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

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9 **Abstract** Synergies between biodiversity conserva-
10 tion objectives and ecosystem service management
11 were investigated in the Succulent Karoo biome
12 (83,000 km²) of South Africa, a recognised biodiver-
13 sity hotspot. Our study complemented a previous
14 biodiversity assessment with an ecosystem service

assessment. Stakeholder engagement and expert con- 15
sultation focussed our investigations on surface water, 16
ground water, grazing and tourism, as the key services 17
in this region. The key ecosystem services and service 18
hotspots were modelled and mapped. The congruence 19
between these services, and between biodiversity 20
priorities and ecosystem service priorities, were 21
assessed and considered ~~these~~ in relation to known 22
threats. Generally low levels of overlap were found 23
between these ecosystem services, with the excep- 24
tion of surface and ground water which had an 80% 25
overlap. The overlap between ecosystem service 26
hotspots and individual biodiversity priority areas 27
was generally low. Four of the seven priority areas 28
assessed have more than 20% of their areas classi- 29
fied as important for services. In specific cases, 30
particular services levels could be used to justify the 31
management of a specific biodiversity priority area 32
for conservation. Adopting a biome scale hotspot 33
approach to assessing service supply highlighted key 34
management areas. However, it underplayed local 35
level dependence on particular services, not effec- 36
tively capturing the welfare implications associated 37
with diminishing and limited service provision. We 38
conclude that regional scale (biome level) approaches 39
need to be combined with local level investigations 40
(municipal level). Given the regional heterogeneity 41
and varied nature of the impacts of drivers and threats, 42
diverse approaches are required to steer land manage- 43
ment towards sustainable multifunctional landscape 44
strategies. 45

A1 **Electronic supplementary material** The online version of
A2 this article (doi:10.1007/s10980-010-9495-9) contains
A3 supplementary material, which is available to authorized users.

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46 **Keywords** Ecosystem service assessment ·
 47 Grazing · Water · Tourism · Biodiversity hotspots ·
 48 Climate change

50 Introduction

51 Classic conservation approaches with their narrow
 52 focus on species preservation and reserve design
 53 have increasingly been supplemented by new strate-
 54 gies in an effort to deal with the unprecedented scale
 55 of human impacts and often constrained resources
 56 (Fischer et al. 2006; Redford and Adams 2009). These
 57 new strategies complement formal protected areas, by
 58 focussing on the management of off-reserve areas and
 59 working landscapes which include humans and their
 60 production activities (Pence et al. 2003; O'Farrell et al.
 61 2009b).

62 More recently these broader approaches have
 63 begun to focus on ecosystem services, the benefits
 64 that people derive from ecosystems (MA 2005; Diaz
 65 et al. 2006), as a way to include human needs and
 66 well-being into conservation strategies. The rationale
 67 behind these ecosystem service based approaches for
 68 conservation is that by understanding and mitigating
 69 the threats posed to ecosystem services one will also
 70 conserve the biodiversity that underpins these ser-
 71 vices, while at the same time increasing the rele-
 72 vance, incentives and funding resources of these
 73 conservation efforts (Vira and Adams 2009). Despite
 74 concerns around possible unintended negative con-
 75 sequences (McCauley 2006; Redford and Adams
 76 2009; Vira and Adams 2009) and limited congruence
 77 between biodiversity and ecosystem services (Chan
 78 et al. 2006; Egoh et al. 2009; Reyers et al. 2009),
 79 ecosystem based approaches have grown in number
 80 and coverage over the past decade and are now a key
 81 focus of many conservation organisations and the
 82 topic of much research and development projects
 83 (Goldman and Tallis 2009; Tallis and Polasky 2009;
 84 Tallis et al. 2009).

85 A recent development, focused at a landscape
 86 scale (several thousand hectares), is the notion of
 87 landscape multi-functionality, which moves away
 88 from the traditional management of a single func-
 89 tion landscape manipulated to, for example, either
 90 produce food or serve as a recreation area, to a
 91 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 (Nassauer
 and Opdam 2008) and management of landscapes
 with multiple goals, including sustainable food pro-
 duction, 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 land-
 scape (McNeely and Scherr 2003). 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 under-
 standing 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 compre-
 hensive assessment of all of the issues listed in the
 previous paragraph, rather it focused on the contri-
 bution 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 is a suitable case study to apply the concept of
 multi-functional landscapes in semi-arid environ-
 ments. The biodiversity of this region has received
 considerable research attention and is well docu-
 mented (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

141 areas of extreme biological richness (Mittermeier
142 et al. 2005), has resulted in substantial investments in
143 the assessment and management of the region's
144 biodiversity through the Succulent Karoo Ecosystem
145 Program (SKEP) (SKEP 2003b). Using a combination
146 of technical expertise and stakeholder involvement,
147 SKEP undertook a detailed conservation assessment.
148 Here they identified both biodiversity priority areas
149 for conservation (Fig. 1) and those areas that also
150 contributed to the creation of living landscapes able to
151 support all forms of life now and in the future (SKEP
152 2003b). SKEP did not explicitly assess the benefits
153 humans get from these landscapes.

