One Ecosystem 7: e86392
doi: 10.3897/oneeco.7.e86392

OPEN ACCESS

Research Article

Accounting for ecosystem services and asset value: pilot accounts for KwaZulu-Natal, South Africa

Jane Kirsten Turpie[‡], Gwyneth Kay Letley[§], Joshua Weiss[§], Kevin Schmidt[§]

‡ School of Economics, University of Cape Town, Rondebosch 7701, South Africa
§ Anchor Environmental Consultants, Cape Town, South Africa

Corresponding author: Jane Kirsten Turpie (jane.turpie@uct.ac.za)

Academic editor: David N. Barton

Received: 10 May 2022 | Accepted: 19 Sep 2022 | Published: 05 Dec 2022

Citation: Turpie JK, Letley GK, Weiss J, Schmidt K (2022) Accounting for ecosystem services and asset value: pilot accounts for KwaZulu-Natal, South Africa. One Ecosystem 7: e86392.
https://doi.org/10.3897/oneeco.7.e86392

Abstract

Pilot monetary ecosystem accounts were compiled for KwaZulu-Natal Province, South Africa, in order to highlight any data, methodological or process issues in their compilation and to contribute towards charting a strategy for ecosystem accounting. The Province is highly diverse, with eight biomes, large proportions under communal, private and state tenure, globally important biodiversity, variable landscape condition and encompassing catchment areas of nine river systems. We accounted for the supply and use of wild biomass, reared animal production, cultivation (including silviculture), nature-based tourism, property value, carbon storage and sequestration, pollination, flow regulation (maintenance of base flows), sediment retention, water quality amelioration and flood attenuation. For each ecosystem service, we devised conceptually valid methods that were suitable for the existing data to produce values consistent with the System of National Accounts. These were then summed to estimate total annual flows from each 100 x 100 m spatial unit and its asset value. Challenges encountered included lack of data on small-scale and subsistence production, mismatches in the classification of landcover and government production statistics, unreliable measures of ecosystem condition, the large scale of hydrological modelling and lack of centralised data organisation relating to hydrological services. There was heavy reliance on past empirical research and on global datasets. The combined value of the annual flow of the ecosystem services valued was R52.5 billion in 2011, equivalent to 12% of the provincial GDP. However, the values of many of the services have decreased over the accounting period, due to a combination of changes in demand and ecosystem condition. Asset value was undermined to some extent by unsustainable use of provisioning services. Some areas will require careful messaging, particularly in regard to the contentious issue of valuing carbon retention and the use of exchange values rather than welfare values that are used in economic analysis.

Keywords

natural capital accounting, ecosystem accounting, valuing ecosystem services, ecosystem asset value

Introduction

The United Nations' System for Environmental Economic Accounting (SEEA) includes a framework for Ecosystem Accounting (SEEA EA) that was finalised in 2021 (United Nations 2021). The SEEA EA complements and builds on the accounting for environmental assets as described in the SEEA Central Framework (United Nations et al. 2014b). It provides a spatially explicit approach that applies and adapts System of National Accounting (SNA) principles to systematically measure and monitor ecosystems for decision-making and planning, both in physical and monetary terms (Remme et al. 2018, Edens et al. 2022).

The primary purpose of valuation in monetary terms is to integrate information on ecosystems and ecosystem services with information in the standard national accounts (United Nations 2021). Therefore, one of the main aims of the SEEA EA is to treat ecosystem services and assets in a way that is comparable to the treatment of produced assets and standard goods and services as described in the SNA. Recognising ecosystem services as outputs produced by ecosystem units allows for them to be recorded as being transacted within an accounting system.

The main aim of this study was to pilot the development of monetary ecosystem accounts at a subnational scale in South Africa, following the then experimental SEEA EA (United Nations et al. 2014b) and associated guidelines (United Nations 2017). This study pre-dated, but contributed to the development of the SEEA EA (United Nations 2021). The accounts were compiled for the Province of KwaZulu-Natal, building on the physical ecosystem extent and condition accounts compiled by Driver et al. (2015), as well as recent ecosystem service valuation studies carried out at national scale (Turpie et al. 2017a) and metro scale for the eThekwini Municipality in KwaZulu-Natal (Turpie et al. 2017b). This study provides the ecosystem services accounts in physical and monetary terms and the monetary ecosystem asset account for the years 2005 and 2011, based on available land-cover datasets. The accounts were presented in tabular form, at the scale of the Province, disaggregated by biome, as well as displayed in maps. This paper provides an overview and does not replicate all of the tables and figures in the Technical Report (Turpie et al. 2021) *[1]

Study area

KwaZulu-Natal is one of South Africa's nine provinces and covers approximately 94000 km ^{2} or 8% of the country's land area. It encompasses several full catchment areas from source to sea (Fig. 1). KwaZulu-Natal contains 10% of South Africa's Strategic Water Source Areas (SWSAs) which deliver 50% of South Africa's water (Nel et al. 2017, Le Maitre et al. 2018). An extensive network of engineered infrastructure supplies towns and cities with water.

