term food security needs with longer term sustainability of water, grazing systems, tourism economies and biodiversity conservation objectives. A focus on the ecosystem service hotspots alone is not recommended as the semi-arid and vulnerable nature of the Succulent Karoo implies that even areas of low ecosystem service supply have an important role to play in this marginal, resource impoverished environment by supporting the limited and vital water, grazing and tourism services.

Furthermore, in addition to these biome scale benefit flows, many of the non-hotspot areas house important local-scale benefits like fuel wood (Archer 1994; Solomon 2000; Price 2005), construction material for dwellings and shelters (Archer 1989), food (Goldblatt and Manning 2000) and medicinal plants (Watt and Breyer-Brandwijk 1962; Archer 1994; van Wyk and Gericke 2000). While these were not assessed in this biome scale assessment, the value of these local-scale benefits in sustaining local inhabitants is substantial (James et al. 2005), particularly in times of hardship. Coupled with this, local inhabitants have developed utilization strategies to exploit these resources and to cope with seasonal fluctuations in resource levels (O'Farrell et al. 2007; Samuels et al. 2007) and periodic extreme events like drought (O'Farrell et al. 2009a). Although adopting a biome scale hotspot approach to assessing service supply is particularly good at highlighting key management areas, it may underplay local-level dependence on particular services and not capture the welfare implications associated with diminishing and limited service provision. In semi-arid regions small changes in the supply of services are likely to cause disproportionally larger impacts on local beneficiaries compared with more well endowed areas. This is particularly important given climate change predictions presented for the region, and clearly regional and biome level assessments need to be complemented with local-level understanding of both social and ecological issues (Cowling et al. 2008).

Multi-pronged approaches for multi-functional sustainable landscapes

Given the threats posed to the biome from both an ecological and socio-economic perspective, there is a need to promote practices based on sustainability, ecological resilience, connectivity and movement in the face of climate change, optimised biodiversity retention and protection of ecosystem service delivery (Bennett and Balvanera 2007). These multiple objectives will be difficult to realise and no single management tool or approach will achieve this. There are likely to be substantial trade-offs associated with choices and these need to be made explicit (Carpenter et al. 2009). The science of ecosystem services needs to be rapidly advanced so that required management tools and knowledge can be delivered (Daily et al. 2009). Furthermore, a variety of arguments for conservation compatible and related actions need to be developed as these are likely to be more persuasive than a single argument (Redford and Adams 2009). Multi-pronged approaches are required where multiple interventions at a variety of scales are undertaken. This poses a real challenge for decision makers (Otte et al. 2007) and strengthening science-land-user connections, science-policy connections, landholder-policy connections is vital. So too is the development of a shared vision and aim for the long term persistence of biodiversity (Opdam et al. 2006), and the actual design of these landscapes (Nassauer and Opdam 2008). Ecological principles, such as maintaining structural complexity, connectivity, heterogeneity, and creating buffers (Fischer et al. 2006) and ecosystem service issues need to be integrated into landscape design (Lovell and Johnston 2009b), and development policies at both the local and regional level. Raising awareness, building capacity and supporting decision making within institutional structures that manage land and water issues, particularly local government, would kick-start the development of sustainable multi-functional landscapes (Cowling et al. 2008; Reyers et al. 2009). Community values also need to be mapped, thereby linking local perceptions and values to broader landscape initiatives (Raymond et al. 2009).

Promoting the development and use of appropriate technologies, like those for sanitation and irrigation, is fundamental in arid areas. These do not have to be highly sophisticated schemes, and could be as simple as establishing woodlots and harvesting rainfall. In addition to these, user demanded information tools need to be developed and, strategic support provided along with policy coordination (Scherr and McNeely 2008). Whilst we acknowledge Redford and Adams (2009) cautionary warnings, the development for payments for ecosystem service schemes where applicable, such as in the identified ecosystem service hotspots, needs serious consideration. Whilst such schemes have a foothold in Europe, where diversification strategies, services payments and support to farmers and land managers are well advanced (Wiggering et al. 2006), these still need to be initiated in South Africa and many other developing countries where there is potential to couple them to poverty relief objectives (Turpie et al. 2008). However, there are currently a wide variety of approaches available aside from these market based instruments and the complexity of policy instrument choice needs to be acknowledged.