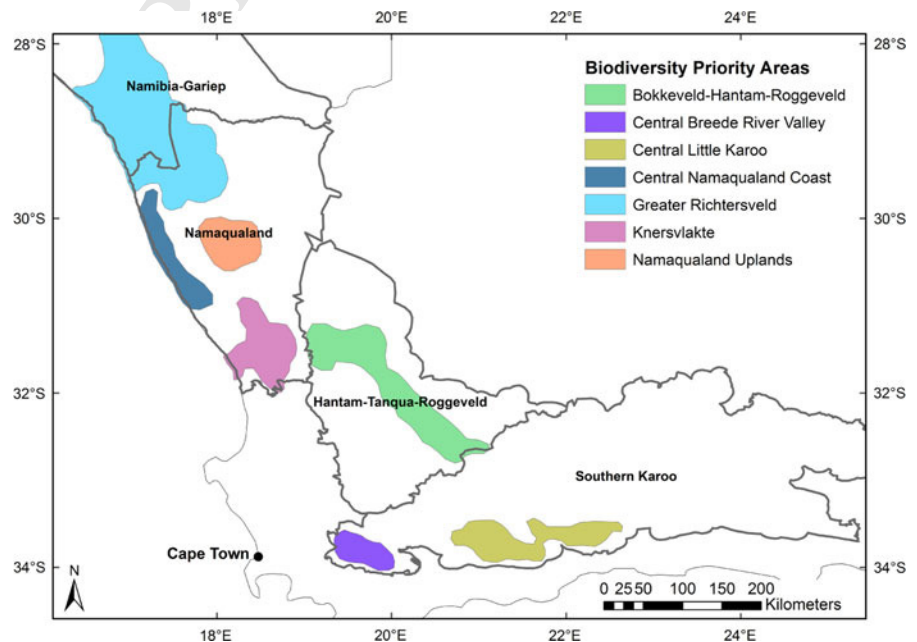
154 Our study complemented this SKEP biodiversity
155 assessment with an ecosystem service assessment
156 (MA 2003; Carpenter et al. 2009; Daily et al. 2009).
157 The key ecosystem services and service hotspots
158 were investigated, modelled and mapped. The con-
159 gruence between these services, and between biodi-
160 versity priorities and ecosystem service priorities, was
161 assessed and considered in relation to known threats
162 to this area, in particular climate change. We conclude
163 with some lessons learnt during the study on the
164 opportunities and constraints offered by these broader
165 approaches to the conservation of the region's biodi-
166 versity and ecosystem services through the adoption
167 of a multi-functional landscape approach.

Methods

Study area

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

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



193	farming are all found in the mountain areas outside of	238
194	the Succulent Karoo biome. Copper and dimond	239
195	mining have been historically important, but is now	240
196	largely confined to the northern region (Carrick and	241
197	Kruger 2007). Tourism has recently displaced mining	242
198	and agriculture in certain regions (Hoffman and	243
199	Rohde 2007), providing financial relief. The Succu-	244
200	lent Karoo, like other semi-arid parts of the world, is	245
201	home to some of the most vulnerable people and	246
202	places in the country, and people depend on a variety	247
203	of natural resources for their survival (James et al.	248
204	2005).	249
205	Identifying services	250
206	An extensive literature review focussed on all aspects	251
207	of the succulent karoo was undertaken, and stake-	252
208	holders and experts consulted, to identify the benefi-	253
209	ciaries and the ecosystem services present in	254
210	Succulent Karoo biome. Eighteen different benefi-	255
211	ciary groups were identified who collectively relied on	256
212	41 associated ecosystem services (Appendix 1, 2 in	257
213	Supplementary material). The provision of three key	258
214	services, namely: water supply, grazing provision, and	259
215	tourism, which were directly linked to the 41 identi-	260
216	fied services, formed the focus of our analysis.	261
217	The Succulent Karoo biome boundary as defined	262
218	by the national vegetation map was used in assessing	263
219	grazing provision and tourism (Mucina et al. 2006).	264
220	In the case of the water provision service, it was	265
221	necessary to extend the service area boundary beyond	266
222	that of the vegetation to align with the most basic	267
223	hydrological units, these being the headwater catch-	268
224	ments of the river systems of the Succulent Karoo	269
225	(Midgley et al. 1994b). Within each of these defined	270
226	areas the key services were modelled and the major	271
227	threats discussed. Our approaches are discussed	272
228	below.	273
229	Water	274
230	The assessment of water services drew on a variety of	275
231	previous studies (e.g., the Water Situation Assessments,	276
232	Internal Strategic Perspectives, Water Resources 1990	277
233	study and its prepublication 2005 update, Water	278
234	Resource Management System, national Groundwater	279
235	Resource Assessment Phase 2 and related studies)	280
236	(Braune and Wessels 1980; Görgens and Hughes 1982,	281
237	1986; Midgley et al. 1994b; DWAF 2003a, b, 2004a, b,	282
	2005; DWAF GRA2 2005). Both the water supply	238
	function and the flow regulation role that ecosystems	239
	play in the service of water provision as focussed on.	240
	The mean annual runoff according to catchments, and	241
	mean the annual groundwater recharge for the hydro-	242
	logical domain was mapped. Groundwater recharge is	243
	an important parameter for estimating how much	244
	groundwater is potentially available for use. The	245
	recharge was estimated from the rainfall and factored	246
	in underlying aquifer types (lithology) and long-term	247
	mean recharge from sample of points spread across the	248
	country (DWAF GRA2 2005).	249
	Grazing	250
	The grazing service spatial data were derived from the	251
	national vegetation map of South Africa (Mucina and	252
	Rutherford 2006) and the South African 1:250,000	253
	maps of areas of homogeneous grazing potential	254
	(Scholes 1998). Scholes's (1998) approach to esti-	255
	mating grazing potential was adopted because it	256
	explicitly incorporates climate, soil type and vegeta-	257
	tion and is been calibrated with long-term observa-	258
	tions of stocking rates of wildlife and livestock	259
	systems that have not caused irreversible degradation	260
	in the short term . This approach estimates the	261
	potential mean carrying capacity of the land, not the	262
	actual available grazing, and therefore does not take	263
	the impacts of overgrazing which may have occurred	264
	into account.	265
	Tourism	266
	Understanding tourism as an ecosystem service	267
	requires the identification of the biodiversity, eco-	268
	system and landscape features or assets that drive	269
	tourism, as well as the socio-economic features that	270
	drive its promotion and development. This has been	271
	recognised as being extremely difficult to achieve	272
	(European Communities 2008; Shackleton et al.	273
	2008). In the case of the Succulent Karoo the best	274
	and most widely known tourism attractions are the	275
	diverse spring flowers (Turpie and Joubert 2001;	276
	James et al. 2007) and the relatively undeveloped	277
	landscapes with little (apparent) evidence of human	278
	impact (Reyers et al. 2009). To determine the travel	279
	routes followed by tourists, we examined tourist	280
	brochures and travel guides, contacted tourism asso-	281
	ciations, examined the Automobile Association's	282

