Ecosystem Services xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Mapping and valuation of South Africa's ecosystem services: A local perspective

J.K. Turpie[a,b,c,*], K.J. Forsythe[c], A. Knowles[d], J. Blignaut[e], G. Letley[c]

[a] Environmental Policy Research Unit, School of Economics, University of Cape Town, Rondebosch 7700, South Africa
[b] South African Institute of Aquatic Biodiversity, Grahamstown 6140, South Africa
[c] Anchor Environmental Consultants, 8 Steenberg House, Silverwood Close, Tokai 7945, South Africa
[d] The Cirrus Group, Postnet Suite #188, Private Bag ×18, Rondebosch 7701, South Africa
[e] Department of Economics, University of Pretoria, 0001, South Africa

ARTICLE INFO

Keywords:
Ecosystem services
Valuation
Mapping
Ecosystem services accounting
Natural capital

ABSTRACT

We used locally-sourced and other relevant information to value ecosystem services provided by South Africa's terrestrial, freshwater and estuarine habitats. Our preliminary estimates suggest that these are worth at least R275 billion per annum to South Africans. Notwithstanding benefits to the rest of the world, natural systems provide a major source of direct income to poor households, and generate significant value in the economy through tourism and property markets, as well as providing considerable non-market benefits. Higher values correspond both to areas of higher biomass, which have higher capacity to supply ecosystem services, and areas of higher population densities, which generate demand as well as threats. The value of regulating services is higher for natural systems closer to population centres. Amenity values are highest in cities and protected areas, with the fragmented green open space areas within cities have among the highest values per ha. Even if the gaps are taken into account, our estimates are far lower than estimates based on average global values, but are likely to be more accurate, relevant and tractable to policymakers. Nevertheless, some services have large global values, the recognition of which is important in developing strategies for financing biodiversity conservation.

1. Introduction

The need to find an optimal balance between conservation and development is increasingly evident, especially in developing countries such as South Africa, where addressing widespread poverty is a priority, and where ecosystems and their biodiversity face escalating threats from land transformation, hydrological alteration, pollution, overexploitation, invasive alien species and climate change. The valuation and mapping of ecosystem services can inform policy by elucidating the role of natural capital in contributing to development objectives, highlighting natural areas of importance for service provision, facilitating the evaluation of alternative locations for project action, and providing better justification for public spending on conservation and restoration efforts (van Jaarsveld et al., 2005).

The valuation of ecosystem services has proliferated since the early 1990s. While most studies focus on single services at a local scale (Turner et al., 2003), these can be used in conjunction with spatial data to develop regional, national or even global estimates. Since Costanza et al.'s (1997)'s estimate of the value of the world's ecosystem servicesin , extrapolated from the few studies available at the time, the execution and scaling up of valuation studies has been significantly improved by advances in satellite data, geographic information systems and models. This has allowed for more accurate means of transferring values, taking geographic variation into account (e.g. Troy and Wilson, 2006; Egoh et al., 2008; Naidoo et al., 2008; UK NEA, 2011). These advances are motivated by growing recognition of the importance of valuing natural systems at a national scale (e.g. CBD Aichi targets) and their incorporation into national accounting systems (UN-SEEA, 2012).

Much of the work carried out to date relies on the increasing pool of estimates from valuation studies around the world, much of which is collated in global databases. These have been particularly valuable in extrapolating values to areas for which estimates are relatively scarce, notably developing countries. However, the reliability and policy relevance of such estimates might be limited. We argue that "local is *lekker*[1]", in that it may often be more useful to apply (scarce) local

* Corresponding author at: Environmental Policy Research Unit, School of Economics, University of Cape Town, Rondebosch 7700, South Africa.
E-mail addresses: jane.turpie@uct.ac.za, jane@anchorenvironmental.co.za (J.K. Turpie), kat@anchorenvironmental.co.za (K.J. Forsythe), tony@cirrusafrica.com (A. Knowles), jnblignaut@gmail.com (J. Blignaut), gwyn@anchorenvironmental.co.za (G. Letley).

[1] A South African expression translating to "local is good".best".

http://dx.doi.org/10.1016/j.ecoser.2017.07.008
Received 27 May 2017; Received in revised form 14 July 2017; Accepted 16 July 2017

Please cite this article as: Turpie, J.K., Ecosystem Services (2017), http://dx.doi.org/10.1016/j.ecoser.2017.07.008

Table 1
Provisioning, cultural and regulating services included and not included in this study. Note that the provision of mineral resources, water and abiotic energy were not considered as ecosystem services.

Category	Services	Brief explanation	Included
Provisioning services	Livestock fodder	Supply of grazing used as an input to free-ranging livestock and game farming	Yes
	Harvested renewable resources	Raw materials, biofuel, wild foods. wild medicines and ornamental products (e.g. flowers) harvested for use or sale	Yes
	Genetic resources, biological compounds	The value of exploration for genetic varieties etc. that are used in agriculture, horticulture, medicine etc.	*No*
Cultural services	Amenity values (aesthetic, recreation)	The value derived from viewing or using nature for relaxation, exercise, spiritual enjoyment etc.	Yes
	Cultural and religious value	The significance of nature in cultural and religious beliefs and activities	*No*
	Existence and bequest (non-use) values	The value derived from the knowledge that wild nature exists and that it can be enjoyed by future generations	Yes
	Scientific and educational value	The value derived from understanding nature and potential lessons etc, including from armchair appreciation of nature (e.g. watching documentaries)	*No*
Regulating services	Carbon storage	Maintenance of carbon stored in plants and soil, rather than allowing their release into the atmosphere leading to climate change damages	Yes
	Regulation of local climate	Reduction of urban heat island effects or wind by natural vegetation	*No*
	Pollination	Pollination of crops by wild pollinators, improving crop yields, saving managed pollination costs	Yes
	Control of pests and pathogens	Control of pest populations by wild animal populations, reducing losses or prevention costs, or avoidance of the proliferation of pests or pathogens by maintaining healthy ecosystems e.g. black fly*, malaria	Part*
	Maintaining soil fertility	Replenishment of fertile soils by flooding	*No*
	Critical habitats/refugia	The role played by critical habitats such as breeding areas, nursery areas or seasonal watering areas, for the maintenance or productivity of broader-scale populations that have value elsewhere, e.g. the value of estuaries for marine fisheries	Yes
	Control of erosion and sedimentation	Prevention of soil loss by vegetative cover and the prevention of sedimentation by eroded sediments through trapping by vegetation and wetlands.	Yes
	Flow regulation	Flood attenuation by vegetated areas and wetlands; and groundwater recharge and the maintenance of low flows through infiltration facilitated by vegetative cover	Yes
	Coastal storm protection	Attenuation of wave energy by natural barriers such as dunes and mangroves, avoiding damages	*No*
	Water quality amelioration	Avoided treatment costs and downstream ES losses through removal of elevated nutrients, suspended sediments and pathogens generated by human activities.	Yes
	Air quality amelioration	Health costs avoided through removal of particulate matter by vegetation, particularly in urban areas	*No*

value estimates than using international estimates that may not be reliably transferable to local contexts. Furthermore, while international values may be useful to inform strategies for financing biodiversity conservation to improve global welfare, local values are more important for optimizing allocations from a national welfare perspective, and are therefore more likely to have traction with policy-makers.

In this study, we provide preliminary estimates of the value of South Africa's untransformed terrestrial, aquatic and estuarine ecosystems to South Africans, using locally-relevant data, and taking spatial variation in ecosystem system characteristics and demand into account as far as possible. In addition to highlighting the patterns of value and their implications, we draw attention to data gaps and areas for further research, and discuss the discrepancies with international estimates.

2. Data and methods

2.1. Valuation framework and scope

Environmental valuation began with the notion of estimating changes in total economic value (direct, indirect, option and non-use values, Pearce and Turner, 1990) obtained from environmental assets as a result of changes in environmental characteristics. The concept of ecosystem services developed later, and along with it, the idea of trying to put a value on natural capital (e.g. Costanza et al., 1997), rather than valuing marginal changes. The development of a standardized approach to classify and value ecosystem services is considered critical to informing sustainable development policy but remains a serious challenge (UN, 2012). This is partly because most benefits derived from ecosystems are the result of a combination of labour and man-made capital as well as natural inputs (Boyd and Banzhaf, 2007; Landers and Nahlik, 2013), which makes it difficult to attribute value to nature.

The concept of ecosystem services was introduced to make the point that nature should also be recognized as a valuable form of capital that contributes to economic production and human wellbeing. The original concept saw ecosystems providing “goods”, such as fish, and “services”, such as water quality amelioration, which provided inputs to or saved on the costs of production. This concept was further clarified by Barbier (1994), who recognized that ecosystems also have “attributes”, such as beauty, rarity or diversity, that generate spiritual, educational, cultural and recreational values. Goods, services and attributes were essentially re-categorized as provisioning, regulating and cultural services by the Millennium Ecosystem Assessment framework document (2005), which also recognized a fourth category of supporting services, comprising the underlying processes which maintain conditions for life on Earth. The Common International Classification of Ecosystem Services (CICES; Haines-Young and Potschin, 2013) has reverted to three main groups (“provisioning”, “regulation and maintenance” and “cultural”), but retains these underlying functions and broadens the concept of ecosystem services to include crop and livestock production and their co-benefits such as draught power, as well as abiotic energy sources such as wind and tidal energy production. There are also other changes such as inclusion of water storage (including by reservoirs) and water purification as a provisioning service. This study follows the more traditional frameworks, but ignoring the supporting services of the MEA to avoid double-counting.

In this study, we focussed our assessment on the direct and indirect use values of the provisioning, regulating and cultural services provided by remaining natural terrestrial, freshwater and estuarine ecosystems in their current condition. These areas represent 85% of South Africa's land area, most of which is under private or communal rangelands, private wildlife-based land uses or state-owned protected areas, including urban green open space areas and beaches. The assessment did not include the value of cropland or plantations, which make up 13% of the country and contribute 2% to GDP (DAFF, 2017). Rather, it sought to value what might be lost when natural systems are further degraded or transformed to these land uses or by other development such as mining or urbanization. However, the study does include the value that natural systems contribute to agricultural production. In addition, we did not include the value of water. It would be fairly straightforward to provide a coarse estimate of value, and the geographic variation in runoff is well known with high runoff areas having been identified as critical ecological infrastructure (WWF, 2013). However, the value of water cannot be attributed to ecosystems or their quality (overall water supply would be the same if the catchment areas were under concrete). Rather, we consider how ecosystem functioning saves on the costs of water supply through regulating the timing of flows. The ecosystem services considered in this study are listed in Table 1, along with information on which services were estimated. The services that were not estimated were omitted because they were considered to be relatively minor, because of a lack of information, or both.

2.2. Overall approach

The nature of each service was described, and based on available literature and data, a method for estimating and mapping ecosystem services and their values was devised. Both the ecosystem capacity for supplying the service and the demand for the service were taken into account as far as possible. Estimates were derived using a range of spatial datasets on ecosystem characteristics and human geography (Table 2). The distribution of urban areas, protected areas and provinces in South Africa are shown in Fig. 1 and population density and the location of main communal land are shown in Fig. 2.

The value of a service was taken to be the cost that would be incurred if it were lost. Where the service is demanded, this cost is ideally taken as the lesser of (a) damages or losses incurred, e.g. a reduction in productive value, or (b) the expenditure that would have to be incurred to replace the lost service.

