Title: Safeguarding biodiversity and ecosystem services: trade-offs and synergies in the Little Karoo, South Africa.

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Abstract

Global declines in biodiversity, together with the widespread degradation of ecosystem services, have led to urgent calls to safeguard both. Responses to this urgency include calls to integrate the needs of ecosystem services and biodiversity into the design of conservation interventions. The benefits of such integration are purported to include improvements in the justification and resources available for these interventions. However, additional costs and potential trade-offs remain poorly understood in the design of interventions that seek to conserve biodiversity and ecosystem services. In this study we aim to investigate the synergies and trade-offs in safeguarding ecosystem services and biodiversity in South Africa's Little Karoo. We use data on three ecosystem services: carbon storage, water recharge and fodder provision, together with data on biodiversity to examine several conservation planning scenarios. First, we investigate the amount of each ecosystem service captured incidentally by a conservation plan to meet targets for biodiversity only whilst minimising opportunity costs. We then examine the costs of adding targets for ecosystem services into this conservation plan, and finally explore tradeoffs between biodiversity and ecosystem service targets at a fixed cost. At least 30% of each ecosystem service was captured incidentally when all of biodiversity targets were met. By including data on ecosystem services, we were able to increase the amount of services captured by at least 20% for all three services, without additional costs. When biodiversity targets were reduced by 8%, an extra 40% of fodder provision and water recharge, and 58% of carbon could be captured for the same cost. The opportunity cost (in terms of forgone production) of safeguarding 100% of the biodiversity targets was about US $ 500M. Our results show that with a small decrease in biodiversity target achievement, we can achieve substantial gains for the conservation of ecosystem services within our biodiversity priority areas for no extra cost.

Keywords: Conservation planning, biodiversity assessments, opportunity cost, payments for ecosystem services, carbon storage, water recharge, fodder provision.

1 INTRODUCTION

Ecosystem services are the benefits that humans derive from natural systems. This service delivery relies on a certain level of biological resource base (natural capital); the degree to which all species contribute to this is unknown (Myers 1996; Balvanera et al. 2001). Reports on the ongoing degradation and unsustainable use of ecosystems services around the world highlight the urgent need to develop strategies to safeguard them (Balvanera et al. 2001; van Jaarsveld et al. 2005; Chan et al. 2006). Responses to this urgency include the emergence of new initiatives on ecosystem service planning and management (e.g. The Natural Capital Project (http://www.naturalcapitalproject.org) and the Valuing the Arc project (Fisher & Turner 2008)). These responses are based on over two decades of research and learning in the field of conservation biology, especially conservation planning (the identification of spatial priority areas for conservation action). By broadening their focus from the conservation of biodiversity alone to the conservation of biodiversity and ecosystem services, these responses propose to increase the support and resources available to conservation efforts (Armsworth et al. 2007, but see McCauley 2006). Unlike biodiversity, ecosystem services are defined by their link to human values and to particular beneficiaries. Furthermore, payments for ecosystem services (PES) schemes can be used to generate money for conservation efforts and organization from multiple sectors can work together to improve implementation success. For example Naidoo and Ricketts (2006) analysed ecosystem services and biodiversity to demonstrate the costs and benefits of various conservation options within a nature conservation area. The inclusion of ecosystem services and their anthropocentric values in conservation planning should help to improve the relevance and ease of implementation of conservation programs.

While the potential benefits from an integrated approach to safeguarding ecosystem services and biodiversity seems logical, the real benefits, trade-offs and costs of safeguarding both simultaneously are still unclear. Few studies have investigated the synergies and trade-offs associated with trying to safeguard both ecosystem services and biodiversity (but see Chan et al. 2006; Naidoo et al. 2008; Nelson et al. 2008). Chan et al. (2006) were among the first to investigate planning for ecosystem services and biodiversity. These assessments focused on spatial coincidence of ecosystem service and biodiversity priorities, highlighting the low levels of congruence. Chan et al (2006) found that in their study region priorities for ecosystem services did not always coincide spatially with priorities for biodiversity conservation. They evaluated the additional area required to meet ecosystem service targets over and above meeting biodiversity targets.

In this paper, we aim to move beyond the analysis of spatial congruence of biodiversity and ecosystem services to an assessment of the synergies, trade-offs and opportunity costs of an integrated approach to safeguarding ecosystem services and biodiversity in the Little Karoo of South Africa. Specifically we (a) evaluate the amount of ecosystem services captured incidentally by a conservation plan focused on biodiversity only; (b) determine if one can improve the amount of ecosystem services captured by simply including data on service distribution without increasing opportunity costs or reducing biodiversity targets; and (c) explore the consequences of including ecosystem services into a conservation plan for both biodiversity targets and total opportunity costs.

2 METHODS

2.1 Study Area

The Little Karoo region (19 730 km^2) (Fig. 1), is a semi-arid, intermontane basin, where vegetation associated with three biomes (the Succulent Karoo, Fynbos and Subtropical Thicket biomes) intersects and intermingles (Vlok et al. 2005). All three of these biomes are included in globally-recognized “biodiversity hotspots”, namely the Succulent Karoo, Maputaland-Pondoland-Albany, and Cape Floristic province, respectively (Mittermeier et al. 2005). Grazing and browsing by domestic livestock (especially ostriches) form the dominant land use in the area and have resulted in extensive overgrazing and degradation of more than 50% of the region, with a further 10% converted to cultivated areas (mostly for livestock feed) (Thompson et al. In Press). This degradation has resulted in declines in biodiversity condition (Rouget et al. 2006), as well as substantial declines in ecosystem services, including water supply, erosion and flood control (Reyers et al. In Press).