283	accommodation database (AA 2005) to determine	utility of an ecosystem service approach in justifying	330
284	where accommodation was located, and identified	the selection of the biodiversity priority areas and	331
285	tourism features, including protected areas, heritage	also to assess the value of the biodiversity priority	332
286	sites, and cultural features from the Environmental	areas for managing ecosystem services.	333
287	Potential Atlas database for South Africa (DEAT		
288	2001). Tourism viewsheds, which were areas visible		
289	to tourists (i.e., up to 10 km) travelling by road along	Results and discussion	334
290	the identified tourist routes, were then created. This		
291	line of sight analysis was corrected for changes in	Water	335
292	elevation, using the SRTM 90-m digital elevation		
293	model. Other landscape features considered to be	High regional variation in rainfall is responsible for	336
294	tourist attractions were mapped as conservation areas	the wide range in mean annual runoff rates (Fig. 2).	337
295	(CSIR 2007). Therefore, we mapped this tourism	All of the catchments to the north and west have less	338
296	service as a combination of tourism routes and their	than 2.5 mm of runoff per year. The inhabitants of	339
297	viewsheds, together with landscape features known to	those areas are completely dependent on groundwater	340
298	attract tourists.	recharge from periodic heavy rainfalls, and ephem-	341
		eral surface flows in the rivers which recharge	342
299	Mapping hotspots and assessing congruence	alluvial aquifers. The south and central region (south	343
		of Nieuwoudtville, Fig. 2) has slightly higher runoff	344
300	The maps of ecosystem services were evaluated in	(>10 mm/year) compared with areas to the north, and	345
301	terms of their area of production and overlap with one	the rivers in this region generally have a seasonal	346
302	another. For the purposes of comparison, each map of	flow. The southern and eastern parts of the hydro-	347
303	ecosystem services was classified into high, medium,	logical domain have relatively high levels of surface	348
304	and low production classes. For the continuous	water runoff (>10 mm), the rain shadow areas in the	349
305	variable maps of grazing production and water	interior are the exception.	350
306	provision, these classes were determined using a	The overall pattern of ground water recharge is	351
307	Jenks natural breaks classification in ArcGIS® 9.2	dominated by the distribution of the rainfall but it is	352
308	(Environmental Systems Research Institute 2008).	also strongly influenced by the higher recharge	353
309	For the tourism map all areas of a viewshed were	potential of the underlying geology in the mountain	354
310	included as high production areas (Prendergast et al.	ranges (Fig. 3). The south western and central eastern	355
311	1993, 2008).	regions are of key importance in ground water	356
312	Following Egoth et al. (2008), overlap was assessed	recharge. These amounts reflect the mean recharge	357
313	between high production areas, hereafter referred to	rates, the actual amounts will vary depending on the	358
314	as “ecosystem service hotspots”, by assessing the	recent rainfall regime and, particularly in arid areas,	359
315	proportional area of overlap as a percentage of the	the periodic occurrence of rainfall events that are	360
316	smallest hotspot (Prendergast et al. 1993).	large enough for the water to pass through the	361
317	These are the key areas of service delivery requir-	unsaturated zone and recharge the aquifer.	362
318	ing specific management, understanding and assess-	Arguably the greatest threat facing the Succulent	363
319	ing threats.	Karoo biome and its inhabitants is climate change.	364
320	We were specifically interested in the levels of	Increases in air temperatures and declines in rainfall,	365
321	congruence between ecosystem service hotspots and	particularly winter rainfall, are expected for most of	366
322	previously identified biodiversity priorities produced	this region (Hannah et al. 2002; Hewitson and Crane	367
323	through the SKEP study (SKEP 2003a). How much	2006; MacKellar et al. 2007). The reduction in rainfall	368
324	of each priority area is covered by ecosystem service	will result in a greater reduction in surface and ground	369
325	hotspots, and how much of the ecosystem service	water availability, as relationships between rainfall	370
326	hotspots fell into priority areas was examined. The	and runoff are non-linear (i.e., the rainfall:runoff and	371
327	levels of overlap between all ecosystem service	rainfall:recharge ratios decline as rainfall decreases)	372
328	hotspots combined and the biodiversity priority areas	(Midgley et al. 1994a; Zhang et al. 2001). Southern	373
329	were also considered. This was done to assess the	African data indicate a non-linear relationship	374