Wherever ecosystem services yielded positive value, such as provision of harvested resources or recreational value, values were estimated in terms of total gross output (exchange value). Other services were valued in terms of costs avoided, such as the engineering costs that would be incurred in replacing the flow regulation services of wetlands, or in the case of erosion control or pest control, the costs that would be incurred if the remaining natural areas were (further) degraded or lost. All monetary values were converted to 2015 values using the consumer price index (CPI) and expressed in terms of Rands per ha of natural per year (2015 Rands, $1 ~ R15.55). Values of each type of service were mapped in free spatial format (polygons) or in a 0.025 degree grid format.

2.3. Provisioning services

2.3.1. Livestock fodder production

A large proportion of South Africa is under rangeland, with small stock predominating in the drier areas to the west, and cattle in the more mesic eastern areas. The gross production value of free ranging livestock (including game) was about R39.75bn in 2016 (DAFF, 2017). The value of fodder production in rangeland areas was estimated as the minimum of its replacement cost (in terms of bought feed) and the value of livestock production.

Based on the provincial livestock statistics for February 2016 (DAFF, 2016), and the distribution of cattle (excluding dairy and feedlot animals) in terms of bulls, cows, heifers, oxen, young oxen and calves (DAFF, 2015, 2014), we developed a provincial profile of beef cattle per province. This we augmented with the number of sheep and goats per province (DAFF, 2016).

Following Mapiye et al. (2009), Scholtz et al., (2008, 2014), Spies (2011) and Blignaut et al. (2017) we were able to estimate the daily, and thus annual, fodder demand for cattle. This was done by multiplying the body mass per animal per animal class (for commercial and communal herds) with its daily fodder requirement (estimated to be 3% of its body weight). The same principle was applied for sheep and goats, assuming sheep to be 70 kg on average and goats 40 kg, and a daily fodder demand of 3% of body mass as well. The replacement value of fodder was the cost of veld grass per ton as sold in Gauteng in 2016. Since the replacement costs of fodder exceeded the value of livestock production, we used the value of livestock production as the value that would be lost through complete degradation or transformation of the rangeland areas.

Provincial values were mapped to the untransformed land outside protected areas, in proportion to relative grazing capacity (DoA, 1999). Ideally the areas under wildlife use should also have been differentiated (the majority of wildlife use is valued as tourism and recreation), but there are no comprehensive spatial data on this land use.

2.3.2. Harvested living resources

Millions of South Africans harvest wild foods, medicines, firewood and raw materials for both subsistence and commercial use (Shackleton et al., 2001; Shackleton and Shackleton, 2004; Lannas and Turpie, 2009; Peterson et al., 2012), particularly where there are limited economic opportunities (Dovie et al., 2006). The provisioning value of resources harvested by subsistence and small-scale users from terrestrial and freshwater habitats was estimated based on the minimum of their sustainable yields and the estimated demand. These estimates were augmented with existing estimates of the value of resources harvested from estuaries and the value of commercial harvests of thatch and flowers. Note that these values do not include

Table 2
Sources of spatial data used in this analysis as well as their type and the ecosystem services they were used for. Livestock Fodder = LF, harvested resources = HR, tourism value = TV, property value = PV, Carbon sequestration = CS, agricultural support = AS, fisheries support = FS, flow regulation = FR, soil erosion = SE, water quality = WQ.

Spatial Data	Source	Type	Ecosystem Service
Landcover/landuse 2014, 30 m	Geoterraimage (2015)	Raster	LF, HR, TV, AS, WQ
Biomes	Low and Rebelo (1996)	Polygon	HR
Vegetation types	Mucina et al. (2005)	Polygon	HR
1:500 Rivers and their integrity	CSIR (2011)	Polylines	AS, WQ
Natural inland wetlands by type	SANBI (2015a, 2015b, 2015c, 2015d)	Polygons	FR, WQ
Estuaries	SANBI (2015a, 2015b, 2015c, 2015d)	Polygons	HR, FS
Administrative areas and protected areas	SANBI (2015a, 2015b, 2015c, 2015d)	Polygons	LF, HR, PV
2011 Census sub-places	StatsSA (2012a) (2012b)	Polygons	HR, PV
Grazing Capacity	DoA (1999)	Polygons	LF
0.025 degree grid (~2.75 × 2.4 km)	This Study	Polygon	TV
South African National Carbon Sink Assessment, ~1.2 km	DEA (2015)	Raster	CS
Quaternary catchments	DWS (2012)	Polygon	FR, SE, WQ
South African Atlas of Climatology and Agrohydrology	Schulze (2007)	Polygons	FR, SE
DEM	90 m SRTM	Raster	SE

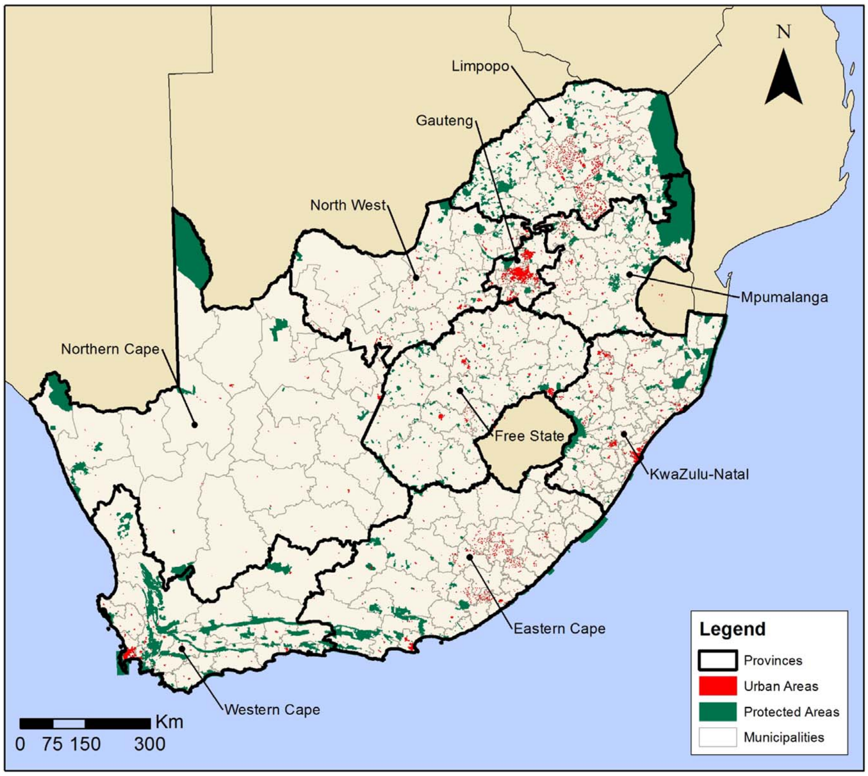

Fig. 1. Map of South Africa showing the provincial (black) and municipal (grey) boundaries, protected areas and national parks (green), and urban areas (red). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

recreational hunting and fishing, which are incorporated elsewhere.

Potential aggregate household demand for all natural resources (grouped into seven categories – water, fuelwood, poles, grass, reeds and sedges, wild plant foods and medicines, bush meat, fish) was estimated at the sub-place (~village) level using models developed by Turpie et al. (2010a) based on household survey data and 2011 Census data. Sustainable yields and prices for these resources within each major vegetation type were obtained from the literature, using locally-

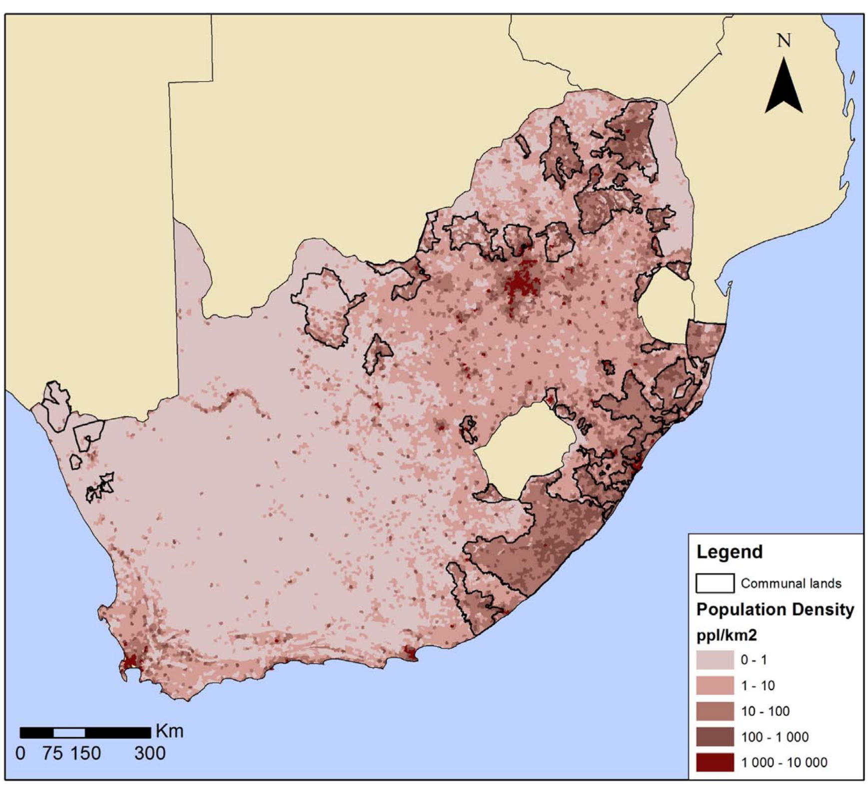

Fig. 2. Map of South Africa showing geographic variation in population density and the location of communal land areas including former homelands and communal reserves in Namaqualand.

sourced information as far as possible. Shackleton (1993), Dovie et al. (2004) and Barnes et al. (2005) provided data on sustainable harvesting rates and prices for woody raw materials. Sustainable harvesting estimates for non-woody raw materials were based on information from Twine et al. (2003), Turpie et al. (2007) and Mmopelwa et al. (2009). Sustainable offtake of wild plant foods and medicines and for wild meat and birds were estimated using data from Mander (1998), Dovie et al. (2002), Shackleton et al., (2002, 2007), and Turpie et al. (2007). Sustainable yields were not available for freshwater fish.

It was conservatively assumed that no resources could be accessed in protected areas (the typical policy), that 10% could be accessed in private lands, and that all resources were accessible in communal land areas. Value estimates for household use of resources were based on the smaller value of household demand and sustainable yield at the municipal scale (recognizing that people travel outside of their villages to obtain resources), and were spatially attributed to natural areas within the municipality.

The value of estuary resources was estimated based on Lamberth and Turpie (2003), and Turpie and Clark (2007) who collated existing information on effort, quantities and values of fish and invertebrates harvested from estuaries, and a recent comprehensive estimate for South Africa's largest estuary system (St Lucia; Turpie et al., 2014).

In addition, a number of terrestrial natural resources are harvested for commercial purposes, mainly from privately-owned land. These include harvests of ornamental products (mainly flowers) and thatching grass for which estimates were taken from Turpie et al. (2003).

2.4. Cultural services

2.4.1. Amenity value

The amenity values of natural systems are reflected to a large extent in tourism expenditures and property prices. Whereas tourism expenditures reflect the value of natural areas to visitors, the premiums paid for property that is close to or has views of natural areas reflect the values held by residents. These values can be considered additive.

In 2015, 8.9 million foreign tourists and 24.5 million domestic tourists spent a total of R68.2 billion and R23.6 billion in South Africa, respectively (SATOUR, 2016). The proportion of tourism expenditure attributed to tourist attractions, as opposed to activities such as visiting family and friends, attending conferences, religious events, or receiving medical treatment was estimated for different types of domestic and foreign tourists from data collected in regional tourism offices (Table 3). Tourists whose main purpose is either visiting friends or family, or business tend to also spend much less of their money on visiting attractions than holiday/leisure tourists. These types of tourists do however make up a large proportion of the total tourism spending

Table 3
Typology of domestic and foreign tourists, the % of spend for each type of tourist, and % of group spending on tourist attractions. The % of group spending on attractions was based on data collected from tourist visitor centres across the Western Cape Province.