These declines have precipitated a regional stakeholder forum (the Gouritz Initiative Forum) – developed under the auspices of CapeNature, the government conservation organization - to explore interventions for improving the sustainability of the Little Karoo. These interventions include land management programs, tourism development and the investigation of carbon markets for restoration (see www.gouritz.com). Conservation plans targeting biodiversity features have been developed for the region; however, the pace of implementation is slow and hampered by organizational jurisdictions (most of the land is managed for livestock production where practices are regulated by the government agriculture and not CapeNature), limited capacity and the lack of appeal to many stakeholders of the planning outcomes (Lombard et al. subm.). The ecosystem services of carbon storage, water supply and fodder production remain important avenues for speeding up the pace of implementation, since these services are likely to have more appeal to stakeholders than biodiversity per se (Pierce et al. 2005, Lombard et al. subm.).

2.2 Data description

2.2.1 Biodiversity

We used Little Karoo vegetation data digitized from polygons hand-drawn on Landsat images after extensive field surveys (Vlok et al. 2005). The fine-resolution, hierachical map (1:50,000) comprised of 56 habitats types and 369 vegetation types. No comprehensive fine-scale coverage of species point locality data exists for the study area. Biodiversity targets were developed for the Little Karoo vegetation types at the level of the habitat type using the quantitative species turnover approach developed by Desmet and Cowling (2004). The targets ranged from 16% to 34% of original extent of each type (Gallo et al. 2009). A land cover and degradation map of the study area was used to evaluate the amount of vegetation remaining in a pristine or moderately degraded condition (Thompson et al. In Press). Areas that are cultivated, urban or severely degraded were classified as transformed and not considered to contribute to biodiversity targets.

2.2.2 Ecosystem services

We considered three ecosystem services in this study: carbon storage, fodder provision by natural vegetation (hereafter referred to as “fodder provision”), and water recharge. We estimated the amount of each ecosystem service provided by each vegetation type under intact and degraded (moderate and severe in some cases) conditions as deduced from the land cover map. Ecosystem services generated in cultivated and urbanised areas were set to zero for carbon storage and fodder provision. The background and detailed descriptions of ecosystem services can be found in Reyers et al. (In Press). Below we provide a brief description on how the ecosystems services were mapped. For the purposes of the study the 369 vegetation types described above were aggregated into 32 major types relevant to the agriculture and wildlife industry in the region by considering their physiognomy of the vegetation units (Vlok et al. 2005).

Carbon storage: The retention of carbon stored below or above the ground has the potential to mitigate climate change impacts. Carbon storage in the region has been found to exceed 20kg/m^2 in intact thicket (Mills and Cowling, 2006). Experts used this information to estimate carbon storage potential for each of the 32 major habitat types in tonnes per hectares. We used these data to estimate carbon storage per planning unit (the building block of a reserve network) (1km^2 grids) for the entire study area. The total amount of carbon stored in the study area was about 8.3*10^7 tons of carbon.

Fodder provision: The South African Department of Agriculture present, livestock carrying capacity in terms of hectares required per large stock unit (LSU) for sustainable grazing practise. Carrying capacity was overlaid with the above-mentioned fine-scale vegetation map to obtain the area (ha) per LSU required for sustainable grazing per habitat type under pristine, moderately degraded and severely degraded conditions. This was then converted to stock rates per planning unit. It was assumed that if an area was selected for conservation, grazing rates would be reduced to sustainable levels, thus providing fodder for wildlife or livestock. The study area could provide fodder for about 21585 LSU without degrading the environment.

Water recharge: Ground water is the main regulator of water flows in river systems. Data on ground water quality were extracted from borehole water analyses stored in the Water Management System database of the Department of Water Affairs and Forestry. The results were summarized by the primary lithology taken from the 1:1 million geological data (Council for Geosciences 1997). Groundwater recharge was estimated for pristine, moderately degraded, and transformed areas separately. The ecosystem service was mapped as millions of m^3 of groundwater recharge per planning unit. The total amount of ground water recharge for the study area was $3.8*10^8$ Mil m^3.

2.2.3 Opportunity cost

We distinguished between stock and flow values within the trade-off analysis. For flow values, we took two mutually exclusive land use practises (transformed land as used in commercial irrigation sector and ecosystem service delivery from conserving an equivalent area) as the foundation for estimating the value of initial trade-offs as per planning unit. In areas where commercial irrigation was feasible (because of water demands), we used over stocking (by doubling the stocking density to degrade pristine vegetation within 20 years) as substitute. Gross margins at the farm gate (as derived from census and industry data) were used as value estimate for opportunity cost (in terms of lost production) of conservation. Gross margin estimates for the deciduous fruit industry and selected cash crops were derived from the literature (Deciduous Fruit Producers Trust, 2008; Statistics South Africa, 2002) and presented in terms of hectares per planning unit. Since most uncultivated areas with potential for cultivation are adjacent to cultivated areas, we determined potential cultivation areas by buffering existing cultivated areas with a 500m radius. The maximum value of potential or actual revenue generated from cultivation was summarised per planning unit. We assume landowners act rationally, choosing the land use that will maximise profit (although often only in the short term).