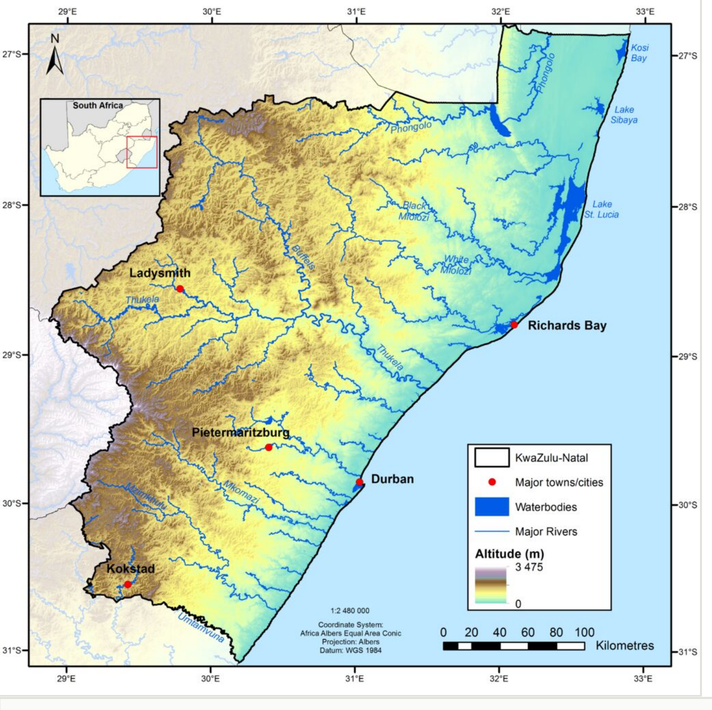

Figure 1.

Topographical map of KwaZulu-Natal showing the main rivers, lakes and estuaries. The inset map shows KwaZulu-Natal's location within South Africa.

Due to its topographical variation and subtropical and coastal location, KwaZulu-Natal features most of South Africa's biomes (Fig. 2) and supports a wealth of biodiversity. In 2011, urban areas (Durban and other towns) covered 6.1% and 25.3% of the areas were under cultivation or tree plantations. There are six major river systems that end in large, permanently open estuaries, namely the Pongola, uMfolozi, Thukela, uMngeni, Mkomazi and the uMzimkhulu, as well as numerous smaller estuaries.

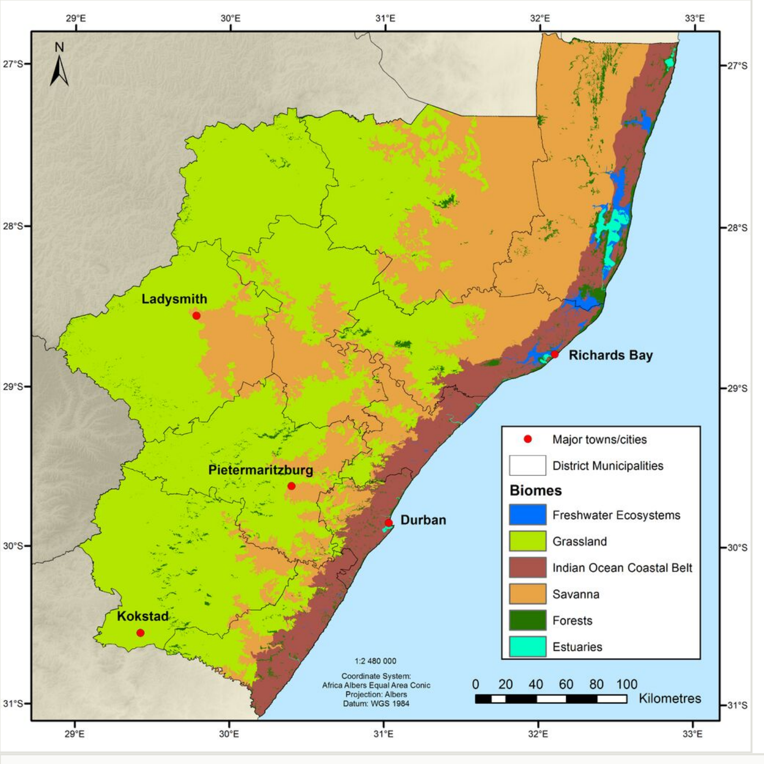

Figure 2.