Main purpose	Domestic tourists (%)	Foreign tourists (%)	Domestic tourists		Foreign tourists	
			% spend	% of group spending on attractions	% spend	% of group spending on attractions
Holiday	11	17	26	100	26	100
Visiting friends and relatives	71	37	52	3	18	2
Business	10	24	18	24	36	4
Other	8	22	4	0	20	15

and so these contributions are not insignificant. Using the % spend for each group of tourists and the % spent on attractions (Table 3), we estimate that approximately 32% (R21.3 billion) and 31% (R7.5 billion) of total domestic and foreign tourism spend was spent on visiting attractions.

We used spatial variation in the density of geo-tagged photographs uploaded to www.panoramio.com to estimate the spatial spread of tourism value generated by tourism attractions. Panoramio hosts images that focus on outdoor natural, agricultural and cultural features and landscapes (Panoramio, 2015). A total of 237 467 photo uploads from within South Africa were extracted using a grid of 0.025 degrees. The total tourism spend on attractions was spatially allocated in proportion to photo density. These values were then apportioned based on land cover data to natural areas, vineyards and orchards, agriculture and plantations, and developed areas (i.e. urban, mining and industrial).

The property value of natural open space areas was estimated based on reanalysis of data used in hedonic pricing studies of Durban (Letley and Turpie, 2016) and coastal areas of the Western Cape (Turpie and de Wet, 2009a, 2009b). In Durban, the average property price premium associated with inland natural open space areas was related to average income per residential census sub-place (~suburb; n = 389, $R^2 = 0.32$, $P < 0.001$). This relationship was used along with detailed census data to produce a ballpark estimate of the likely magnitude of premiums paid for natural open space in all urban areas. In 11 smaller towns along the Cape south coast, the premiums paid for coastal access and views, relative to households further than walking distance from the sea accounted for 7–19% of total property value (Turpie and de Wet, 2009a, 2009b). However, this underestimated the premium for living near the coast relative to inland towns, because average house prices in these coastal towns are already relatively high because of their general proximity to the coast. We therefore adjusted the estimates based on average price of a house in Durban (R740,000, n = 16,149 sales). The positive relationship between total coastal premium and number of households per coastal town (n = 11, $R^2 = 0.97$, $P < 0.001$) was used to produce an order-of-magnitude estimate of this coastal value at a national scale.

2.4.2. Existence value

Beyond tourism and property values, people may often derive value merely from the knowledge that nature exists and that it can be enjoyed by future generations. The existence value of South Africa's biodiversity to South Africans had previously been estimated in a stated-preference study by Turpie (2003). This was updated using CPI and scaled to incorporate South Africa's population growth since the study was conducted.

2.5. Regulating services

2.5.1. Carbon sequestration and storage

Since the inception of the Kyoto protocol, the sequestration and storage of carbon by ecosystems has become a valuable commodity (Cihlar, 2007). About half of vegetative biomass comprises carbon. In addition to accumulation in woody biomass, carbon accumulates in soils and peat as a result of the accumulation of leaf litter and partially decayed biomass. Based on the South African National Carbon Sink Assessment (DEA, 2015), total ecosystem carbon was estimated as 7170 Tg C, which equates to approximately 26 314 Tg CO_2 (using molecular weight of CO_2/molecular weight of carbon; EPA, 2016).

Degradation of vegetated habitats releases carbon and contributes to global climate change with impacts on biodiversity, water supply, droughts and floods, agriculture, energy production and human health (IPCC, 2007), whereas restoration or protection of these habitats mitigates or avoids these damages, respectively. The global social cost of carbon is a sum of the damages that would be incurred under climate change resulting from a given amount of carbon dioxide released into the atmosphere. Estimates of this cost vary greatly; the most recent of which placed the social cost of carbon at US$31.25 per ton of CO_2 (in 2010 USD; Nordhaus, 2017). Of this, an estimated 3% would be borne in Africa (Nordhaus, 2017). We estimated that the cost to South Africa would be proportional to its GDP contribution to Africa, scaled by level of vulnerability to climate change. The Notre Dame Global Adaptation Initiative (ND-GAIN) vulnerability index was used to scale GDP contributions across Africa. The vulnerability index measures a country's exposure and sensitivity to negative impacts of climate change. The overall vulnerability index is scored based on six life-supporting sectors; food, water, health, ecosystem services, human habitat and infrastructure. Based on this index, it was estimated that South Africa is likely to bear only 0.35% of the global social cost of each ton of carbon emitted. These values were used to estimate the total value of carbon storage from a South African perspective as well as from a global perspective.

2.5.2. Agricultural support services

Natural environments can contribute to agricultural production through pollination and pest control. A majority of commercial crops are dependent upon animal pollination in order to produce fruit and seed, and as much as 30% of worldwide food production is reliant upon this service (de Groot, 2002, Kremen et al., 2002). In South Africa, this service is provided primarily by two subspecies of the common honeybee; *Apis mellifera capensis* in the winter rainfall region of the Western Cape, and *Apis mellifera scutellata* in the remainder of the country (Eardley et al., 2001). These honeybees rely on a combination of native vegetation, crops, and alien gum trees (*Eucalyptus* spp.) as forage habitat. While native vegetation is estimated to account for less than 23% of honey production in South Africa, it is these minor sources of pollen and nectar that allow hives to endure periods between major nectar flows (Johansmeier and Mostert, 2001). As such, it has been estimated that as many as 80% of hives are dependent upon native vegetation for survival (Turpie et al., 2003).

The value of pollination services was estimated in terms of the additional input costs that would be incurred if pollinators (wild and managed) were no longer present. This was based on the cost of hand pollination developed in Allsopp et al. (2008) with updated costs of pollen and labour.

This value would be supplied by natural areas adjacent to farming areas from which wild bees originate, as well as by other natural areas that might be used for commercial bee-keeping during the off-season. The proportion of this value attributable to wild vs. managed pollinators was estimated using average proportions from Allsopp et al. (2008). The value attributable to wild pollinators was then spread to natural vegetation within 2 km of orchard boundaries as it is assumed that wild pollinators within this range contribute to pollination. The value attributable to managed bees was spread across all natural vegetation as managed bees are often moved large distances and there are no spatial data on where commercial beekeepers keep their hives.

In addition to pollination, animals residing in natural habitats provide some degree of control of agricultural pests through predation (Cardinale et al., 2003; Cullen et al., 2008; Griffiths et al., 2008), although estimates of this service are rare (Jonsson et al., 2008). Losey and Vaughan (2006) estimated that pest control saves 4.24% of total crop production value in the USA. Assuming that such ecological interactions can be assumed to occur generally (rather than that values can be generalized), this suggests that pest control services could be worth some R2.09 billion in South Africa (based on gross income from field crops, DAFF, 2013). Based on studies of insect dispersal in this regard (Byrne, 1999; Zehnder et al., 2007; Bianchi et al., 2008; Tscharntke et al., 2007), this value would be mostly attributed to natural habitats within about 2 km of agricultural fields.

Maintaining intact ecosystems also helps to prevent the emergence and spread of livestock pests. Black-fly *Simulium chutteri* outbreaks which affect livestock productivity, particularly in the arid Northern Cape, are linked to reduction in the quantity and variability of river flows (Nevill, 1988; Myburgh and Nevill, 2003; Palmer et al., 2007; Rivers-Moore et al., 2008). Annual losses along the Orange River Africa (Palmer et al., 2007) were used to value the ecosystem service of black-fly control provided by undisturbed, healthy rivers. For this study, only the costs incurred due to livestock death and loss of productivity were incorporated into the calculations (a total of R80 million). The service was considered for ‘healthy’ (i.e. classed as A or B on a scale of A to F), lower order (4th – 7th order) rivers in sheep farming areas.

2.5.3. Fisheries support

South Africa has about 300 estuaries which provide some of the only sheltered habitat along its approximately 3000 km of mostly rugged coastline (van Niekerk and Turpie, 2012). These estuaries play an important role as nursery areas for many fish and invertebrate species that spend the rest of their life cycle in marine or freshwater habitats, including many species that are harvested for recreational or commercial purposes (Whitfield, 1994; Beck et al., 2001). Estimates of nursery value have been made for all South African estuaries (Lamberth and Turpie, 2003). These regional estimates were allocated to individual estuaries based on their water area and condition, and adjusted for declines in inshore marine fisheries effort and catches (~60% of former levels, Dunlop and Mann, 2012, 2013) as well as for inflation. These were used in conjunction with a more recent estimate of the nursery value of the St Lucia estuary which was based on the impacts on fisheries following a decade of closed-mouth conditions (Turpie et al., 2014).

2.5.4. Erosion control

Vegetative cover can contribute to the prevention of erosion by stabilizing soil and intercepting rainfall (de Groot et al., 2002), particularly where soils are highly erodible. A number of factors influence the soil loss from a given area including the land use, slope, soil erodibility as well as the amount and type of rainfall received. Schulze et al. (2007) estimate the sediment yield per catchment across South Africa. Using the InVEST 3.3.0 landscape sediment retention model we estimated that in the absence of natural vegetation cover, sediment yields would increase by an average of 300%. These increased sediment loads would end up in reservoirs, harbours and the coastal environment, resulting in decreased storage, increased dredging costs and/or the loss of aquatic ecosystem services. Due to the potentially large and costly damages of sedimentation (see Pimentel et al., 1995), we assumed that the service would be fully demanded, and we used the replacement cost method to estimate its value as being likely to be lower than the damage costs avoided. This was done by estimating the amount of storage that would have to be constructed to prevent a similar amount of sediment from reaching downstream aquatic environments, using an average cost of R2.37 per m^3 (N = 272 dams for which capacity data available, Dept of Water and Sanitation, unpublished data, March 2008). Within each quaternary catchment, the replacement value of the service in that catchment was then mapped to untransformed natural areas.

2.5.5. Flow regulation

Vegetative cover and wetlands slow the movement of water through the landscape, which, particularly in the case of wetlands, reduces flood peaks (Krasnostein and Oldham, 2004) and in the case of vegetation cover, facilitates infiltration of rainfall into the soil to recharge groundwater aquifers and maintain dry season stream flows (Brauman et al., 2007). Without these services, runoff during high rainfall events would be greater, flood damages higher, and the overall yields of water supply systems would be lower.

If natural systems were lost, current water yields and flood risk could be maintained by increased investment in grey infrastructure. Both the losses in natural storage by wetlands and recharge to groundwater storage facilitated by vegetation could be replaced by equivalent artificial surface storage capacity. Thus for each catchment, the replacement storage capacity required was taken as the total of infiltration in m^3 per annum and storage capacity of wetlands in m^3, as a parsimonious way to capture the value of complex flow regulation services for which few studies have been carried out in South Africa (Smakhtin and Batchelor, 2005; Kleynhans et al., 2009; Turpie et al., 2010b) and that are normally modelled at relatively small scales (Kusler, 2004; Thiesing, 2001).