Stock values were accounted for via discounting (Polasky et al. 2001) the above mentioned flow values against a discount rate of 6% for a period of 50 years to obtain a net present value as minimum estimate of the compensation cost for transformed land (Gollier, 2002; Howarth, 1996). We took the NPV as an estimate of compensation costs for landowner to manage their land according to a conservation stewardship program (see Gallo et al. 2008).

2.3 Analysis

We used simulated annealing within MARXAN vs1.8.2, which selects sets of reserve systems that meet targets for biodiversity features at a minimal cost (Possingham et al. 2000). MARXAN uses planning units which are the building blocks of a reserve system. All data were summarised at the level of the planning unit (1km^2 equal sized, 19357 in total). MARXAN selects multiple sets of alternative networks, all of which are near optimal at achieving the conservation objective. A species penalty factor (SPF) determines the importance of meeting targets – higher penalties can be set for not meeting targets for the most important features to increase the likelihood of the target being met, or penalties can be set high for all features if meeting all targets is a requirement.

Four scenarios were designed to evaluate the consequences of different conservation strategies for safeguarding biodiversity and/or ecosystem services in the Little Karoo. A zero cost was assigned to any planning unit classified as protected and these were selected in every scenario. At least 100 runs with 1,000,000 iterations were used for each analysis.

Scenario 1: Targeting biodiversity only

The objective here was to assess the amount of an ecosystem service captured in areas selected to meet biodiversity targets most efficiently. We did this across a range of biodiversity targets at 5% intervals, from 10% to 100% of the original target specified in Desmet and Cowling (2004). We estimated both the opportunity cost of achieving the targets, using the best solution from MARXAN at each target level, which is the network that meets the targets at least cost. We also estimated the amount of ecosystem services captured incidentally in the best solution, compared with the amount of ecosystem services captured in a randomly drawn sample (repeated 100 times) equal to the area selected at each target level.

Scenario 2: *Targeting biodiversity and ecosystem services*

Here we investigate the influence of including data on ecosystem services in the conservation plans described in Scenario 1. Within each target level, the opportunity cost was fixed at the cost of meeting the biodiversity targets in Scenario 1. For example, at the biodiversity target of 10%, the opportunity cost of meeting 10% biodiversity targets was held constant and ecosystem service targets were introduced and gradually increased to find the maximum amount of ecosystem services captured for the same opportunity cost. This was carried out for all three ecosystem services.

Scenario 3: Trading off biodiversity and ecosystem services targets

The objective of this analysis was to evaluate the tradeoffs between biodiversity and ecosystem services by finding out how much ecosystem services can be captured by reducing some biodiversity targets within a fixed opportunity cost. A cost threshold was set (cost of meeting 50% of biodiversity targets), and different ratios of biodiversity/ecosystem service conservation were explored. We use the 50% target, as at the 100% target much of the study area is selected leaving little room for the flexibility required in this scenario. *Scenario 1* told us how much of each ecosystem service was captured by meeting 50% of the biodiversity targets. We systematically increased this amount for each ecosystem service and calculated the number of biodiversity features whose targets were not met for the same opportunity cost.

Scenario 4: Scenario 3 with a flexible budget

The objective here was to assess the increased opportunity cost of increasing targets for ecosystem services, while maintaining biodiversity targets. We held biodiversity targets constant (at 50% of the original targets as per Scenario 3) and systematically increased targets for each ecosystem service and calculated the cost increase of the resulting conservation area network. The starting target for each ecosystem service was the amount captured incidentally while planning for biodiversity alone and meeting 50% of the biodiversity target.

3 RESULTS

Opportunity costs across the landscape

There was a high degree of cost variability throughout the study site (Fig. 1). The maximum gross income per planning unit varied across the study area from US$0-$489 000. The net present value (NPV) of planning units ranged from US$0-$8 152 000. Gross margins from grazing was generally lower as compared to cultivation. The most profitable land use was the cultivation of deciduous fruits. The average maximum revenue that could be generated for any land use per planning unit was US$109 000. The average NPV per planning unit was $1 823 000. Most of the high value lands were concentrated in the low-lying eastern parts of the study area.

The opportunity cost of reaching 100% of the biodiversity targets was about US $ 500M per annum. The NPV of the land that met this target was about US$8.3 billion. When only 50% of the biodiversity targets were met, the opportunity cost dropped to about US$200M with the NPV of the land required also dropping to about US$3.2 billion.

Scenario 1: Targeting biodiversity only

When the full biodiversity targets were met, approximately 37% of all carbon stored in the study area, 45% of all fodder and 57% water recharge were captured incidentally. Meeting 50% of the target captured 23% of carbon, 32% fodder provision, from earlier nomenclature? and 48% water recharge. We observed a roughly linear increase in both the amount of ecosystem services captured incidentally and cost (and the area requiring conservation) as we increased biodiversity targets (Fig. 2a-c). When the outputs of scenario 1 were compared to the random selections the numbers of LSU for fodder provision captured was not significantly different, the amount of carbon captured was lower and water recharge was significantly higher than the random sample.