The findings of this study suggest that for effective management, engagement at the local level should not be overlooked, and ecosystem services assessments focussed on making a case for biodiversity need to incorporate a variety of scales. Engagement at the local scale is seen as critically important and a useful point of entry to start co-developing and designing place specific strategies for realising the potential of these multi-functional landscapes (Nassauer and Opdam 2008). Creating multi-functional landscapes is only possible with full cognisance of all the dynamic drivers of a landscape. Multipronged approaches initiated at appropriate scales are vital in steering management decisions towards the achievement of sustainable multi-functional landscapes.

References

AA (2005) AA travel guides. Accommodation South Africa. Access online: http://www.aatravel.co.za/index.html

Allsopp N, Laurent C, Debeaudoin LMC, Samuels MI (2007) Environmental perceptions and practices of livestock keepers on the Namaqualand commons challenge conventional rangeland management. J Arid Environ 70:740–754

Anderson PML, Hoffman MT (2007) The impacts of sustained heavy grazing on plant diversity and composition in lowland and upland habitats across the Kamiesberg mountain range in the Succulent Karoo, South Africa. J Arid Environ 70:686–700

Anderson BJ, Armsworth PR, Eigenbrod F, Thomas CD, Gillings S, Heinemeyer A, Roy DB, Gaston KJ (2009) Spatial covariance between biodiversity and other ecosystem service priorities. J Appl Ecol 46:888–896

Archer F (1989) Die konstruksie van 'n tradisionele Nama matjieshuis. Sagittarius 4:20–22

Archer FM (1994) Ethnobotany of Namaqualand: the Richtersveld. University of Cape Town, Cape Town

Archer S (2000) Technology and ecology in the Karoo: a century of windmills, wire and changing farming practice. J South Afr Stud 26:675–696

Beinart W (2003) The rise of conservation in South Africa. Settlers, livestock and the environment 1770–1950. Oxford University press, Cape Town

Belnap J, Lange OL (2003) Biological soil crusts: structure, function, and management. Springer-Verlag, Berlin

Belnap J, Phillips SL, Miller ME (2004) Response of desert biological soil crusts to alterations in precipitation frequency. Oecologia 141:306–316

Belnap J, Phillips SL, Flint S, Money J, Caldwell M (2008) Global change and biological soil crusts: effects of ultraviolet augmentation under altered precipitation regimes and nitrogen additions. Glob Change Biol 14:670–686

Bennett EM, Balvanera P (2007) The future of production systems in a globalized world. Front Ecol Environ 5:191–198

Braune E, Wessels HPP (1980) Effects of land-use on runoff from catchments and yield of present and future storage. Workshop on the effects of rural land-use and catchment management on water resources. CSIR, Pretoria

Carpenter SR, Mooney HA, Agard J, Capistrano D, DeFries RS, Diaz S, Dietz T, Duraiappah AK, Oteng-Yeboah A, Pereira HM, Perrings C, Reid WV, Sarukhan J, Scholes RJ, Whyte A (2009) Science for managing ecosystem services: beyond the millennium ecosystem assessment. Proc Natl Acad Sci USA 106:1305–1312

Carrick PJ, Kruger R (2007) Restoring degraded landscapes in lowland Namaqualand: lessons from the mining experience and from regional ecological dynamics. J Arid Environ 70:767–781

Cavé L, Beekman HE, Weaver J (2003) Impact of climate change on groundwater recharge estimation. In: Xu Y, Beekman HE (eds) Groundwater recharge estimation in southern Africa. UNESCO, Paris, pp 189–197

CEPF (2003) The Succulent Karoo hotspots. Namibia and South Africa. Ecosystem profile. Critical Ecosystem Partnership Fund, Conservation International, Washington

Chan KMA, Shaw MR, Cameron DR, Underwood EC, Daily GC (2006) Conservation planning for ecosystem services. PLoS Biol 4:2138–2152

Costanza R, Fisher B, Mulder K, Liu S, Christopher T (2007) Biodiversity and ecosystem services: a multi-scale empirical study of the relationship between species richness and net primary production. Ecol Econ 61:478–491

Cousins B, Hoffman MT, Allsopp N, Rohde RF (2007) A synthesis of sociological and biological perspectives on sustainable land use in Namaqualand. J Arid Environ 70:834–846

Cowling RM, Pierce SM (1999) Namaqualand: a succulent desert. Fernwood Press, Cape Town