Spatial variation in groundwater recharge rate of untransformed landscapes was taken from Conrad (2005). The recharge occurring in untransformed areas amounted to total of 316 001 Mm^3 per year. In order to estimate the proportion of this that was due to the presence of vegetation, factors derived from the literature presented in Le Maitre et al. (1999) were used to estimate the contribution of different biomes to the proportion of recharge taking place. These factors, ranging between 62% and 95%, were applied to untransformed areas within the different biomes. Because the presence of alien vegetation in the Western Cape can lead to lower recharge rates, the area of upland alien vegetation in each quaternary catchment were removed from the total untransformed vegetation in each quaternary. The groundwater storage estimated to be attributable to native vegetation was therefore estimated at 22 062 Mm^3 per year.

The storage capacity of wetlands, which includes water stored in saturated soils, was estimated based on wetland type, and taking effective soil moisture storage depth into account. Soil moisture storage depths were estimated for individual wetlands by intersecting wetlands with the South African Atlas of Climatology and Agrohydrology soil layers (Schulze and Horan, 2007b) to determine topsoil and subsoil depths and porosities. For each wetland a different extent was calculated and a volume equation was applied based on wetland type. Triangular prisms of 0.5 m depth were used for valley bottom wetlands, discs of 0.8 m depth for floodplains and bowls of 0.8 m depth for pans.

Since the capacity of wetlands to capture flows during a rainfall event depends on antecedent conditions, it was conservatively assumed that a maximum of 30% of total wetland volume is available for flood attenuation storage. Based on this, it was estimated that natural wetlands in the study area contribute about 2 370 Mm^3 in terms of flood attenuation storage.

Given the situation of water scarcity in South Africa, it was assumed that groundwater recharge was fully demanded, but the demand for flood attenuation was adjusted by a demand factor applied at a secondary catchment scale. If urban areas or mines occurred within 100 m of rivers then the service was considered fully demanded, if irrigated agriculture was present, the service was considered 50% demanded, otherwise it was not considered to be demanded. Flow regulation services were valued jointly, based on the replacement costs of the overall volume of storage.

2.5.6. *Water quality amelioration*

When loads of nutrients, sediments and pathogens entering rivers and water supply reservoirs are elevated due to anthropogenic activities in catchment areas, these can lead to loss of reservoir capacity (described above), deterioration in raw water quality in reservoirs, and impacts on downstream ecosystems and their capacity to supply ecosystem services. Natural areas, especially wetlands and the vegetation alongside rivers, may remove some of these anthropogenic inputs before they enter drainage systems, thus ameliorating these damages. Since sedimentation and the affected provisioning and cultural services are valued elsewhere, this section only focuses on the impacts of this service on water treatment costs.

Wetlands are generally regarded as the most efficient natural system for removing pollutants, partly because they have much greater capacity for trapping sediments, but forests and other terrestrial vegetation types also have the capacity for water quality amelioration (Asmussen et al., 1979). Terrestrial systems have been shown to improve water quality at a landscape scale (Dixon and Rowlands, 2007), and it has also been shown that natural vegetation along streams acts as an important buffer between agricultural landscapes and river systems, removing a high percentage of sediments and nutrients from surface and subsurface flows (Mayer et al., 2007; Liu et al., 2008; Yuan et al., 2009; Weller et al., 2011; Sweeney and Newbold, 2014).

Elevated loads of phosphorous (P) and suspended sediments entering reservoirs lead to algal blooms and increased turbidity, increasing the costs of potable water supply. A number of studies have analysed the effect of water quality variables on water treatment costs in South Africa (e.g. Dennison and Lynne, 1997; Graham, 2004; Friedrich et al., 2009; Gebremedhin, 2009; Graham et al., 2012; Rangeti, 2014) as well as globally (e.g. Dearmont et al., 1998; Telles et al., 2013; McDonald and Shemie, 2014; TNC, 2015). However, few studies have investigated the link between catchment land cover and water quality (Turpie et al., 2010b), land cover and water treatment costs (Vincent et al., 2015; Kutela and Turpie, 2017), or between nutrient loads entering reservoirs and water treatment costs (Letley and Turpie, 2016), with most of these being difficult to extrapolate geographically. Generic models developed to estimate this service (e.g. InVEST) are still based on fairly limited quantitative understanding of the generation and uptake of nutrients in complex landscapes. The application and calibration of such models at national scale will require a considerable investment in time and resources and should be a follow up step.

Meta-analyses of the international literature suggest that natural wetlands can remove up to 25 kg N and 10 kg P per ha per year without resulting in significant changes to their structure and function (Verhoeven et al., 2006), and terrestrial buffers can remove in excess of 3–5 kg per ha (Zhou et al., 2014; Zaimes and Schultz, 2002). Based on these estimates, as well as published estimates of rates of nutrient generation from different types of land use (Natural Capital Project global literature dataset of nutrient parameters, www.naturalcapitalproject.org), we estimated the non-point source production of phosphorous at the tertiary catchment scale, and the extent to which these loads could be removed by natural vegetation (wetland or terrestrial) within 15 m of streams and rivers (based on 1:500 000 river layer CSIR, 2011). The value of the service was then estimated using the marginal value of removal of a ton of P per year (R4.90 per ML), based on a study of the impacts of catchment P loads entering reservoirs on the cost of water treatment in two South African water treatment facilities (Letley and Turpie, 2016), and applied to the estimated contribution of each catchment to potable water production. The latter was based on provincial estimates that were apportioned to the tertiary catchments in proportion to their mean annual runoff. Gauteng's water production was excluded due to the water transfers from Lesotho.

3. Results

3.1. *Provisioning services*

The replacement value of fodder for South Africa exceeded the total value of livestock production therefore the value of this service is the R39.75 billion worth of production that would be lost if ecosystems providing these services were completely degraded. These values were highest in the eastern half of the country (Fig. 3a).

The total value of terrestrial natural resources harvested for subsistence use was estimated to be in the order of R7.5 billion per year. Average value per ha is highest in the east of the country, where both biological productivity and human population densities are high, and where there is a concentration of homelands (Fig. 3b). The value of subsistence harvesting from estuarine and coastal habitats was estimated to be R35.7 million per year. Estuaries tended to be more valuable where larger systems coincided with

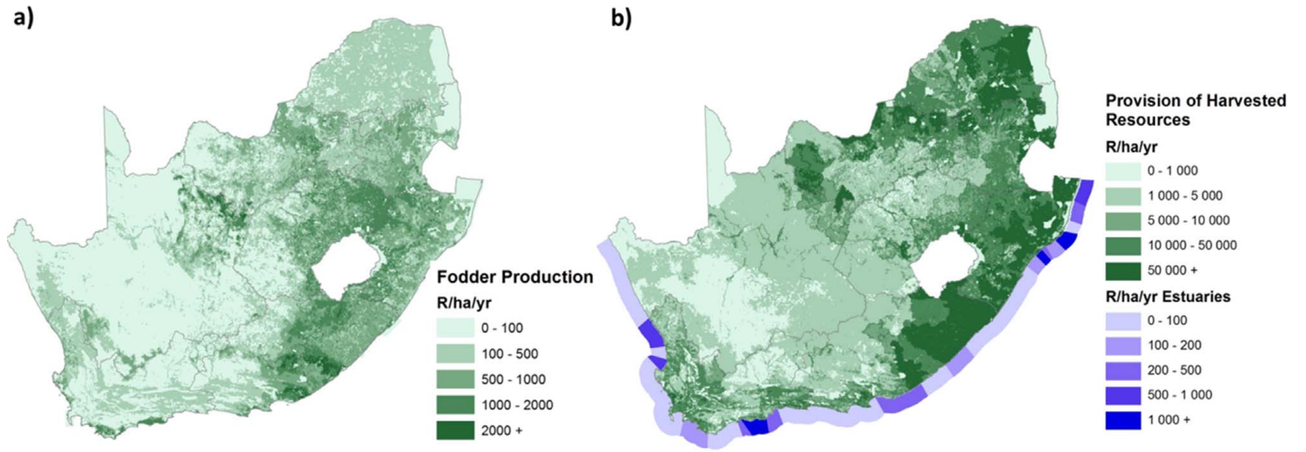

Fig. 3. Value of provisioning services in the form of (a) fodder production and (b) harvested natural resources, including instream water and estuarine/coastal resources.

urban areas or dense former homeland populations (Fig. 3b). In addition the value of commercially harvested fynbos products totaled R169 million per annum.

3.2. Cultural services

Tourism expenditure attributed to natural ecosystems was estimated to be R25.2 billion per year. Close to half (49%) of this national value was attributed to protected areas which only cover 8% of South Africa's area (Fig. 4a). The highest nature-based tourism values (up to R304 320 per ha) occurred near urban centres, where overall tourism value was orders of magnitude higher than other parts of the country. Other areas that featured strongly were the Western Cape and Garden Route coast, Mpumalanga and the Kruger Park, the Elephant Coast region of KwaZulu-Natal, the Drakensberg area and the Richtersveld. The capital investment in property in proximity to natural open space was estimated in the order of R91 billion for inland open space areas and R907 billion for the coast (Fig. 4b). These values are equivalent to R8 billion and R79 billion per year, respectively.

In addition to tourism and property values, the existence value of South Africa's biodiversity to South Africans was estimated at R6.45 billion per annum. The distribution of this value is unknown.

3.3. Regulating services

South Africa's 7170 Tg of carbon represents an avoided social cost of R11.6 trillion per annum at a global scale, and South Africa's share of this would be R40.7 billion. Carbon storage values were highest in areas of relatively high biomass and productivity towards the east, and where habitats were relatively intact away from the main cropping areas (Fig. 5a). Highest values were estimated for the relatively intact areas of the thicket biome. Carbon sequestration opportunities (through restoration of biomass), would be highest in the eastern parts of the country, particularly in former homeland areas.

Pollination services were estimated to be on the order of R6.9 billion per annum, which we believe is a conservative but realistic estimate. Agricultural pest control was estimated to be worth R2.09 billion in South Africa and in addition the prevention of black-fly, a livestock pest, was estimated to yield an average disease control value of R60 024/km for healthy, lower-order rivers and total of R80 million per year. Agricultural support services were highest in the winter rainfall regions of the Western Cape, where highly profitable (and pollination-intensive) deciduous fruits are produced as well as Mpumalanga and Limpopo regions where some sub-tropical fruits are grown (Fig. 5b).

The nursery value of estuaries was estimated to be R803 million per annum, with the highest values along the south Western Cape and Eastern Cape (Fig. 5b). This value is an estimated 58% of what it would be if all estuaries were in their natural condition.

The value of erosion control by vegetation cover was estimated to be R2.1 billion per year. This gave an average value of R27/ha per year for untransformed natural areas in terms of their ability to retain sediment. Highest value areas for erosion control occur in parts of the Eastern and Northern Cape, where combined effects of slope, soil type, and overgrazing have made soils extremely vulnerable to erosion (Fig. 5c). Other areas of high value for erosion control include portions

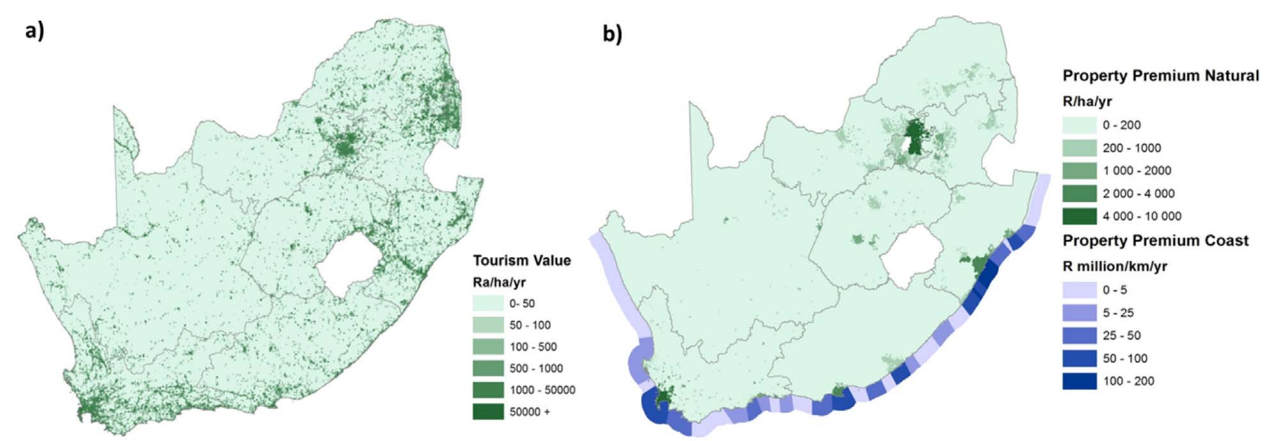

Fig. 4. Amenity values: (a) tourism value attributable to natural attractions; and (b) property premiums associated with natural vegetation and coastal proximity.