Scenario 2: *Targeting biodiversity and ecosystem services within*

The amount of ecosystem services captured by targeting ecosystem services within the same opportunity cost threshold as scenario 1 increased by at least 20% for water and 30% for carbon and fodder provision (Fig. 2a-c). In this scenario MARXAN selected more planning units (Fig. 3 and 4a-d). The large variation in the cost of planning units allowed MARXAN to trade planning units with higher opportunity cost selected for biodiversity only, with cheaper ones that contributed to both biodiversity and ecosystem service objectives. For example, a reserve network aimed at meeting biodiversity targets and 37% of carbon storage was 1.5 times larger than that for biodiversity only, but had the same total opportunity cost. Although these two conservation area networks share about 65% of the planning units, 9% of the planning units selected for the “biodiversity-only” network and not selected for the “integrated” network had much higher opportunity costs. The difference in the number of planning units selected for the biodiversity only network and for both biodiversity and ecosystem service network was greatest for carbon compared to the other two services.

Scenario 3: Trading off biodiversity and ecosystem services targets

Relinquishing small amounts of biodiversity resulted in large gains in ecosystem services in this scenario for the same total opportunity cost as scenarios 1 and 2. When targets for 8% of the biodiversity features (vegetation types) are not met, an extra 40% of fodder provision and water recharge, and 58% of carbon are captured for the same total opportunity cost. However, more than 70% of the vegetation types whose target were not met had lost at least 50% of their original extent and are recognised as threatened ecosystems.

Scenario 4: Targeting ecosystem services

Increasing targets for ecosystem services by about 30% did not significantly increase the opportunity cost of the network from the biodiversity-only amount (Fig. 5). However, the percentage area required for conservation increased significantly. For example, a 10% increase in target for fodder provision did not significantly increase the cost but resulted in a 10% increase in area. Beyond this amount, we could increase targets for carbon for a lower increase in cost than that for the other two services.

4 DISCUSSION

Can biodiversity based conservation plans effectively incorporate ecosystem services?

While it is true that conservation plans designed to conserve biodiversity do capture some ecosystem services coincidentally (e.g. Naidoo et al. 2008), this study shows that by including data on ecosystem services the conservation plans can be far more efficient in selecting areas for both biodiversity and ecosystem services at no, or at minimal additional costs. So while there might be biodiversity features that co-occur with some ecosystem services at global and local scales (Chan et al. 2006; Turner et al. 2007; Egoh et al. 2009), as well as some congruence between different ecosystem services (Chan et al. 2006, Egoh et al. 2008, Reyers et al. In Press), the inclusion of data on biodiversity and ecosystem services allows the conservation plan to optimise all targets as efficiently as possible. This will be particularly true in regions where alternative options for meeting biodiversity targets still exist. In the Little Karoo there are still large tracts of pristine or moderately degraded land which means that the conservation plan can select several different combinations of planning units to meet biodiversity targets. If one includes data on the distribution of ecosystem services into this conservation plan then this will guide the selection of planning units to those that meet biodiversity as well as ecosystem service targets without changing the associated opportunity costs. In parts of the world where land cover change is more widespread and options more limited, trade-offs between biodiversity and ecosystem service targets will be stronger where budgets are limited.

In the Little Karoo we can see these trade-offs begin to develop in scenario 3 where as one increases ecosystem service targets some biodiversity features can no longer meet their targets within a constrained budget. This indicates that there are areas which perform well in meeting biodiversity targets but not ecosystem services and *vice versa.* The biodiversity features traded for ecosystem services in scenario 3 were mostly those that are already threatened. These vegetation types with limited extant cover are those needing the most conservation action. One way of solving this problem is to assign a higher penalty factor to any such important conservation feature, such that less vulnerable features will be traded-off against in the increased ecosystem service targets. Including ecosystem services in a biodiversity plan come at some cost to biodiversity conservation, assuming a limited budget. However if the use of ecosystem services as a marketing tool can increase the pool of funds for conservation, then we could theoretically increase the protection of biodiversity. These trade-offs, as well as the size of the costs associated with all scenarios raise some concerns which we elaborate on below.

The costs of conservation.

The Little Karoo, like the rest of South Africa, consists of mostly privately owned land with state land totalling less than 20% of the region (Gallo et al. 2009). This implies that the costs of safeguarding biodiversity and ecosystem services in the Little Karoo will be high and will include acquisition or opportunity and other compensatory costs. The estimated opportunity costs of US$ 500 million for scenarios 1 is very high when compared with existing conservation budgets, which currently total $12 million a year for CapeNature, the agency tasked with managing the entire Western Cape Province’s conservation areas (Frazee et al. 2003). Gallo et al. (2009) have demonstrated the role that privately owned reserves can play in helping to achieve conservation goals in the Little Karoo especially in the more productive (and expensive) lowland areas. Currently the reasons for land owners to conserve their land are not well understood, but appear to include pro-conservation values, the benefits of tourism, the game industry and lifestyle choices (O’ Farrell et al. 2008). The data and techniques used in this study could prove helpful in identifying synergies between biodiversity targets, land owner choices and new incentives provided by ecosystem services. For example, meeting biodiversity targets in the Little Karoo also captures about 31 million tonnes of carbon and at the time of this study, carbon was trading at prices ranging from US$6.46 to US$38.46 per tonne CO_2 (http://www.ecosystemmarketplace.com, accessed June 2008). At a conservative price of US$7.50 per tonne CO_2 (about $ 27 per tonne of carbon), the carbon captured in this study could produce an income of about a billion dollars (including transaction cost) for avoided carbon release (also see Mills et al. 2007).

These markets and other funding mechanisms provided by ecosystem services could provide additional incentives to land owners to use their land sustainably, safeguarding biodiversity and ecosystem services, and being paid to do so (Blignaut & Aronson 2008). Grazing of domestic livestock and game provide additional incentives. Sustainable grazing levels are amenable with biodiversity and ecosystem service management goals and can generate income.