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

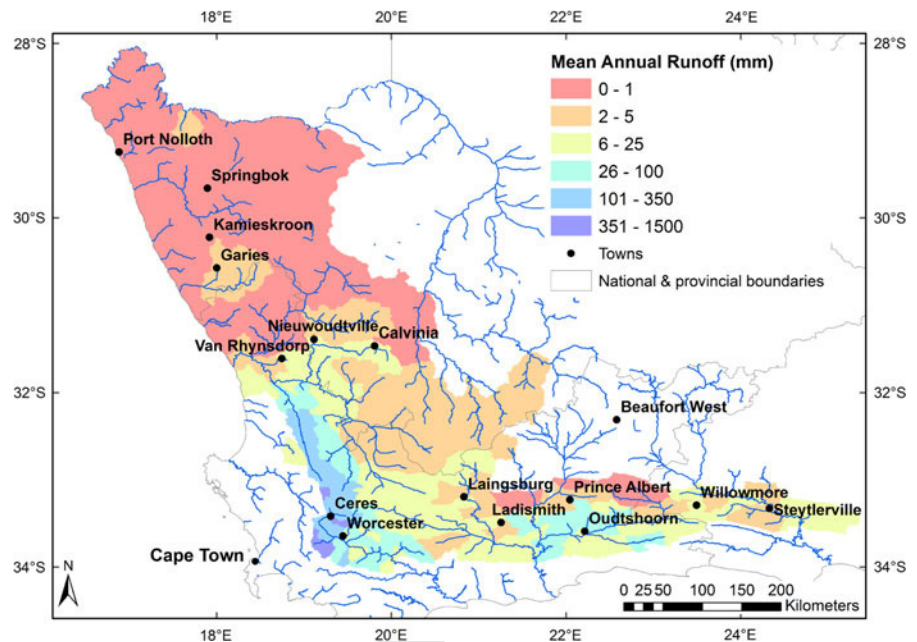
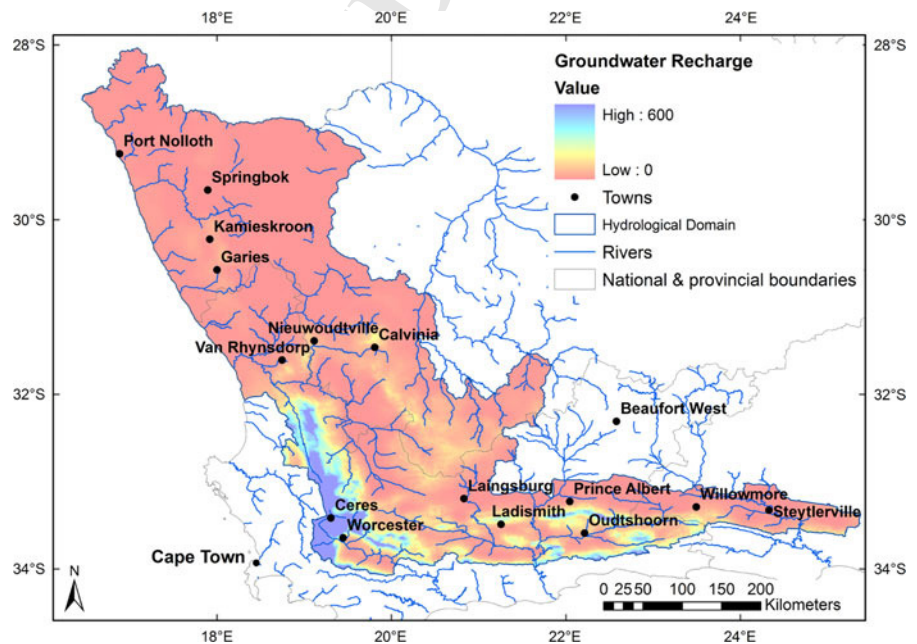


Fig. 3 Mean annual groundwater recharge (mm) in the hydrological domain of the Succulent Karoo (DWAf GRA2 2005)



375 between mean annual rainfall and mean recharge, with
 376 a steep decline in recharge once annual rainfall drops
 377 below 400 mm (Cavé et al. 2003). Furthermore, higher
 378 air temperatures will increase evaporative demand
 379 which will further increase soil moisture losses. The
 380 northern catchments are expected to be the most
 381 severely affected, moving towards a more extreme
 382 desert climate. In addition to climate change impacts,

increased demand for water, wasteful use, and the
 depletion of fossil groundwater resources present
 further challenges.

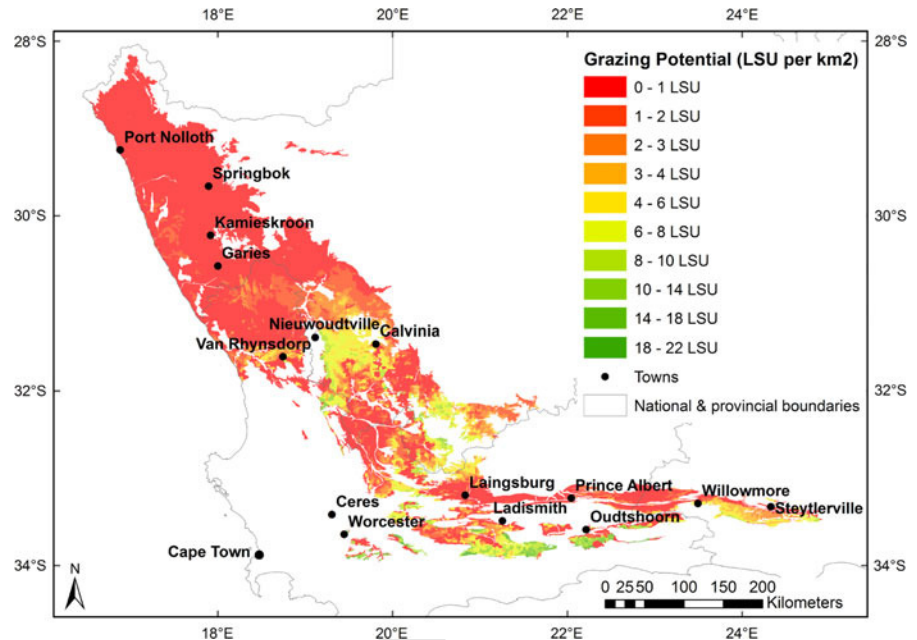
Grazing capacity

The grazing capacity of the Succulent Karoo study
 area was found to be spatially heterogeneous (Fig. 4),