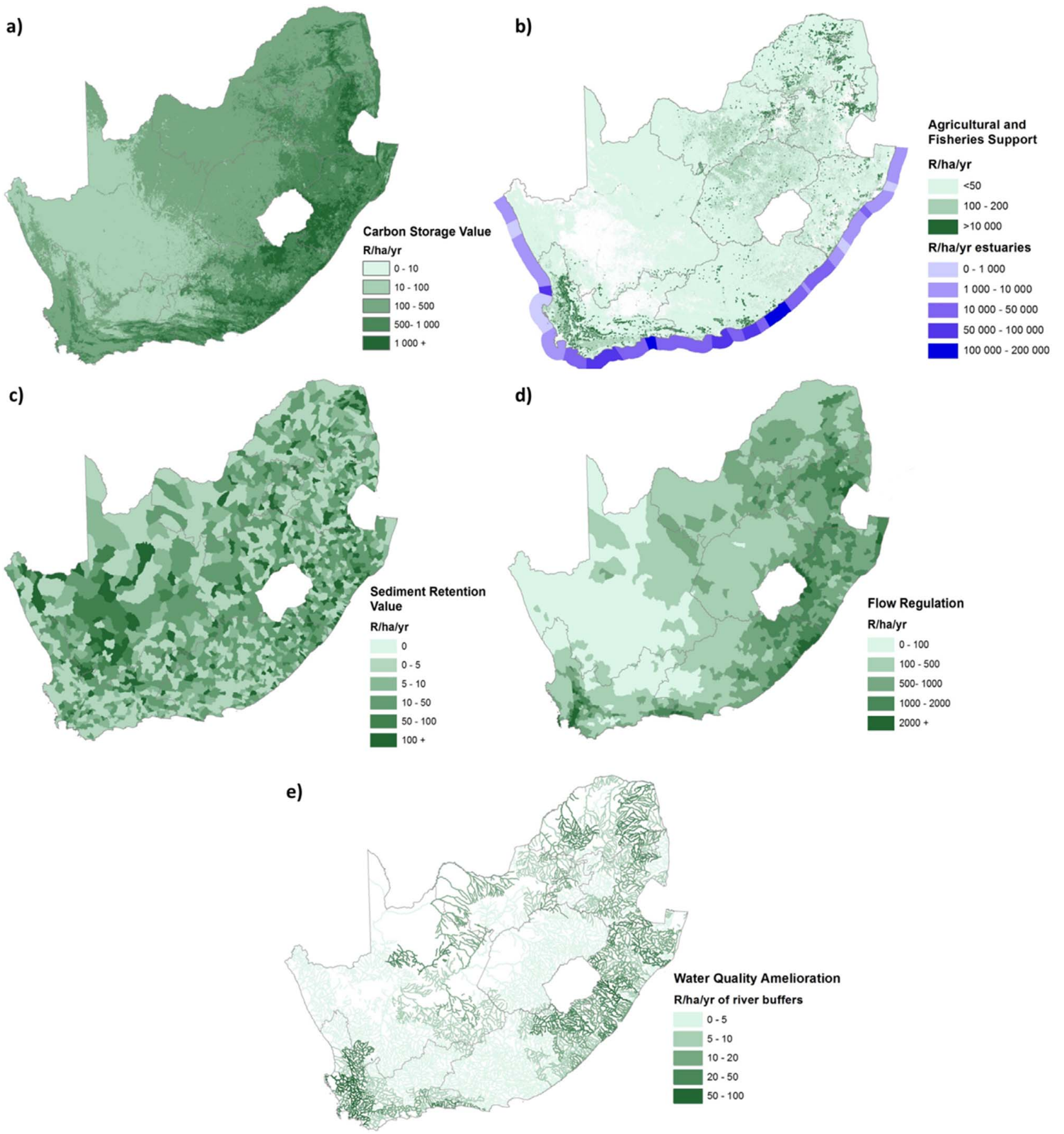

Fig. 5. Values of regulating services for (a) carbon storage, (b) agricultural and fisheries support, (c) sediment retention, (d) flow regulation and (e) water quality amelioration.

of eastern South Africa, where high intensity storms cause soils in non-vegetated areas to wash away during the summer rainfall season.

Flow regulation services performed by natural vegetation cover (facilitating infiltration) and wetlands (attenuating floods) were estimated to be worth about R52.3 billion and R3.5 billion per year, respectively. Values are highest close to areas where irrigated crops occur along rivers such as in the Breede Valley as well as highly vegetated areas in the east of the country (Fig. 5d).

The value of water quality amelioration was conservatively estimated as ranging from < R1 to R100 per ha for natural buffer areas in different catchments (Fig. 5e), amounting to an approximately R9 million per annum (~4%) saving in the production cost of 3.2 million ML nationally.

3.4. Summary

In aggregate, ecosystem services valued in this study were estimated to be worth at least R275 billion per annum to South Africans. The highest values were from the amenity, flow regulation and carbon storage values (Table 4).

4. Discussion

The aim of this study was to offer a first approximation of values of a wide range of ecosystem services in South Africa and identify emerging patterns and implications, as well as to consider the validity of this approach and stimulate further research to build on these

Table 4
Overall estimates for each ecosystem service valued in this study, including where gaps have been identified and still need to be filled. Values in R millions.

Category	Services	Value (R million million)
Provisioning services	Livestock fodder	**39 750**
	Harvested renewable resources	**7 716**
	Genetic resources, biological compounds	?
Cultural services	Amenity values (aesthetic, recreation)	**112 261**
	Cultural and religious value	?
	Existence and bequest (non-use) values	**6 450**
	Scientific and educational value	?
Regulating services	Carbon storage	**40 686**
	Regulation of local climate	?
	Pollination	**6 908**
	Control of pests and pathogens	**> 2 170**
	Maintaining soil fertility	?
	Critical habitats/refugia	**804**
	Control of erosion and sedimentation	**2 112**
	Flow regulation	**55 795**
	Coastal storm protection	?
	Water quality amelioration	**9**
	Air quality amelioration	?
Total		**> 274 661**

findings. The study suggests that maintaining untransformed natural systems generates substantial value equivalent to at least 7% of the country's GDP (R4014bn in 2015), either in the form of inputs to productive activities and welfare or the losses avoided by retaining these systems. This is more than three times the value of the agricultural, forestry and fishing sector (2.2%). This is a conservative and incomplete estimate. It is important to note that the estimates provided in this study do not cover all values generated by ecosystems, nor do ecosystem valuation studies represent all the costs of ecosystem degradation. For example, pollution of the environment can come at very high social cost in addition to the loss of ecosystem and biodiversity values described here.

Excluding water, ecosystems contribute some R47 billion annually in terms of provisioning services that support the livelihoods of South Africa's rural inhabitants. These services are vital in a country where unemployment rates are over 25%, poverty levels at almost 60% (StatsSA, 2017), and where more than 17 million South Africans already rely on government welfare payouts to the value of R139 billion annually. Furthermore, the market value of natural resources estimated here does not capture the accompanying cultural values, such as those associated with broom making and indigenous medicine (Cocks and Møller, 2002; Cocks and Wiersum, 2003; Cocks and Dold, 2004), or the cultural value attached to livestock (Cousins, 1999). It also does not capture the value of the indigenous medicinal practices, or the value obtained from bioprospecting and the sale of indigenous knowledge about biodiversity to the pharmaceutical and other industries. South Africa is home to a number of biodiversity hot spots including the Fynbos and the Succulent Karoo biomes. The genetic resources of these biodiverse regions have given rise to a number of commercial enterprises including the indigenous tea and flower industriesworth some R150 million and R800 million, respectively (Van Rooyen et al., 2001; DAFF, 2012). Water use, if it were to be included, would amount to more than R12 billion in the formal sector (StatsSA, 2009), and a further R4 billion for household use of instream water (this study).

Cultural values were found to be among the highest values associated with natural systems. Our estimates suggest that these systems generate substantial, tangible income within the economy from their contribution to the income generated from tourism and property sales. Urban green spaces and coastal areas add millions to property value, with coastal areas estimated to be worth up to R200 million per km to year in terms of property value alone. Tourism values exceed R50,000 per ha per year in some areas. The high contribution of protected areas and urban centres to the tourism value of natural systems highlights the role of infrastructure and management that unlocks the potential of these areas (de Vos et al., 2016). While property values capture much of the value of urban green spaces, they do not adequately capture the recreational benefits to people that use these spaces that may not necessarily live near them but whose travel costs are also not captured as domestic tourism. Neither do these estimates fully capture the health benefits (or health costs avoided) associated with the use of natural areas.

The less tangible existence, spiritual and cultural values of wilderness and its biodiversity are more difficult to estimate. South Africans have expressed considerable existence value for biodiversity of over R6 billion, but this and other spiritual and cultural values are inherently difficult to translate into monetary terms, especially in a country where the ability to pay is very low. For example, Xhosa women and men in South Africa also expressed that collecting resources in the forest also provide them with value through spiritual connection and increased mental well-being (Cocks et al., 2013). A study conducted in Lesotho found that people were unwilling to accept even relatively high compensation for the loss of cultural value associated with the degradation of rivers (Turpie et al., 2006). Nature also holds scientific and educational values which include the enjoyment in learning about nature, through books and documentaries as well as through supporting the fields of scientific research related to ecosystems. These services are very difficult to value, but are at least equal to the investment in research and environmental education and the market value of books and films relating to the environment (Chiesura and de Groot, 2003).

Regulating services are more difficult to value than provisioning and cultural services, since their values are not as direct, and are often linked to landscape-scale processes. Very little work has been done on these services in South Africa, apart from carbon storage, the assessment of which is relatively simple, and localised studies of other services. Through their regulating services, natural ecosystems and vegetative cover either contribute to production (e.g. through pollination, nursery areas), or avoid damages (e.g. caused by climate change, urban heat island effects, coastal storms, flooding, sedimentation and reduced water quality, and damages wreaked by livestock and crop pests). Their value is the lessor of (a) the losses or costs that would be incurred if they were lost and (b) the cost of replacing the service, but it is seldom easy to estimate both of these. In some cases, such as for carbon storage, nursery value, water quality amelioration and pest control, values have been expressed in terms of avoided production losses or damages. For example, notwithstanding the more significant value to the rest of the world, our study suggests that carbon storage has considerable value to South Africans in terms of the local climate change damages avoided. In the case of water quality amelioration, our conservative assumptions yielded lower estimates than localised studies (Turpie et al., 2010b, 2017; Kutela and Turpie, 2017), and this needs to be improved through the design of empirical studies that are better suited to extrapolation.