Cowling RM, Esler KJ, Rundel PW (1999a) Namaqualand, South Africa—an overview of a unique winter-rainfall desert ecosystem. Plant Ecol 142:3–21
Cowling RM, Esler KJ, Rundel PW (1999b) Special issue editorial: the plant ecology of Namaqualand, South Africa. Plant Ecol 142:1–2
Cowling RM, Pressey RL, Rouget M, Lombard AT (2003) A conservation plan for a global biodiversity hotspot—the Cape Floristic Region, South Africa. Biol Conserv 112:191–216
Cowling RM, Egoh B, Knight AT, O'Farrell PJ, Reyers B, Rouget'll M, Roux DJ, Welz A, Wilhelm-Rechman A (2008) An operational model for mainstreaming ecosystem services for implementation. Proc Natl Acad Sci USA 105:9483–9488
CSIR (2007) Geospatial analysis platform and NSDP spatial profiles. Incorporating SA Mesoframe Version 2. The Presidency, dti, GTZ, EDAP, Built Environment CSIR, Pretoria
Daily GC, Polasky S, Goldstein J, Kareiva PM, Mooney HA, Pejchar L, Ricketts T, Salzman J, Shallenberger R (2009) Ecosystem services in decision making: time to deliver. Front Ecol Environ 7:21–28
De Fries RS, Asner GP, Houghton R (2004) Trade-offs in land-use decisions: towards a framework for assessing multiple ecosystem responses to land-use changed. Ecosyst Land Use Change 153:1–9
de Groot R (2006) Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. Landscape Urban Plan 75:175–186
Deacon HJ, Deacon J, Brooker M, Wilson M (1978) The evidence for herding at Boomplaas Cave in the southern Cape, South Africa. S Afr Archaeol Bull 33:39–65
Dean WRJ, Macdonald IAW (1994) Historical changes in stocking rates of domestic livestock as a measure of semiarid and arid rangeland degradation in the Cape-Province, South-Africa. J Arid Environ 26:281–298
DEAT (2001) The environmental potential atlas for South Africa, Department of Environment Affairs and Tourism, Pretoria. Available from: http://gis.deat.gov.za/enpat.asp
Desmet PG (2007) Namaqualand—a brief overview of the physical and floristic environment. J Arid Environ 70:570–587
Diaz S, Fargione J, Chapin FS, Tilman D (2006) Biodiversity loss threatens human well-being. PLoS Biol 4:1300–1305
DWAF (2003a) Gouritz water management area. Overview of water resources availability and utilisation, P WMA 16/000/00/0203. Department of Water Affairs and Forestry, Pretoria
DWAF (2003b) Lower orange water management area: Overview of water resources availability and utilisation, P WMA14/000/00/0203. Department of Water Affairs and Forestry, Pretoria
DWAF (2004a) Lower orange water management area. Internal strategic perspective, P WMA 14/000/00/0304, Department of Water Affairs and Forestry, Pretoria
DWAF (2004b) National water resource strategy, 1st edn. September 2004. Department of Water Affairs and Forestry, Pretoria
DWAF (2005) Olifants/Doorn internal strategic perspective. Olifants/Doorn water management area, PWMA 17/000/00/0305, Department of Water Affairs and Forestry, Pretoria
DWAF GRA2 (2005) Groundwater resource assessment. Phase II. Methodology. Groundwater–surface water interactions. Department of Water Affairs and Forestry, Pretoria
Egoh B, Reyers B, Rouget M, Richardson DM, Le Maitre DC, van Jaarsveld AS (2008) Mapping ecosystem services for planning and management. Agric Ecosyst Environ 127:135–140
Egoh B, Reyers B, Rouget M, Bode M, Richardson DM (2009) Spatial congruence between biodiversity and ecosystem services in South Africa. Biol Conserv 142:553–562
Environmental Systems Research Institute (2008) ArcGIS Desktop (ArcInfo) Software. ESRI, Redlands, California, USA
Esler KJ, Milton SJ, Dean WRJ (2006) Karoo Veld: ecology and management. Briza Publications, Pretoria
European Communities (2008) The economics of ecosystems and biodiversity. Interum report. European Community http://ec.europa.eu/environment/nature/biodiversity/economics/index_en.htm
Farquhar GD (1997) Carbon dioxide and vegetation. 278:1411
Fischer J, Lindenmayer DB, Manning AD (2006) Biodiversity, ecosystem function, and resilience: ten guiding principles for commodity production landscapes. Front Ecol Environ 4:80–86
Goldblatt P, Manning J (2000) Cape plants: a conspectus of the Cape Flora of South Africa. National Botanical Institute, Pretoria
Goldman RL, Tallis H (2009) A critical analysis of ecosystem services as a tool in conservation projects the possible perils, the promises, and the partnerships. Ann NY Acad Sci 1162:63–78
Görgens AHM, Hughes DA (1982) Synthesis of streamflow information relating to the semi-arid Karoo biome of South Africa. S Afr J Sci 78:58–68
Görgens AHM, Hughes DA (1986) Hydrology. SANSP Report No 124 Foundation for Research Development, Pretoria, pp 53–83
Hannah L, Midgley GF, Lovejoy T, Bond WJ, Bush M, Lovett JC, Scott D, Woodward FI (2002) Conservation of biodiversity in a changing climate. Conserv Biol 16:264–268
Herling MC, Cupido CF, O'Farrell PJ, du Plessis A (2009) The financial costs of ecologically non-sustainable farming practices in a semi-arid system. Restor Ecol 17:827–836
Hewitson BC, Crane RG (2006) Consensus between GCM climate change projections with empirical downscaling: precipitation downscaling over South Africa. Int J Climatol 26:1315–1337
Hoffman T, Ashwell A (2001) Nature divided. Land degradation in South Africa. University of Cape Town Press, Cape Town
Hoffman MT, Rohde RF (2007) From pastoralism to tourism: the historical impact of changing land use practices in Namaqualand. J Arid Environ 70:641–658
Hoffman MT, Allsopp N, Rohde RF (2007) Sustainable land use in Namaqualand, South Africa: key issues in an interdisciplinary debate. J Arid Environ 70:561–569
James I, Hoffman MT, Cowling RM, Roberts R, Campbell BM, Boumans R, Allsopp N (2005) Valuing Namaqualand's natural resources: the costs and benefits of