383
 384
 385
 386
 387
 388

Author Proof

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)



389 largely following rainfall patterns and soil types. The
 390 grazing potential ranges from 18 to 22 LSU/km² right
 391 down to 0 to 1 LSU/km². Areas with the highest
 392 grazing potential are situated in the south of the
 393 region. Areas with moderate grazing potential are
 394 closely associated with areas of high potential, but
 395 also occur further north as well. Low potential
 396 grazing areas occur in all of the above locations,
 397 but are dominant in the west and far north. Most of
 398 the far northern region (Namaqualand) is in the 0–1
 399 LSU/km² range and this is also the area where most
 400 of the non-commercial, subsistence livestock farming
 401 is practiced. This finding highlights the marginal
 402 nature and fragility of the grazing service in these
 403 areas where it is an important factor in peoples’
 404 livelihood security and value systems.

405 With soil moisture as the key driver of grazing
 406 production, reduction in rainfall will result in con-
 407 comitant decreases in this service. However, more
 408 research is needed to address key uncertainties in
 409 assessing the magnitude of the impacts (Tietjen and
 410 Jeltsch 2007). The increase in the concentration of
 411 CO₂ in the atmosphere may increase the water-use
 412 efficiency, particularly of plants with C₃ photosyn-
 413 thetic pathways (Farquhar 1997). Biological soil crusts
 414 play an important role in soil stabilisation and in
 415 vegetation productivity through nitrogen fixation and,
 416 at least in some cases, increased water infiltration

(Belnap and Lange 2003; Le Maitre et al. 2007a).
 417 Cover of biological crust is broken and reduced by
 418 livestock trampling making fine-textured soils vulner-
 419 able to erosion by wind and water (Esler et al. 2006).
 420 These crusts are also known to be sensitive to increases
 421 in temperature and decreases in rainfall which, com-
 422 bined with their sensitivity to ultraviolet radiation,
 423 makes them vulnerable to climate change (Belnap
 424 et al. 2004, 2008). Therefore, the utilisation of grazing
 425 services into the future may compromise service
 426 production under conditions of climate change.
 427

428 The grazing services of the Succulent Karoo
 429 biome have been utilized for livestock production
 430 for around 2000 years (Deacon et al. 1978; Smith
 431 1983). The indigenous Khoikhoi pastoralists followed
 432 a transhumance lifestyle moving livestock between
 433 different vegetation types according to seasons
 434 (Smith 1983), allowing them to access both water
 435 and grazing throughout the year (Penn 1986). These
 436 strategies were adopted by settlers to the region and
 437 continue being practiced today to a much lesser
 438 degree and in specific areas. This is largely due to
 439 political and economic development, and private land
 440 ownership, that has constrained movements to within
 441 specific areas, or between two farms with one being
 442 outside of the Succulent Karoo biome. Whilst move-
 443 ments are constrained, farmers perceive seasonal
 444 differences in vegetation types and move stock on a

445 seasonal base between these within one farm (O'Farrell et al. 2007). Transhumance movements between
 446 the Succulent Karoo and adjacent biomes historically
 447 stabilized subsistence economies, but changes in land
 448 tenure in the past century have led to sedentary
 449 grazing and damage to the resource base (Archer
 450 2000; Beinart 2003; Hoffman and Rohde 2007).
 451 Additional damage to this grazing service was caused
 452 by ploughing of alluvial deposits for subsistence
 453 crops (Macdonald 1989; Thompson et al. 2009), and
 454 by overstocking, particularly with ostriches at high
 455 density on natural veld by supplementing the grazing
 456 with food purchased from outside the biome (Dean
 457 and Macdonald 1994; Herling et al. 2009).

459 Intensive heavy grazing resulting from a lack of
 460 mobility and access to sufficiently different grazing
 461 resources has resulted in changes in plant community
 462 composition within this biome (Todd and Hoffman
 463 1999; Anderson and Hoffman 2007). Natural plant
 464 communities in valley bottoms have been demon-
 465 strated to have reduced cover and dominance of
 466 palatable species, and an increased dominance of
 467 unpalatable species under sustained heavy grazing
 468 (Allsopp et al. 2007). Anderson and Hoffman (2007)
 469 found that sustained heavy grazing results in a
 470 reduction in leaf succulent and woody plant cover,
 471 increases in dwarf shrub cover, and plant commu-
 472 nity functional composition shifts towards more