Apart from carbon storage, none of these regulating services is well understood in South Africa at this stage, and more rigorous modelling and empirical work is required to improve these estimates. In addition, further research is needed to fill a number of gaps. Our estimates do not include the avoided impacts on human health as a result of control of pests and pathogens (e.g. malaria), or as a result of ecosystem contributions to air quality amelioration and local climate regulation. Vegetation has the potential to improve local air quality, through reducing levels of certain air pollution by up taking the gaseous compounds into their leaves and allowing deposition of particulate matter on leaves (Beckett et al., 1998). Trees and vegetation in an urban setting have also been shown to decrease the ambient temperature not only through shading but also through the cooling effects of evapotranspiration (Akbari et al., 2001). These benefits would be expected to be at least partly reflected in property premiums paid for living in greener areas.

Our estimates did not includethe value of coastal storm protection. While mangrove systems are too small and/or remote in South Africa to provide a meaningful service in this regard, there is certainly a role played by coastal dune systems in the protection of some coastal urban areas. We have also not estimated the value of maintaining soil fertility. For example, seasonal flooding has been shown to elevate crop yields by 40% in the Okavango (Turpie et al., 2006). In South Africa, only a small proportion of croplands occur in floodplains that might benefit from this service (e.g. in the coastal plains of northern KwaZulu-Natal). Beyond this, note that we have not included the value of nutrients derived by crops within cultivated areas since our study focuses on untransformed natural areas.

Some interesting spatial patterns can be observed from these preliminary results. Firstly, areas of high value tend to be associated with areas of high rainfall, biomass and population density. This is to be expected, since higher rainfall areas are more productive and biodiverse, and in an arid country, higher rainfall and biomass areas are also more likely to be attractive for settlement. There are exceptions, of course, where human settlement patterns have been influenced by the presence of minerals (e.g. in Gauteng), and where technological advances have allowed inter-basin transfers of water. Secondly, since regulating services tend to be supplied by natural areas away from population centres, the association of their value with population centres would only be observable at a larger scale. Thirdly, there are important relationships between amenity value and the built environment. These areas have the highest value of any natural areas in the country, because of the sheer numbers of people and relative scarcity of open space areas in cities. This highlights the fact that areas of high socio-economic value, such as these highly fragmented habitat remnants, do not necessarily coincide with areas of high biodiversity value. Determining the asset value of nature from ecosystem services as carried out in this study does not constitute a measure of biodiversity value. Fourthly, it is clear from the patterns in amenity value that with more investment, the tourism and property value of ecosystems could be further enhanced. There is potential tension, however, between tourism and property values and the less tangible existence, spiritual and cultural values of wilderness and its biodiversity which are more difficult to estimate.

On the whole, the activities that give ecosystems their economic value also undermine them. Our study has identified some of the areas where ecosystems have been pushed beyond their sustainable limits. Demand for natural resources exceeded sustainable yields in 47% of municipalities. Almost half (42%) of the capacity of estuaries to replenish marine fishery stocks has been lost due to freshwater starvation and recreational fishing pressure in estuaries. The extent to which degradation and loss of indigenous biomass or its replacement by alien invasive species has impacted on the supply of ecosystem services still needs to be assessed. Such impacts have been quantified at local and national scales (Higgins et al., 1997; Richardson and van Wilgen, 2004, Le Maitre et al., 2016), but their full impact on ecosystem services is yet to be assessed.

Even if the gaps in our estimates are taken into account, the overall value estimated from a local perspective is still more than an order of magnitude smaller than the value of the US$610 billion estimated by Anderson et al. (2017) from the transfer of average values of different biomes obtained from international studies. There are five main reasons that the latter study produced a much higher estimate. Firstly, the values from the TEEB database used by Anderson et al., 2017 (op cit) include crop production as well as some estimates that we are missing. Secondly, values derived from international studies are likely to be biased towards more productive, higher value areas. This problem is exacerbated by the fact that a large proportion of South Africa's ecosystems, including wetlands, occur in arid areas which are also sparsely populated. Thirdly, the values are largely derived from wealthier countries, where ability to pay, willingness to pay and market prices tend to be higher. Fourthly, and most importantly, the values were derived by adding together the average value of each type of service from studies in each biome type, which assumes that all values are both supplied and demanded across each habitat, irrespective of land ownership, and that none of the values are in conflict (e.g. hunting versus wildlife tourism). Finally, the purpose of the Anderson et al. study was to estimate the global benefits of South Africa's biodiversity. Indeed, we estimated that the global value of South Africa's terrestrial carbon stock is in the order of US$894 billion, far higher than the total value of ecosystem services to South Africans. In addition, we acknowledge that South Africa's ecosystems have cultural value to the international community over and above the value reflected in international tourism which, in aggregate, may well exceed local values. For example, the value of documentary and book industry based on African ecosystems, especially those pertaining to charismatic megafauna, is large in wealthier countries, as would be the global existence value for South Africa's biodiversity. Recognition of this value differential is important in the negotiation of international agreements and in developing strategies for financing biodiversity conservation.

In this study, we have attempted to explore the value of ecosystem services to South Africans, since globally-derived estimates have failed to gain traction for the reasons cited above. A "*local is lekker*" approach may be based on fewer studies, but is likely to be more relevant to decision-makers. It is important to emphasize that the value of a study such as this does not lie so much in generating a large total value for ecosystem services. Rather, it is the consideration of how these services work and the emerging understanding of the spatial variation in their values that will be of more relevance to policy and decision-makers. Furthermore, the identification of gaps in our knowledge will hopefully spur on further empirical research in the appropriate areas. South Africa still has a long way to go before it can create the satisfactory baseline required for the meaningful incorporation of ecosystem values in its national accounts. Furthermore, while understanding spatial variation is useful in informing planning decisions, it should be noted that the marginal cost of losing one hectare of habitat depends not only on its location but on the extent to which other areas are retained or developed. Thus a study of this nature is just a first step in developing tools that can make meaningful contributions to policy through the use of scenario-based approaches that model the effects of specific policies at appropriate scales and allow more accurate scrutiny of trade-offs (e.g. UK NEA, 2011; TNC, 2015).

Acknowledgements

This research was funded by Anchor Environmental Consultants and the Environmental Policy Research Unit at the School of Economics, University of Cape Town. We thank four anonymous reviewers for their comments on an earlier draft.

References

Akbari, H., Pomerantz, M., Taha, H., 2001. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Sol. Energy 70 (3), 295–310.

Allsopp, M., de Lange, W.J., Veldtman, R., 2008. Valuing insect pollination services with cost of replacement. PLoS ONE 3 (9), e3128.

Anderson, S., Ankor, B.L., Sutton, P.C., 2017. Ecosystem service valuation of South Africa using a variety of land cover data sources and resolutions. Ecosyst. Serv.. http://dx.doi.org/10.1016/j.ecoserv.2017.06.001.

Asmussen, L.S.E., Sheridan, J.M., Booram, C.V., Jr., 1979. Nutrient movement in streamflow from agricultural watersheds in the Georgia coastal Plain. Trans. ASAE 22 (809–915), 821.

Barbier, E., 1994. Valuing environmental functions: tropical wetlands. Land Econ. 70, 155–173.

Barnes, J.I., Nhuleipo, O., Muteyauli, P.I., MacGregor, J., 2005. Preliminary economic asset and flow accounts for forest resources in Namibia. DEA Res. Discuss. Pap., Minist. Environ. Tour..