communal, commercial and conservation land use practices in Namaqualand incorporating ecological, economic and social values. Leslie Hill Institute for Plant Conservation and Terrestrial Ecology Research Unit, University of Cape Town, Cape Town

James I, Hoffman T, Munro A, O'Farrell P, Smart R (2007) The value of flower tourism at the Namaqua National Park. S Afr J Econ Manag Sci 10:442–456

Joubert DF, Ryan PG (1999) Differences in mammal and bird assemblages between commercial and communal rangelands in the Succulent Karoo, South Africa. J Arid Environ 43:287–299

Keay-Bright J, Boardman J (2006) Changes in the distribution of degraded land over time in the central Karoo, South Africa. Catena 67:1–14

Le Maitre DC, Milton SJ, Jarmain C, Colvin CA, Saayman I, Vlok JHJ (2007a) Linking ecosystem services and water resources: landscape-scale hydrology of the Little Karoo. Front Ecol Environ 5:261–270

Le Maitre DC, O'Farrell PJ, Reyers B (2007b) Ecosystems services in South Africa: a research theme that can engage environmental, economic and social scientists in the development of sustainability science? S Afr J Sci 103:367–376

Lovell ST, Johnston DM (2009a) Creating multifunctional landscapes: how can the field of ecology inform the design of the landscape? Front Ecol Environ 7:212–220

Lovell ST, Johnston DM (2009b) Designing landscapes for performance based on emerging principles in landscape ecology. Ecol Soc 14:44

MA (2003) Ecosystems and human well-being: a framework for assessment. Island Press, Washington, DC

MA (2005) Ecosystems and human well-being: desertification synthesis. World Resources Institute, Washington, DC

Macdonald IAW (1989) Man's role in changing the face of southern Africa. In: Huntley BJ (ed) Biotic diversity in southern Africa: concepts and conservation. Oxford University Press, Cape Town, pp 51–78

MacKellar NC, Hewitson BC, Tadross MA (2007) Namaqualand's climate: recent historical changes and future scenarios. J Arid Environ 70:604–614

McCauley DJ (2006) Selling out on nature. Nature 443:27–28

McNeely JA, Scherr S (2003) Ecoagriculture. Island Press, Washington, DC

Midgley GF, Thuiller W (2007) Potential vulnerability of Namaqualand plant diversity to anthropogenic climate change. J Arid Environ 70:615–628

Midgley DC, Pitman WV, Middleton BJ (1994a) The surface water resources of South Africa 1990, 1st edn. Water Research Commission, Pretoria