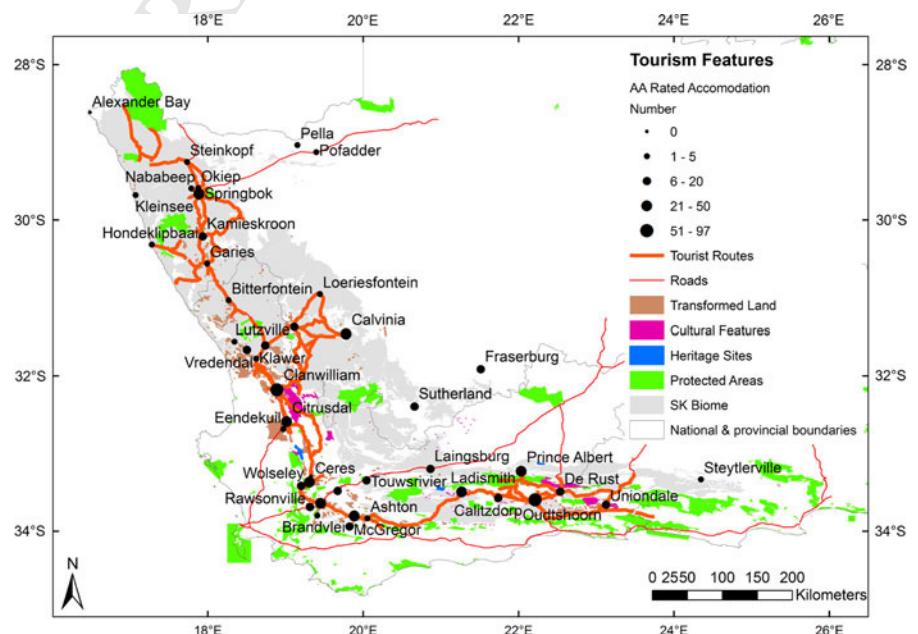
ephemeral communities. These changes are a major
 cause for concern as grazing services become more
 tightly coupled to rainfall. Changes in rainfall will
 result in less grazing and poorer quality livestock with
 lower growth rates and, thus, decreased production of
 secondary goods such as meat and 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 charac-
 terised 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 special-
 ist 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 region, flower displays on transformed or
 previously ploughed lands, and protected areas, are
 key attractions (Fig. 5). Based on the numbers of AA

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



499 rated tourist accommodation facilities, the urban
 500 centres of Oudtshoorn, Clanwilliam, and Springbok
 501 all feature as important tourism destinations, but
 502 accommodation is available even in small settle-
 503 ments. The important cultural and heritage features
 504 such as the Cederberg (east of Clanwilliam) and the
 505 Swartberg mountains north of De Rust (Fig. 5), both
 506 renowned for their San rock art, are on the margins of
 507 the Succulent Karoo biome. The major tourism routes
 508 within the south region of the Succulent Karoo are
 509 popular for their scenery and the vistas characterised
 510 by wide open spaces with little obvious evidence of
 511 human impacts (Fig. 6). The analysis highlights the
 512 limited areas that tourists encounter and, unlike
 513 grazing, the viewshed is typically not a landscape
 514 or area feature. There are many vantage points
 515 which provide extensive vistas over the Succulent
 516 Karoo, but because these are not situated in the biome
 517 itself, they were excluded from the assessment.

518 Climate change is also expected to have two major
 519 implications for tourism in this region, affecting both
 520 the biological attractions and constraining develop-
 521 ments through water supply issues. Annual plant
 522 species which typify spring in the Namaqualand and
 523 Bokkeveld–Hantam–Roggeveld regions (Fig. 1) are
 524 directly cued by rainfall (Van Rooyen et al. 1990) and
 525 decreases in the size and probability of flower displays
 526 are highly likely to result in a decrease in flower

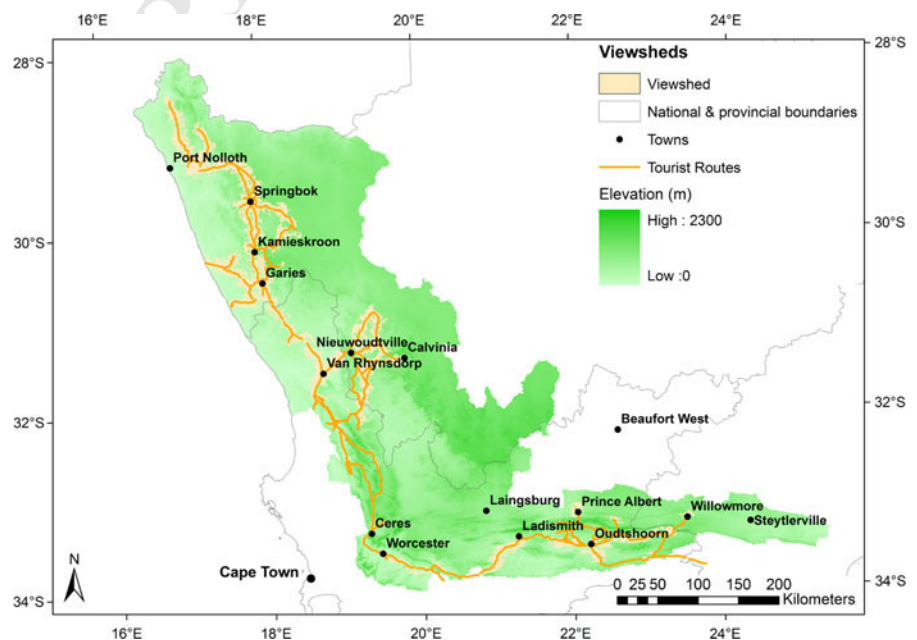
527 tourism to the region (James et al. 2007). If temper-
 528 atures increase beyond the optimal range then certain
 529 succulent species, for which this region is acclaimed,
 530 are likely to experience severe mortality and even
 531 become extinct (Musil et al. 2005; Midgley and
 532 Thuiller 2007). In addition, current tourism develop-
 533 ments in this region are water intensive; thus water-
 534 use efficiency and equitable allocation would need to
 535 be considered if tourism is to continue as a growth
 536 industry. A change in mindset of both tourists and the
 537 tourism service industry, as well as the development
 538 and use of water efficient technology are required.