Beck, M.W., Heck, K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Halpern, B., Hays, C.G., Hoshino, K., Minello, T.J., Orth, R.J., Sheridan, P.F., Weinstein, M.P., 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51, 633–641.
Beckett, K.P., Freer-Smith, P.H., Taylor, G., 1998. Urban woodlands: their role in reducing the effects of particulate pollution. Environ. Pollut. 99 (3), 347–360.
Bianchi, F., Goedhart, P., Bavecco, J., 2008. Enhanced pest control in cabbage crops near forest in the Netherlands. Landsc. Ecol. 23, 595–602.
Blignaut, J., Crookes, D., Saki, A., 2017. The demand for ecosystem services of different calf production systems in South Africa. Afr. J. Agr. Resour. Econ. 12 (2).
Boyd, J.W., Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecol. Econ. 63, 616–626.
Brauman, K.A., Daily, G.C., Duarte, K.T., Mooney, H.A., 2007. The nature and value of ecosystem Services: an overview highlighting hydrologic services. Annu Rev. Environ. Resour. 32, 67–98.
Byrne, D., 1999. Migration and dispersal by the sweet potato whitefly, Bemisia tabaci. Agric. For. Meteorol. 97, 309–316.
Cardinale, B., Harvey, C., Gross, K., Ives, A., 2003. Biodiversity and biocontrol: emergent impacts of a multi-enemy assemblage on pest suppression and crop yield in an agroecosystem. Ecol. Lett. 6, 857–865.
Chiesura, A., de Groot, R., 2003. Critical natural capital: a socio-cultural perspective. Ecol. Econ. 44, (219-123).
Cihlar, J., 2007. Quantification of the regional carbon cycle of the biosphere: policy, science and land-use decisions. J. Environ. Manag. 85, 785–790.
Cocks, M., Dold, A.P., 2004. A new broom sweeps clean. The economic and cultural value of grass brooms in the Eastern Cape Province, South Africa. For. Trees Livelihoods 14 (1), 33–42.
Cocks, M.L., Dold, T., Vetter, S., 2013. 'God is my forest' Xhosa cultural values provide untapped opportunities for conservation. S. Afr. J. Sci. 108, 8.
Cocks, M., Møller, V., 2002. Use of indigenous and indigenised medicines to enhance personal well being: a South African case study. Soc. Sci. Med. 54, 387–397.
Cocks, M.L., Wiersum, K.F., 2003. The significance of biodiversity to rural households in Eastern Cape Province of South Africa. For. Trees Livelihoods 13, 39–58.
Conrad, J., 2005. Preparation and production of a series of GIS-based maps to identify areas where groundwater contributes to baseflow. Report. No. G2005/02-1, GEOSS, Stellenbosch.
Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van der Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.
Council for Scientific and Industrial Research (CSIR), 2011. NFEPA Rivers1:500 000 Integr. scores. GIS shapefile.
Cousins, B., 1999. Invisible capital: the contribution of communal rangelands to rural livelihoods in South Africa. Dev. South. Afr. 16, 299–318.
Cullen, R., Warner, K., Jonsson, M., Wratten, S., 2008. Economics and adoption of conservation biological control. Biol. Control 45, 272–280.
De Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecol. Econ. 41, 393–408.
De Vos, A., Cummings, G.S., Moore, C.A., Maciejewski, K., Duckworth, G., 2016. The relevance of spatial variation in ecotourism attributes for the economic sustainability of protected areas. Ecosphere 7, e01207. http://dx.doi.org/10.1002/ecs2.1207.
Dearmont, D., McCarl, B., Tolman, D., 1998. Costs of Water Treatment Due to Dimished Water Quality: a Case Study in Texas. Water Resour. Res. 34 (4), 849–854.
Dennison, D.B., Lyne, M.C., 1997. Analysis and prediction of water treatment costs at the DV Harris Plant in Umgeni Catchment Area. Agrekon 36, 40.
Department of Agriculture (DoA), 1999. Grazing Capacity Map (GIS data). Pretoria, South Africa.
Department of Agriculture, Forestry and Fisheries (DAFF), 2012. A profile of the South African Rooibos tea market value chain. Directorate of Marketing, Department of Agriculture, Forestry and Fisheries, Pretoria.
Department of Agriculture, Forestry and Fisheries (DAFF), 2013. Economic review of theAgriculture SectorGovernment of South Africa, 17.
Department of Agriculture, Forestry and Fisheries (DAFF), 2014. Trends in the Agricultural Sector. Department of Agriculture, Forestry and Fisheries, Pretoria.
Department of Agriculture, Forestry and Fisheries (DAFF), 2015. Abstract of Agricultural Statistics. Department of Agriculture, Forestry and Fisheries, Pretoria.
Department of Agriculture, Forestry and Fisheries (DAFF), 2016. Livestock numbers from 1996. Available at: ⟨http://www.daff.gov.za/daffweb3/Portals/0/Statistics⟩ and EconomicAnalysis/Statistical Information/Livestock Numbers from 1996 to current. xls (Accessed 7 March 2017).
Department of Agriculture, Forestry and Fisheries (DAFF), 2017. Economic review of South African Agriculture 2016. Department of Agriculture, Fisheries and Forestry, Republic of South Africa.
Department of Environmental Affairs (DEA), 2015. South African National Terrestrial Carbon Sink Assessment. Data of the South African National Terrestrial Carbon Sink Assessment is published on the SAEON shared platform. Link to detailed report: ⟨https://www.environment.gov.za/sites/default/files/docs/nationalterrestrial_carbonsinksassessment_sect1.pdf⟩.
Department of Water and Sanitation (DWS), 2012. Quaternary catchments of South Africa. GIS Data.
Dixon, R., Rowlands, D., 2007. Water Resource Technical Series Report. Western Australia Department of Water.
Dovie, B.D.K., Shackleton, C.M., Witkowski, E.T.F., 2002. Direct-use values of woodland resources consumed and traded in a South African village. Int. J. Sust. Dev. World 9 (3), 269–283.
Dovie, D.B.K., Witkowski, E.T.F., Shackleton, C.M., 2004. The fuelwood crisis in southern Africa – relating fuelwood use to livelihoods in a rural village. GeoJournal 60, 123–133.
Dovie, D.B.K., Shackleton, C.M., Witkowski, E.T.F., 2006. Conceptualizing the human use of wild edible herbs for conservation in South African communal areas. J. Environ. Manag. 84, 146–156.
Dunlop, S.W., Mann, B.Q., 2012. An assessment of participation, catch and effort in the KwaZulu-Natal shore-based marine linefishery, with comments on management effectiveness. Afr. J. Mar. Sci. 34, 479–496.
Dunlop, S.W., Mann, B.Q., 2013. An assessment of participation, catch and effort in the offshore boat-based marine linefishery in KwaZulu-Natal. South Afr. J. Mar. Sci. 35, 79–97.
Eardley, C.D., Tribe, G.D., Kryger, P., 2001. Biodiversity of bees. Pages XXX. In: Johannsmeier, M.F. (Ed.), Beekeeping in South Africa. Plant Protection Research Institute Handbook No. 14. Agricultural Research Council, Pretoria.
Egoh, B., Reyers, B., Rouget, M., Richardson, D.M., Le Maitre, D.C., van Jaarsveld, A.S., 2008. Mapping ecosystem services for planning and management. Agric. Ecosyst. Environ. 127, 135–140.
Environmental Protection Authority (EPA), 2016. Technical Support Document: technical Update of the Social Cost of Carbon for Regulatory Impact Analysis – Under Executive Order 12866. Interagency Working Group on Social Cost of Greenhouse Gases, United States Government.
Friedrich, E., Pillay, S., Buckley, C.A., 2009. Environmental life cycle assessments for water treatment processes – a South African case study of an urban water cycle. Water SA 35 (1), 73–84.
Gebremedhin, S.K., 2009. Analysis and Prediction of Chemical Treatment Cost of Potable Water in the Upper and Middle Vaal Water Management Areas. MSc Thesis, Agricultural Economics. University of KwaZulu-Natal, Pietermaritzburg.
Geoterraimage,, 2015. 2013–2024 South African National Land-cover DatasetGeoterraimage. Pretoria, South Africa.
Graham, M., Blignaut, J., de Villiers, L., Mostert, D., Sibande, X., Gebremedhin, S., Harding, W., Rossouw, N., Freese, N.S., Ferrer, S., Browne, M., 2012. Development of a generic model to assess the costs associated with eutrophication. WRC Report. No. 1568/1/12, (ISBN 978-1-4312-0265-2).
Graham, P., 2004. Modelling the water quality in dams within the Umgeni Water operational area with emphasis on algal relations. (Ph.D. Thesis), North West University.
Griffiths, G., Holland, J., Bailey, A., Thomas, M., 2008. Efficacy and economics of shelter habitats for conservation biological control. Biol. Control 45, 200–209.
Haines-Young, R., Potschin, M., 2013. Common International classification of ecosystem services (CICES): consultation on version 4, August-December 2012. EEA Framew. Contract No EEA/IEA/09/003.
Higgins, S.I., Turpie, J.K., Costanza, R., Cowling, R.M., le Maitre, D.C., Marais, C., Midgley, G., 1997. An ecological economic simulation model of mountain fynbos ecosystems: dynamics, valuation and management. Ecol. Econ. 22, 155–169.
IPCC, 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Johannsmeier, M.F., Mostert, A.J.N., 2001a. South African Nectar and Pollen Flora. In: Johannsmeier, M.F. (Ed.), Beekeeping in South Africa. Plant Protection Research Institute Handbook No. 14, Agricultural Research Council, Pretoria.
Jonsson, M., Wratten, S., Landis, D., Gurr, G., 2008. Recent advances in conservation biological control of arthropods by arthropods. Biol. Control 45, 172–175.
Kleynhans, M.T., Turpie, J.K., Rusinga, F., Görgens, A.H.M., 2009. Quantification of the flow regulation services provided by Nylsvlei wetland, South Africa. In: Turpie, J.K. (Ed.), Development of a protocol for the valuation of wetlands in South Africa. Volume II. The valuation of provisioning, regulating and cultural services provided by wetlands: case studies from South Africa and Lesotho. Water Research Commission Report, Pretoria.
Krasnostein, A.L., Oldham, C.E., 2004. Predicting wetland water storage. Water Resour. Res. 40, W10203.
Kremen, C., Williams, N.M., Thorp, R.W., 2002. Crop pollination from native bees at risk from agricultural intensification. PNAS 99, 16812–16816.
Kusler, J., 2004. Final Report 1: Wetland Assessment for Regulatory PurposesAssessing Functions and Values. Association of State Wetland Managers, New York.
Kutela D., Turpie, J., 2017. Valuation of water purification services of forests: Panel data evidence from South Africa. Environment for Development Discussion Paper (in preparation).
Lamberth, S.J., Turpie, J.K., 2003. The role of estuaries in South African fisheries: economic importance and management implications. Afr. J. Mar. Sci. 25, 131–157.
Landers, D.H., Nahlik, A.M., 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS)EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency. Office of Research and Development, Washington, D.C.
Lannas, K.S.M., Turpie, J.K., 2009. Valuing the provisioning services of wetlands: contrasting a rural wetland in Lesotho with a peri-urban wetland in Cape Town. Ecol. Soc. 14 (2), 18 , (online) (URL)⟨http://www.ecologyandsociety.org/vol14/iss2/art18/⟩.
Le Maitre, C.D., Scott, D.F., Colvin, C., 1999. A review of interactions between vegetation and groundwater. Water SA 25 (2), 137–152.
Le Maitre, C.D., Forsyth, G., Dzikit, S., Gush, M.B., 2016. Estimates of the impacts of invasive alien plants on water flows in South Africa. Water SA 42, 505–517.
Letley, G., Turpie, J.K., 2016. The contributions of natural and man-made green open space to property value in Durban, South Africa: a hedonic pricing study. Environment for Development Discussion Paper Series.
Liu, Y., Villalba, G., Ayres, R.U., Schroder, H., 2008. Global phosphorus flows and