Midgley DC, Pitman WV, Middleton BJ (1994b) The surface water resources of South Africa 1990, 1st edn. Volumes 1 to 6. Report Numbers 298/1.1/94 to 298/6.1/94 (text) and 298/1.2/94 to 298/6.2/94 (maps) and CD-ROM with selected data sets. Water Research Commission, Pretoria

Mittermeier RA, Gil PR, Pilgrim J (2005) Hotspots revisited: earth's biologically richest and most endangered terrestrial ecoregions. Conservation International, Washington, DC

Mucina L, Rutherford MC (2006) The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. South African National Biodiversity Institute, Pretoria

Mucina L, Jurgens N, le Roux A, Rutherford MC (2006) Succulent Karoo Biome. In: Mucina L, Rutherford MC (eds) The vegetation of South Africa. Lesotho and Swaziland Strelitzia, Pretoria

Musil CF, Schmiedel U, Midgley GF (2005) Lethal effects of experimental warming approximating a future climate scenario on southern African quartz-field succulents: a pilot study. New Phytol 165:539–547

Nassauer JI, Opdam P (2008) Design in science: extending the landscape ecology paradigm. Landscape Ecol 23:633–644

O'Farrell PJ, Donaldson JS, Hoffman MT (2007) The influence of ecosystem goods and services on livestock management practices on the Bokkeveld plateau, South Africa. Agric Ecosyst Environ 122:312–324

O'Farrell PJ, Anderson PML, Milton SJ, Dean WRJ (2009a) Human response and adaptation to drought in the arid zone: lessons from southern Africa. S Afr J Sci 105:34–39

O'Farrell PJ, Donaldson JS, Hoffman MT (2009b) Local benefits of retaining natural vegetation for soil retention and hydrological services. S Afr J Bot 75:573–583

Opdam P, Steingrover E, van Rooij S (2006) Ecological networks: a spatial concept for multi-actor planning of sustainable landscapes. Landscape Urban Plan 75:322–332

Otte A, Simmering D, Wolters V (2007) Biodiversity at the landscape level: recent concepts and perspectives for multifunctional land use. Landscape Ecol 22:639–642

Pence GQK, Botha MA, Turpie JK (2003) Evaluating combinations of on-and off-reserve conservation strategies for the Agulhas Plain, South Africa: a financial perspective. Biol Conserv 112:253–273

Penn NG (1986) Pastoralists and pastoralism in the northern Cape frontier zone during the eighteenth century. S Afr Archaeol Soc Goodwin Ser 5:62–68

Prendergast JR, Quinn RM, Lawton JH, Eversham BC, Gibbons DW (1993) Rare species, the coincidence of diversity hot spots and conservation strategies. Nat Resour 356:335–337

Price L (2005) The electrifying impact on the fuelwood resources of a Namaqualand rural community. University of Cape Town, Cape Town

Raymond CM, Bryan BA, MacDonald DH, Cast A, Strathearn S, Grandgirard A, Kalivas T (2009) Mapping community values for natural capital and ecosystem services. Ecol Econ 68:1301–1315

Redford KH, Adams WM (2009) Payment for ecosystem services and the challenge of saving nature. Conserv Biol 23:785–787

Reyers B, O'Farrell PJ, Cowling RM, Egoh BN, Le Maitre DC, Vlok JHJ (2009) Ecosystem services, land-cover change, and stakeholders: finding a sustainable foothold for a semiarid biodiversity hotspot. Ecol Soc 14:38

Richardson FD, Hahn BD, Hoffman MT (2007) Modelling the sustainability and productivity of pastoral systems in the communal areas of Namaqualand. J Arid Environ 70:701–717

Rodriguez JP, Beard TD, Bennett EM, Cumming GS, Cork SJ, Agard J, Dobson AP, Peterson GD (2006) Trade-offs across space, time, and ecosystem services. Ecol Soc 11:28

Rouget M, Cowling RM, Vlok J, Thompson M, Balmford A (2006) Getting the biodiversity intactness index right: the