Fodder provision captured by the conservation plan in scenario 1 would generate about US $6.5 million in livestock sales. If revenue from other sources of income for sustainable land use are combined, the opportunity costs of conservation become smaller and makes the tasks of conservation agencies less onerous.

While the above appears to support integrated planning for biodiversity and ecosystem services, there are many practical challenges that lie ahead. These include the scale of benefit flows, the absence of markets, and institutional needs. Although there is the potential for land owners to benefit from sustainable use of the land, a shift in land use is only possible if the benefits are made clear. Carbon sequestration benefits are global, yet land owners can derive local benefits through international markets although transaction costs are high (Mills et al. 2007). Water provision on the other hand generates benefits at a variety of scales, but markets are either absent or weak and currently there is little incentive for land owners to safeguard water supplies beyond their property. Fodder provision benefits the land owner directly, but in this case the land owner can make greater short term profits by overstocking land and buying additional feed (O' Farrell et al. 2008). It becomes clear that identifying areas where one can safeguard biodiversity and ecosystem services will need to be supplemented with the creation of new markets, institutions and certification processes, to ensure these benefits are realised. It will take time and effort to establish these institutions, markets and processes, and build the necessary capacity to support these schemes (Cowling et al. 2008). Government and NGO support and resources are vital in these early phases (e.g. Turpie et al. 2008).

Biodiversity and ecosystem service trade-offs

The trade-offs evident in scenario 3 and increasing ecosystem service targets are traded off against biodiversity targets under a limited budget highlights a final cautionary note in integrated planning. These trade-offs would be even greater if we had used more limited (and real) budgets, or if we had done this analysis in another more productive part of the world where competition for land is greater and opportunity costs higher. What these trade-offs indicate to us is that there will be pieces of land or biodiversity features that will rely on agencies and resources dedicated to the intrinsic value of biodiversity.

Bohensky et al. (2004) argue that making trade-offs transparent to decision makers can help to clarify the likely consequences of alternative choices. In support of this need for information, tools and methods to quantify the trade-offs between biodiversity and ecosystem services will be essential. MARXAN and the scenarios used here provide a useful start, however further development is needed to investigate the relationship between biodiversity and ecosystem service targets across a range of services and contexts. Software that can place planning units into management zones of differing costs, actions and contribution to targets will also be very valuable in recognising the different management requirements of biodiversity and ecosystem services.

Conclusions

This study, together with earlier work, has highlighted the benefits of integrating biodiversity with ecosystem services in conservation planning. These benefits however will not be realised without the support of markets and institutions for ecosystem services, many of which do not yet exist. It is recommended that while work on the data and techniques required for this type of integrated planning progresses, attention is also paid to these institutional requirements to ensure that planning results in actions to safeguard biodiversity and ecosystem services (Cowling et al. 2008). Finally, it is important to note that ecosystem services will not solve all the funding and implementation challenges associated with conserving biodiversity. If we are to fulfil our national and international obligations to biodiversity conservation, we will have to ensure that money and people remain committed to biodiversity.

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List of Figures

Figure 1: Map of study with variability in planning unit cost.

Figure 2: Percentage increase in ecosystem service captured by increasing biodiversity targets for two conservation plans, one of which targets ecosystem service (*scenario 1 and 2*). *Scenario 1* only used data on biodiversity while *scenario 2* used data on biodiversity and ecosystem services within same opportunity cost. A) Fodder. B) Carbon. C) Water recharge

Figure 3: Percentage increase in area selected as ecosystem service targets increases (*scenario 2*).

Figure 4: Map of study area showing conservation priorities when only biodiversity is targeted in *scenario 1* and when both biodiversity and various ecosystem services are targeted simultaneously in *scenario 2*. A) Biodiversity only. B) Biodiversity and fodder. C) Biodiversity and carbon. D) Biodiversity and water recharge.

Figure 5: Cost of increasing targets for ecosystem services starting with a biodiversity plan that meets 50% of the targets for vegetation types at the minimum cost (*scenario 4*).