Ecosystem services distribution and hotspots 539

540 There are generally low levels of overlap between the
 541 various ecosystem service hotspots, implying that
 542 areas important for one ecosystem service are rarely
 543 important for another (Table 1). An exception is the
 544 80% overlap between groundwater recharge and
 545 surface water hotspots, largely because they are both
 546 directly related to rainfall.

547 The overlap between the area of the ecosystem
 548 service hotspots and the individual biodiversity prior-
 549 ity areas is generally low (Fig. 7; Table 2). All priority
 550 areas have at least 15% of their area classified as
 551 important for a particular ecosystem service (usually
 552 tourism), with four of these (Central Breede River

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



553 Valley, Central Little Karoo, Knersvlakte and Nam-
554 aqualand Uplands) being comprised with more than
555 20%. Tourism viewsheds occupy most of the priority

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

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>)

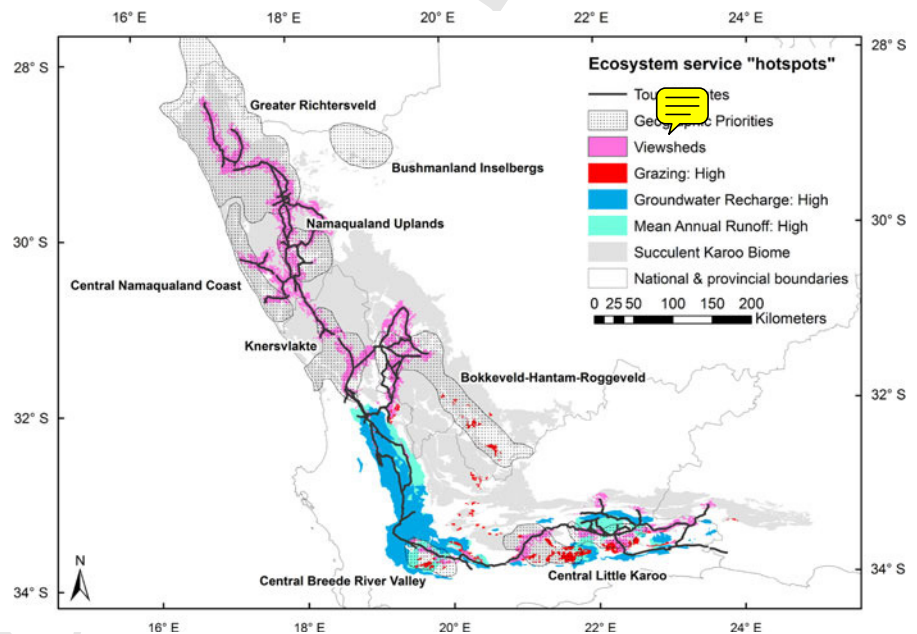


Table 2 Percentage of each biodiversity priority area which is contained within each ecosystem service hotspot

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

556 areas, with the exception of surface water supply, 556
557 where this service's hotspot covers more than 50% of 557
558 the Central Breede River Valley. The remaining 558
559 ecosystem service hotspots do not occupy a large 559
560 proportion of the SKEP priority areas. It is, however, 560
561 important to differentiate between area of congruence 561
562 and the quantity of each ecosystem service provided. 562
563 Although ecosystem service hotspots may not occupy 563
564 much area of a priority area, the priority areas still 564
565 supply quantities of ecosystem services in an area of 565
566 overall ecosystem service scarcity. 566

567 The findings point to the potential for surface water 567
568 management to help promote the conservation of the 568
569 Central Breede River Valley and parts of the Central 569
570 Little Karoo priority areas, while tourism and the 570
571 maintenance of attractive viewsheds may help the 571
572 cases of these and the other priority areas. When the 572

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

573 overlap of all ecosystem service hotspots combined
574 with the priority areas are assessed, there is good
575 support for the Central Breede River Valley and
576 Central Little Karoo as being important for a few
577 ecosystem services.

578 When assessing how well the priority areas incor-
579 porate ecosystem service hotspots it was found that,
580 with the exception of the Central Little Karoo and the
581 Greater Richtersveld, there is a low level of overlap
582 between ecosystem service hotspots and biodiversity
583 priority areas (Table 3). The Central Little Karoo
584 contains more than 40% of the areas important to
585 grazing services, while the Greater Richtersveld
586 contains more than 20% of the tourism viewshed.

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

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

608 The low levels of overlap found between services
609 is in line with similar studies (Egoh et al. 2008;

610 Reyers et al. 2009) that demonstrated variable and
611 often low congruence between certain services. These
612 studies highlight the resource and area intensive
613 requirements of managing multiple ecosystem ser-
614 vices. The lack of congruence between ecosystem
615 services and biodiversity priorities evident in our
616 study concurs with similar studies (Chan et al. 2006;
617 Anderson et al. 2009; Egoh et al. 2009), which show
618 that ecosystem services approaches will not ensure
619 complete biodiversity protection. Turner et al. (2007)
620 also notes the importance of considering regional
621 variation when developing these approaches for
622 protecting biodiversity. The implication here is that
623 a comprehensive multi-functional landscape analysis
624 is required when assessing both biodiversity and
625 ecosystem services, and ecosystem services analysis
626 alone cannot be relied on as an approach for
627 conserving all biodiversity. The selection of the
628 SKEP conservation priorities regions was driven by
629 endemism criteria rather than biological production
630 which often drives ecosystem services (Costanza
631 et al. 2007). A lack of congruence here may have
632 been anticipated. However, any analysis of this nature
633 is valuable as it highlights where gains and synergies
634 are possible. Santelmann et al. (2004) provide a very
635 similar demonstration of how innovative agricultural
636 practices can both benefit biodiversity and ecosystem
637 services and be acceptable to farmers.