environmental impacts from a consumption perspective. J. Ind. Ecol. 12 (2), 229–247.
Losey, E., Vaughan, M., 2006. The economic value of ecological services provided by insects. BioScience 56, 311–323.
Low, A.B., Rebelo, A.G. (Eds.), 1996. Vegetation of South Africa. Lesotho and Swaziland, Pretoria.
Mander, M., 1998. Marketing of indigenous medicinal plants in South Africa: a case study in KwaZulu-Natal. Food and Agriculture Organisation of the United Nations.
Mapiye, C., Chimonyo, M., Dzama, K., 2009. Seasonal dynamics, production potential and efficiency of cattle in the sweet and sour communal rangelands in South Africa. J. Arid Environ. 73 (4–5), 529–536.
Mayer, P.M., Reynolds, S.K., Jr., McCutchen, M.D., Canfield, T.J., 2007. Meta-analysis of nitrogen removal in riparian buffers. J. Environ. Qual. 36 (4), 1172–1180.
McDonald, R.I., Shemie, D., 2014. Urban Water Blueprint: Mapping conservation solutions to the global water challenge. The Nature Conservancy, Washington, D.C.
Millennium Ecosystem Assessment (MEA), 2005. Ecosystems and Human Well-being: A Framework for Assessment. Island Press, London.
Mmopelwa, G., Blignautm, J.N., Hassan, R., 2009. Direct use values of selected vegetation resources in the Okavango Delta wetland. S. Afr. J. Econ. Mange-. Sci. 12, 242–255.
Mucina, L., Rutherford, M.C., Powrie, L.W. (Eds.), 2005. Vegetation Map of South Africa, Lesotho and Swaziland, 1:1 000 000 scale sheet maps. South African National Biodiversity Institute, Pretoria.
Myburgh, E., Nevill, E.M., 2003. Review of blackfly (Diptera: simuliidae) control in South Africa. Onderstepoort J. Vet. Res. 70, 307–317.
Naidoo, R., Balmford, A., Costanza, R., Fisher, B., Green, R.E., Lehner, B., Malcolm, T.R., Ricketts, T.H., 2008. Global mapping of ecosystem services and conservation priorities. PNAS 105, 9495–9500.
Nevill, E.M., 1988. The creation of permanent blackfly problems by the construction of dams. In: MacDonald, I.A.W., Crawford, R.J.M. (Eds.), Long-term data series relating to South Africa's renewable natural resources. South African National Scientific Programmes Report No.157. CSIR, Pretoria, South Africa, 353–355.
Nordhaus, W.D., 2017. Revisiting the social cost of carbon. PNAS 144 (7), 1518–1523.
Palmer, R.W., Rivers-Moore, N., Mullins, W., McPherson, V., Hattingh, L., 2007. Guidelines for integrated control of pest blackflies along the orange River. Water Res. Comm. Proj. K5/1558, Pretoria.
Panoramio, 2015. Panoramio acceptance policy for Google Earth and Google Maps. Available: ⟨http://www.panoramio.com/help/acceptance⟩ policy. Accessed 3 August 2015.
Pearce, D., Turner, R.K., 1990. Economics of Natural Resources and the Environment. Harvester Wheatsheaf.
Peterson, L.M., Moll, E.J., Collins, R., Hockings, M.T., 2012. Development of a compendium of local, wild-harvested species used in the informal economy trade, Cape Town, South Africa. Ecol. Soc. 17, 26.
Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R., 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267, 1117–1123.
Rangeti, I., 2014. Determinants of Key Drivers for Potable Water Treatment Cost in uMngeni Basin (Master of Technology Thesis)Environmental Health in the Faculty of Health Sciences. Durban University of Technology.
Richardson, D.M., van Wilgen, B.W., 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts? S. Afr. J. Sci. 100, 45–52.
Rivers-Moore, N.A., Hughes, D.A., De Moor, F.C., 2008. A model to predict outbreak periods of the pest blackfly Simulium Chutteri Lewis (Simuliidae, Diptera) in the Great Fish River, Eastern Cape Province, South Africa. River Res. Appl. 24, 132–147.
Scholtz, M.M., Bester, J., Mamabolo, J.M., Ramsay, K.A., 2008. Results of the national cattle survey undertaken in South Africa, with emphasis on beef. Appl. Anim. Husb. Rural Dev. 1, 1–9.
Scholtz, M.M., Theunissen, A., Frylinck, L., Strydom, P.E., 2014. Beef cattle management and systems development for optimal production. Report submitted to the Department of Agriculture, Land Reform, and Rural Development. Northern Cape Government, South Africa.
South African Atlas of Climatology and Agrohydrology. In: Schulze, R.E. (Ed.), Water Research Commission, GIS Data.
Schulze, R.E., Horan, M.J.C., 2007b. Soils: hydrological Attributes. In: Schulze, R.E. (Ed.), South African Atlas of Climatology and Agrohydrology 2007. Water Research Commission.
Schulze, R.E., Lorentz, S.A., Horan, M.J.C., Maharaj, M., 2007a. Sediment Yield. In: Schulze, R.E. (Ed.), 2007. South African Atlas of Climatology and Agrohydrology. Water Research Commission, Pretoria, RSA, (WRC Report 1489/1/06, Section 21.7).
Shackleton, C.M., 1993. Fuelwood harvesting and sustainable utilisation in a communal grazing land and protected area of the eastern Transvaal lowveld. Biol. Cons. 63, 247–254.
Shackleton, C.M., Shackleton, S.E., 2004. The importance of non-timber forest products in rural livelihood security and as safety nets: a review of evidence from South Africa. S. Afr. J. Sci. 100, 658–664.
Shackleton, C.M., Shackleton, S.E., Cousins, B., 2001. The role of land-based strategies in rural livelihoods: the contribution of arable production, animal husbandry and natural resource harvesting in communal areas of South Africa. Dev. South. Afr. 18, 581–604.
Shackleton, C.M., Shackleton, S.E., Ntshudu, M., Ntzebeza, J., 2002. Direct use values of non-timber forest products from three rural villages in the Kat River Valley, Eastern Cape Province. South Afr. J. Trop. For. Prod. 8, 45–65.
Shackleton, C.M., Timmermans, H.G., Nongwe, N., Hamer, N., Palmer, R., 2007. Direct-use values of non-timber forest products from two areas on the Transkei Wild Coast. Agrekon 46, 135–156.
Smakhtin, V.U., Batchelor, A.L., 2005. Evaluating wetland flow regulating functions using discharge time-series. Hydrol. Process. 19, 1293–1305.
South African National Biodiversity Institute (SANBI), 2015a. Administrative areas Map. GIS Dataset.
South African National Biodiversity Institute (SANBI), 2015b. Protected areas Map. GIS Dataset.
South African National Biodiversity Institute (SANBI), 2015c. Wetlands Map. GIS Dataset.
South African National Biodiversity Institute (SANBI), 2015d. Estuaries Map. GIS Dataset.
South African Tourism (SATOUR), 2016. South African tourism performance report for 2015. South Afr. Tour., Strateg. Res. Unit.⟨http://www.southafrica.net⟩.
Spies, D.C., 2011. Analysis and quantification of the South African red meat value chain. Unpublished Spies, D.C., 2011. Analysis and quantification of the South African red meat value chain. Unpublished Ph.D. Thesis. Bloemfontein: University of the Free State.. Bloemfontein: University of the Free State.
StatsSA, 2009. Water Accounts for South Africa:2000, updated march 2009. Statistics South Africa, Pretoria.
StatsSA, 2012a. National Census 2011. Stat. South Afr..
StatsSA, 2012b. National Census 2011 Subplace boundaries. statistics South Africa. GIS Dataset.
StatsSA, 2017. ⟨http://www.statssa.gov.za⟩ (Accessed 10 July 2017).
Sweeney, B.W., Newbold, J.D., 2014. Streamside forest buffer width needed to protect stream water quality, habitat, and organisms: a literature review. J. Am. Water Resour. Assoc. 50 (3), 560–584.
Telles, T.S., Dechen, S.C.F., de Souza, L.G.A., de Fatima Guimaraes, M., 2013. Valuation and assessment of soil erosion costs. Sci. Agric. 70 (3), 209–216.
Thiesing, M.A., 2001. An evaluation of wetland assessment techniques and their applications to decision making. In: Finlayson, C.M. , Davidson, N.C. & Stevenson, N. J. (Eds.). Wetland inventory, assessment and monitoring: Practical techniques and identification of major issues. Workshop 4, Proceedings of the 2nd International Conference on Wetlands and Development, Dakar, Senegal, 8-14 November 1998, Supervising Scientist Report 161, Supervising Scientist, Darwin.
TNC, 2015. Upper Tana-Nairobi Water Fund Business Case. The Nature Conservancy, Nairobi, Kenya.
Troy, A., Wilson, M.A., 2006. Mapping ecosystem services: practical challenges and opportunities in linking GIS and value transfer. Ecol. Econ. 60, 435–449.
Tscharntke, T., Bommarco, R., Clough, Y., Crist, T., Kleijn, D., Rand, T., Tylianakis, J., van Nouhuys, S., Vidal, S., 2007. Conservation biological control and enemy diversity on a landscape scale. Biol. Cont. 43, 294–309.
Turner, R.K., Paavola, J., Cooper, P., Farber, S., Jessamy, V., Georgiou, S., 2003. Valuing nature: lessons learned and future research directions. Ecol. Econ. 46, 493–510.
Turpie, J., Feigenbaum, T., Hayman, M., Hutchings, K., Cousins, T., Chipeya, T., Talbot, M., 2014. Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system: socio-economic assessment. Report. iSimangaliso Wetl. Park Auth., 300.
Turpie, J.K., 2003. The existence value of biodiversity in South Africa: how interest, experience, knowledge, income and perceived level of threat influence local willingness to pay. Ecol. Econ. 46, 199–216.
Turpie, J.K., Clark, B.M., 2007. The Health Status, Conservation Importance, and Economic Value of Temperate South African Estuaries and Development of a Regional Conservation Plan (Unpublished report). Anchor Environmental Consultants, Cape Town, South Africa.
Turpie, J.K., de Wet, J., 2009a. The recreational value of the garden route coast, South Africa, and implications of changes in management. Anchor Environ. Consult. Report. World Wide Fund. Nat. – South Afr..
Turpie, J.K., de Wet, J., 2009b. The recreational value of the Kogelberg coast, South Africa, and implications of changes in management. Anchor Environ. Consult. Report. World Wide Fund. Nat. – South Afr..
Turpie, J.K., Heydenrych, B.J., Lamberth, S.J., 2003. Economic valuation of terrestrial and marine biodiversity in the Cape Floristic Region: implications for defining effective and socially optimal conservation strategies. Biol. Conserv. 112, 233–251.
Turpie, J.K., Scovronick, N., Brown, C., 2006. Intangible resource losses and gains in phase 1 areas of the Lesotho highlands water Project. Report. Lhda., 69.
Turpie, J.K., O'Connor, T., Mills, A., Robertson, H., 2007. The ecological and economic consequences of changing land use in the southern Drakensberg grasslands. South Afr. S. Afr. J. Econ. Manag. Sci. 10, 423–441.
Turpie, J.K., Day, E., Ross-Gillespie, V., Louw, A., 2010a. Estimation of the Water Quality Amelioration Value of Wetlands: A Case Study of the Western Cape. Environment for Development Discussion Paper Series EfD DP, South Africa, 10–15.
Turpie, J.K., de Wet, J., Clark, B., Orr, K., Brown, C., Joubert, A., Karl, R., Magoba, R., Beuster, H., Clarke, T., Kotze, D., 2010b. The nature and value of aquatic ecosystem services in the Olifants, Inkomati and Usutu to Mhlatuze water management areas. Report. Dep. Water Aff., 362.
Turpie, J.K., Letley, G., Chrystal, R., Corbella, S., Stretch, D., 2017. A spatial valuation of the natural and semi-natural open space areas in eThekwini Municipality. Case studies for promoting green urban development in Africa: enhancing the relationship between urbanization, environmental assets and ecosystem services. Report prepared by Anchor Environmental Consultants, Cape Town.
Twine, W.C., Moshe, D., Netshiluvhi, T.R., Siphungu, V., 2003. Consumption and direct-use values of savanna bioresources used by rural households in Mametja, a semi-arid area of Limpopo Province. S. Afr. J. Sci. 99, 467–473.
UK National Ecosystem Assessment (NEA), 2011. The UK National Ecosystem Assessment Technical ReportCambridge. UNEP-WCMC.
United Nations System of Environmental-Economic Accounting (UN-SEEA), 2012. System of Environmental-Economic Accounting 2012: Central Framework. United

Nations, New York.
Van Jaarsveld, A.S., Scholes, R.J., Bohensky, E., Reyers, B., Lynam, T., Musvoto, C., Fabricius, C., 2005. Measuring conditions and trends in ecosystem services at multiple scales: the Sothern African Millennium Ecosystem assessment (SAfMA) experience. Philos. Trans. R. Soc. 360, 425–441.
National Biodiversity Assessment for South African Estuaries. In: Van Niekerk, L., Turpie, J.K. (Eds.), Report to South African National Biodiversity Institute.
Van Rooyen, I.M., Kirsten, J.F., van Rooyen, C.J., 2001. The competitiveness of the South African and Australian flower industries. Paper presented at the 45th Annual Conference of the Australian Agricultural and Resource Economics Society, January 23-25, 2001, Adelaide, South Australia.
Verhoeven, J.T.A., Arheimer, B., Chengqing, Y., Mariet, M.H., 2006. Regional and global concerns over wetlands and water quality. Trends Ecol. Evol. 21, 96–103.
Vincent, J., Ahmad, I., Adnan, N., Burwell, W., Pattanayak, S., Tan-Soo, J., Thomas, K., 2015. Valuing water Purification by forests: an analysis of Malaysian panel data. Environ. Res. Econ. 64, 59–80.
Weller, D.E., Baker, M.E., Jordan, T.E., 2011. Effects of riparian buffers on nitrate concentrations in watershed discharges: new models and management implications. Ecol. Appl. 21 (5), 1679–1695.
Whitfield, A.K., 1994. An estuary-association classification for the fishes of southern Africa. S. Afr. J. Sci. 90, 411–417.
World Wildlife Fund for Nature (WWF), 2013. Defining South Africa's water source areas. Report by WWF – World Wildlife Fund for Nature, Cape Town.
Yuan, Z.Y., Chen, H.Y., 2009. Global-scale patterns of nutrient resorption associated with latitude, temperature and precipitation. Glob. Ecol. Biogeogr. 18 (1), 11–18.
Zaimes, G.N., Schultz, R.C., 2002. Phosphorus in Agricultural Watersheds: A Literature ReviewReport by the Department of Forestry. Iowa State University, Ames Iowa.
Zehnder, G., Gurr, G., Kuhne, S., Wade, M., Wratten, S., Wyss, E., 2007. Arthropod pest management in organic crops. Annu. Rev. Entomol. 52, 57–80.
Zhou, X., Helmers, M.J., Asbjornsen, H., Kolka, R., Tomer, M.D., Cruse, R.M., 2014. Nutrient removal by prairie filter strips in agricultural landscapes. J. Soil Water Conserv. 69 (1), 54–64.