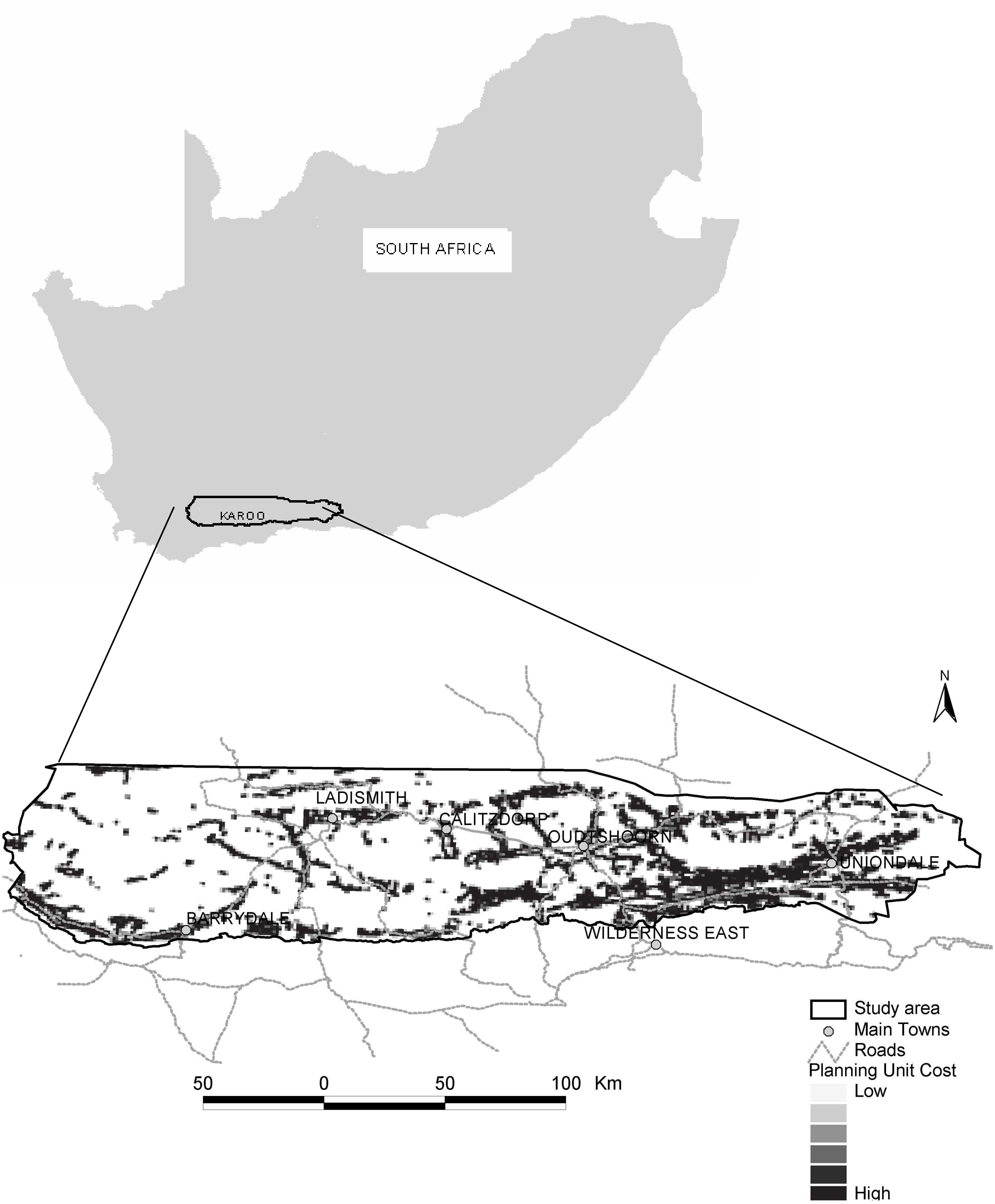
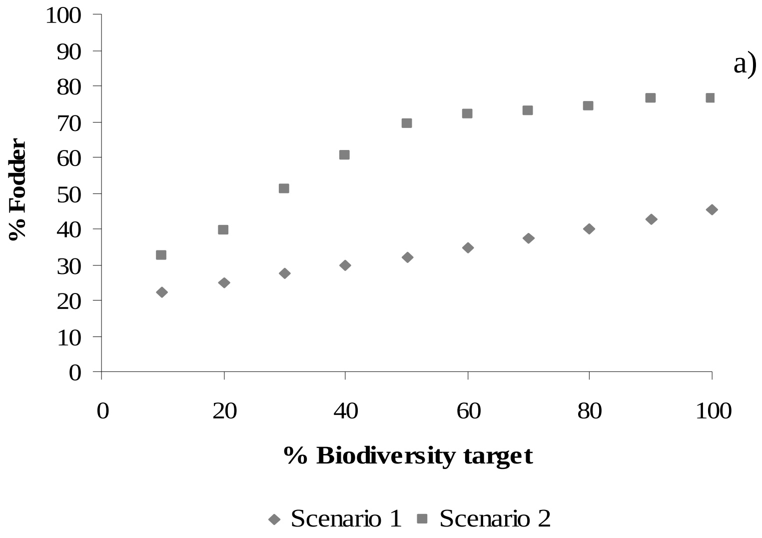
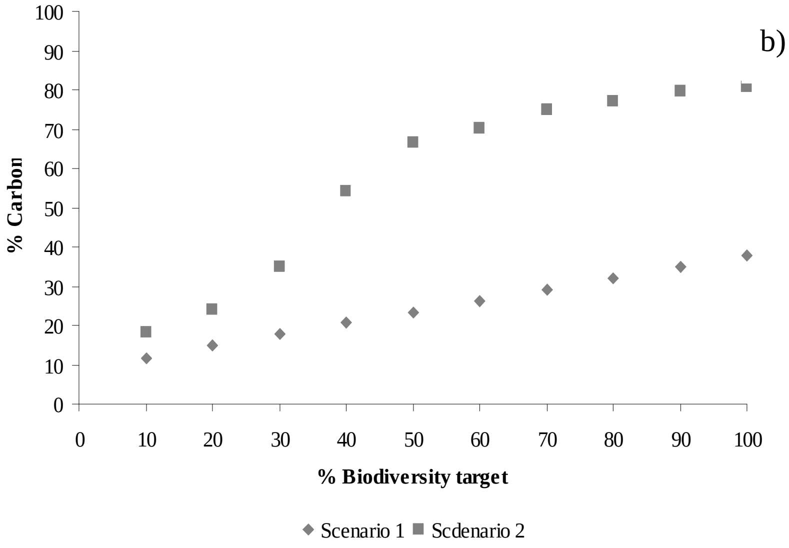