638 Conclusions and recommendations 638

639 Multi-functional landscapes: conceptual 639
640 relevance and the value of local scale benefits 640

641 The Succulent Karoo, like many other parts of the 641
642 world, displays heterogeneity in the distribution of 642

643	ecosystem services and biodiversity. This means that	692
644	a small number of spatially distinct areas house most	693
645	of the region's biodiversity and ecosystem services.	694
646	A multi-functional landscape approach highlights the	695
647	importance of all of these areas to meeting multiple	696
648	objectives associated with biodiversity conservation,	697
649	agricultural activities and human wellbeing, while	
650	pointing to the potential trade offs between these	698
651	objectives. In this study, taking a multi-functional	699
652	landscape approach, as opposed to single objective	
653	approach, proved a useful tool for highlighting the	700
654	multiple functions associated with the Succulent	701
655	Karoo and the need to manage the landscape with	702
656	broader sustainability objectives in mind: balancing	703
657	short term food security needs with longer term	704
658	sustainability of water, grazing systems, tourism	705
659	economies and biodiversity conservation objectives.	706
660	A focus on the ecosystem service hotspots alone is	707
661	not recommended as the semi-arid and vulnerable	708
662	nature of the Succulent Karoo implies that even areas	709
663	of low ecosystem service supply have an important	710
664	role to play in this marginal, resource impoverished	711
665	environment by supporting the limited and vital	712
666	water, grazing and tourism services.	713
667	Furthermore, in addition to these biome scale	714
668	benefit flows, many of the non-hotspot areas house	715
669	important local scale benefits like fuel wood (Archer	716
670	1994; Solomon 2000; Price 2005), construction	717
671	material for dwellings and shelters (Archer 1989),	718
672	food (Goldblatt and Manning 2000) and medicinal	719
673	plants (Watt and Breyer-Brandwijk 1962; Archer	720
674	1994; van Wyk and Gericke 2000). While not	721
675	assessed in this biome scale assessment, the value	722
676	of these local scale benefits in sustaining local	723
677	inhabitants is substantial (James et al. 2005), partic-	724
678	ularly in times of hardship. Coupled with this, local	725
679	inhabitants have developed utilization strategies to	726
680	exploit these resources and to cope with seasonal	727
681	fluctuations in resource levels (O'Farrell et al. 2007;	728
682	Samuels et al. 2007) and periodic extreme events like	729
683	drought (O'Farrell et al. 2009a). Adopting a biome	730
684	scale hotspot approach to assessing service supply is	731
685	particularly good at highlighting key management	732
686	areas, it may potentially underplay local-level depen-	733
687	dence on particular services and not capture the	734
688	welfare implications associated with diminishing and	735
689	limited service provision. In semi-arid regions small	736
690	changes in the supply of services are likely to cause	737
691	disproportionally larger impacts on local beneficiaries	738
	compared with more well endowed areas. This is	
	particularly important given climate change predic-	
	tions presented for the region, and clearly regional	
	and biome level assessments need to be comple-	
	mented 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 multi-functional land-	
	scapes 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, opti-	
	mised biodiversity retention and protecting 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 is also 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, het-	
	erogeneity, 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 sup-	
	porting 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	

739 also need to be mapped, thereby linking local percep-
740 tions and values to broader landscape initiatives
741 (Raymond et al. 2009).

742 Promoting the development and use of appropriate
743 technologies, like those for sanitation and irrigation, is
744 fundamental in arid areas. These do not have to be
745 highly sophisticated schemes, and could be as simple
746 as establishing woodlots and harvesting rainfall. In
747 addition to these, ~~the development of~~ user demanded
748 information tools need to ~~take place~~, strategic support
749 provided along with policy coordination (Scherr and
750 McNeely 2008). Whilst we acknowledge Redford and
751 Adams (2009) cautionary warnings, the development
752 for payments for ecosystem service schemes where
753 applicable, such as in the identified ecosystem service
754 hotspots, ~~needs to developed~~. Whilst such schemes
755 have a foothold in Europe, where diversification
756 strategies, services payments and support to farmers
757 and land managers are well advanced (Wiggering et al.
758 2006), these still need to be initiated in South Africa
759 and many other developing countries where there is
760 potential to couple them to poverty relief objectives
761 (Turpie et al. 2008). However, there are currently a
762 wide variety of approaches available aside from these
763 market based instruments and the complexity of policy
764 instrument choice needs to be acknowledged.

765 The findings of this study suggest that for effective
766 management, engagement at the local level should not
767 be overlooked, and ecosystem services assessments
768 focussed on making a case for biodiversity need to
769 incorporate a variety of scales. Engagement at the
770 local scale is seen as critically important and a useful
771 point of entry to start co-developing and designing
772 place specific strategies for realising the potential
773 of these multi-functional landscapes (Nassauer and
774 Opdam 2008). Creating multi-functional landscapes
775 is only possible with full cognisance of all the dynamic
776 drivers of a landscape. Multipronged approaches
777 initiated at appropriate scales are vital in steering man-
778 agement decisions towards sustainable multi-func-
779 tional landscapes.
780

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