importance of habitat degradation data. Glob Change Biol 12:2032–2036
Samuels MI, Allsopp N, Knight RS (2007) Patterns of resource use by livestock during and after drought on the commons of Namaqualand, South Africa. J Arid Environ 70:728–739
Santelmann MV, White D, Freemark K, Nassauer JI, Eilers JM, Vache KB, Danielson BJ, Corry RC, Clark ME, Polasky S, Cruse RM, Sifneos J, Rustigian H, Coiner C, Wu J, Debinski D (2004) Assessing alternative futures for agriculture in Iowa, USA. Landscape Ecol 19:357–374
Scherr SJ, McNeely JA (2008) Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes. Philos Trans R Soc B Biol Sci 363:477–494
Scholes RJ (1998) The South African 1:250 000 maps of areas of homogeneous grazing potential. ENV-P-C 98190 Division of Water. Environment and Forestry Technology, CSIR, Pretoria
Seymour CL, Dean WRJ (1999) Effects of heavy grazing on invertebrate assemblages in the Succulent Karoo, South Africa. J Arid Environ 43:267–286
Shackleton C, Shackleton S, Gambiza J, Nel E, Rowntree K, Urquhart P (2008) Links between ecosystem services and poverty alleviation: situation analysis for arid and semi-arid lands in southern Africa. Ecosystem Services and Poverty Reduction Research Programme. DFID, NERC,ESRC, DFID, UK
SKEP (2003a) SKEP biodiversity component technical report, March 2003. Report No CCU 1/03 Cape Conservation Unit, Botanical Society of South Africa, Cape Town
SKEP (2003b) SKEP: a 20 year strategy. The Botanical Society of South Africa, Cape Town
SKEP (2008) Succulent Karoo ecosystem programme rapid appraisal report. A discussion paper in preparation for strategic planning 2009–2014. SANBI, Cape Town
Smith AB (1983) Prehistoric pastoralism in the Southwestern Cape, South-Africa. World Archaeol 15:79–89
Solomon AM (2000) The use and evaluation of natural fuelwood resources in Paulshoek, Namaqualand and the ecological impacts on rangeland dynamics. University of Cape Town, Cape Town
Tallis H, Polasky S (2009) Mapping and valuing ecosystem services as an approach for conservation and natural-resource management. Ann NY Acad Sci 1162:265–283
Tallis H, Goldman R, Uhl M, Brosi B (2009) Integrating conservation and development in the field: implementing ecosystem service projects. Front Ecol Environ 7:12–20
Thompson M, Vlok JHJ, Rouget M, Hoffman MT, Balmford A, Cowling RM (2009) Mapping grazing-induced degradation in a semi-arid environment: a rapid and cost effective approach for assessment and monitoring. Environ Manag 43:585–596
Tietjen B, Jeltsch F (2007) Semi-arid grazing systems and climate change: a survey of present modelling potential and future needs. J Appl Ecol 44:425–434
Todd SW, Hoffman MT (1999) A fence-line contrast reveals effects of heavy grazing on plant diversity and community composition in Namaqualand, South Africa. Plant Ecol 142:169–178
Turner WR, Brandon K, Brooks TM, Costanza R, da Fonseca GAB, Portela R (2007) Global conservation of biodiversity and ecosystem services. Bioscience 57:868–873
Turpie J, Joubert A (2001) Estimating potential impacts of a change in river quality on the tourism value of Kruger National Park: an application of travel cost, contingent and conjoint valuation methods. Water SA 27:387–398
Turpie JK, Marais C, Blignaut JN (2008) The working for water programme: evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. Ecol Econ 65:788–798
van Jaarsveld AS, Biggs R, Scholes RJ, Bohensky E, Reyers B, Lynam T, Musvoto C, Fabricius C (2005) Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SAfMA) experience. Philos Trans R Soc B Biol Sci 360:425–441
Van Rooyen MW, Grobbelaar N, Theron GK, van Rooyen N (1990) The ephemerals of Namaqualand: effects of photoperiod, temperature and moisture stress on development and flowering of three species. J Arid Environ 19:15–29
van Wyk B-E, Gericke N (2000) People's plants: a guide to useful plants of Southern Africa. Briza Publications, Pretoria
Vira B, Adams WM (2009) Ecosystem services and conservation strategy: beware the silver bullet. Conserv Lett 2:158–162
Watt JM, Breyer-Brandwijk MG (1962) The medicinal and poisonous plants of southern and eastern Africa: being an account of their medicinal and other uses, chemical composition, pharmacological effects and toxicology in man and animal. E. & S. Livingstone, Edinburgh
Wiggering H, Dalchow C, Glemnitz M, Helming K, Muller K, Schultz A, Stachow U, Zander P (2006) Indicators for multifunctional land use—linking socio-economic requirements with landscape potentials. Ecol Indic 6:238–249
Zhang L, Dawes WR, Walker GR (2001) Response of mean annual evapotranspiration to vegetation changes at catchment scale. Water Resour Res 37:701–708