SOUTH AFRICA
KAROO
N
LADISMITH
CALITZDORP
OUDTSHOORN
UNIONDALE
BARRYDALE
WILDERNESS EAST
50
0
50
100
Km
Study area
Main Towns
Roads
Planning Unit Cost
Low
High

Figure 1.


a)
% Fodder
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
% Biodiversity target
◆ Scenario 1 ■ Scenario 2


b)
% Carbon
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
% Biodiversity target
◆ Scenario 1 ■ Scdenario 2

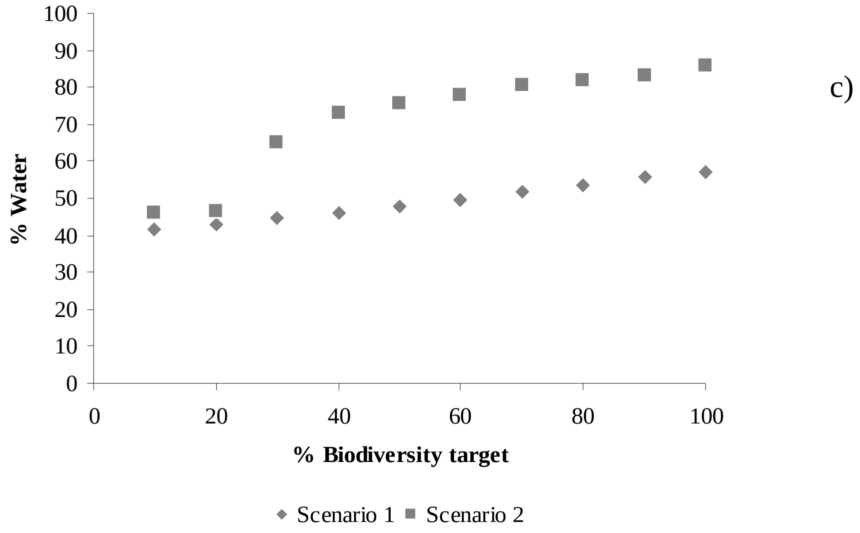


Figure 2

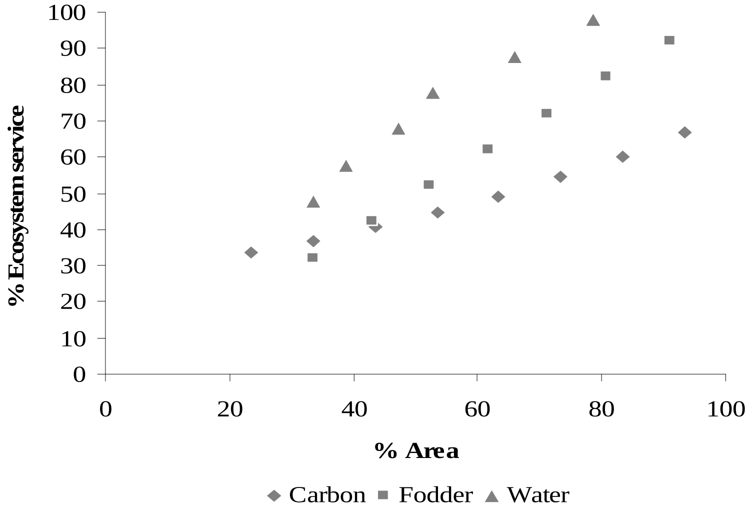
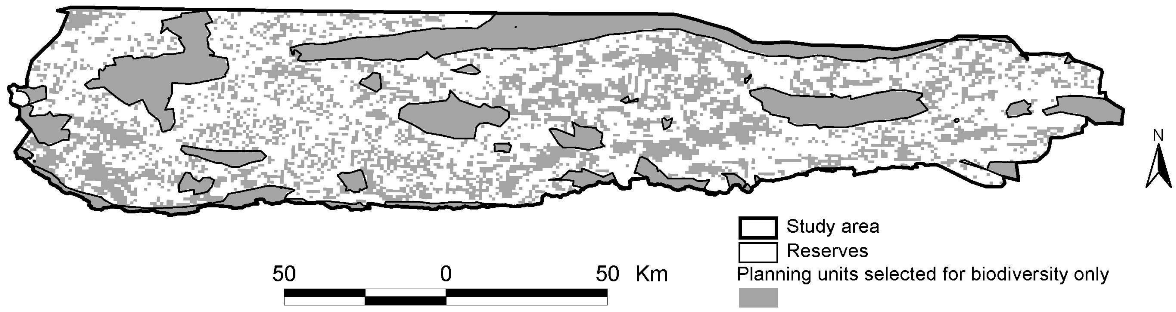
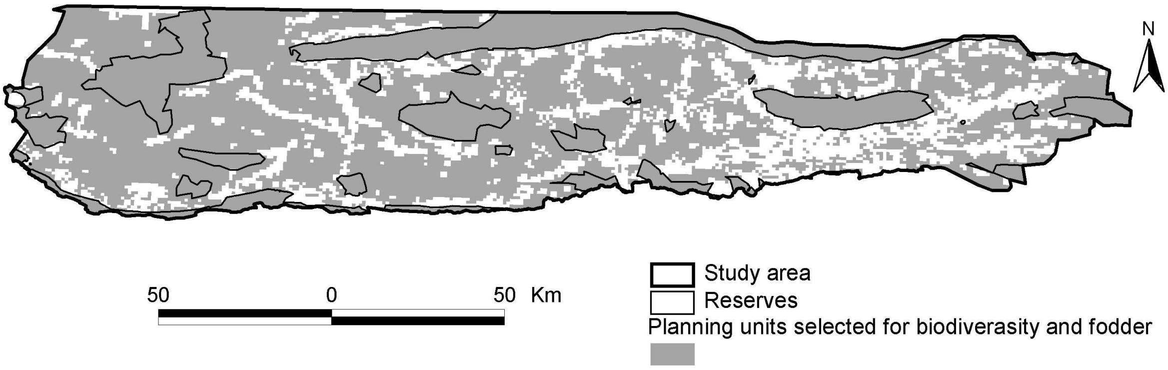


Figure 3

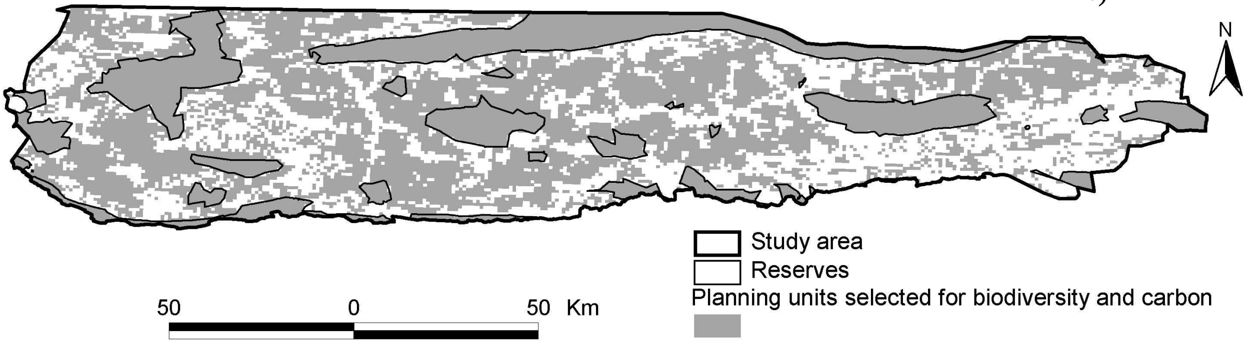
a)


Study area
Reserves
Planning units selected for biodiversity only
50
0
50 Km
N

b)


Study area
Reserves
Planning units selected for biodiverasity and fodder
50
0
50 Km
N

c)


Study area
Reserves
Planning units selected for biodiversity and carbon
50
0
50 Km
N

d)

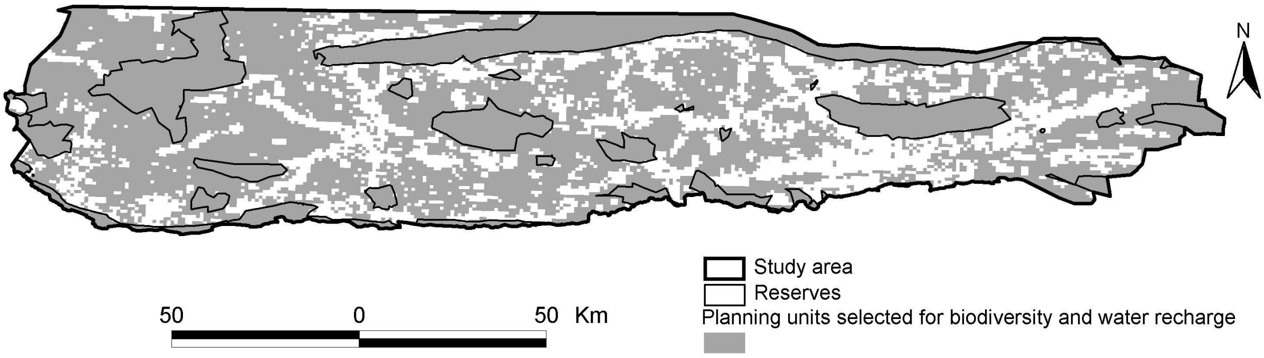


Figure 4

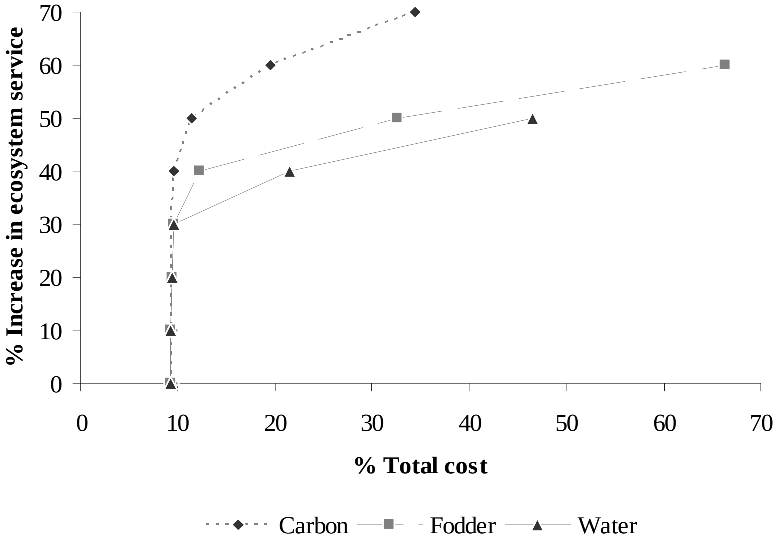


Figure 5