The main towns, district municipality boundaries and the biomes of KwaZulu-Natal. Biomes from SANBI 2018 Vegetation Map (South African National Biodiversity Institute 2018). Note that ”freshwater ecosystems” and “azonal vegetation” (mainly associated with wetlands and riparian areas) have been combined as “freshwater ecosystems” for this study.

KwaZulu-Natal contributed to 15.8% of South Africa’s GDP in 2011, with manufacturing and tertiary industries (trade, business services and transport and communications) being the dominant sectors (Statistics South Africa 2014). The sectors likely to benefit most from ecosystem services - Agriculture, forestry and fishing; Electricity, gas and water; Trade, catering and accommodation; and Finance, real estate and business services - contributed about 4%, 3%, 15% and 16%, respectively, in 2011. The Province is also the second most populous in the country with 10.3 million inhabitants in 2011 (almost 20% of the South African population). It has a youthful population with high birth rates and lower-than-average life expectancy and high dependency ratios (Statistics South Africa 2012). Unemployment rates were at 33% in 2011 (Statistics South Africa 2012). As of 2014, over 60% of the adult population were classified as living in poverty, the third highest rate in South Africa (Statistics South Africa 2018).

Almost 30% of the land area falls under the traditional authority (the Ingonyama Trust), which is largely under communal tenure (Fig. 3). State protected areas make up 8.7% of the land area and the remainder is under private tenure.

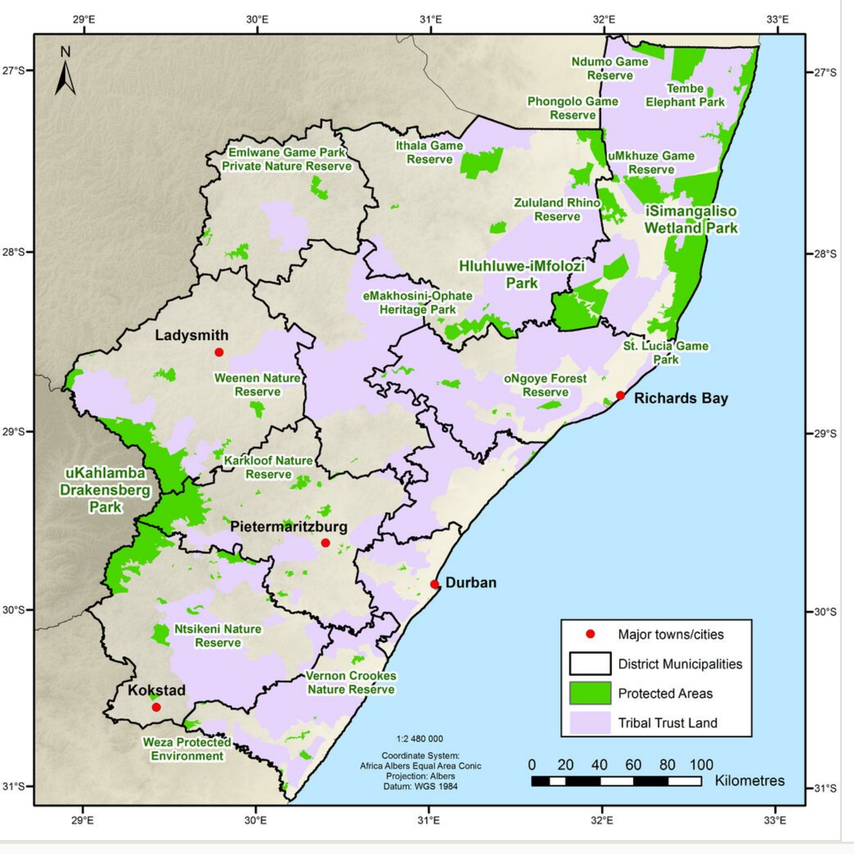

Figure 3.

Map of KwaZulu-Natal showing proclaimed protected areas (largely state-owned) as of 2011, Ingonyama Tribal Trust land (largely communal) and land under private tenure.

Methodological Framework

Ecosystems and ecosystem services

Based on the full extent of accounting required for the SEEA EA, the KwaZulu-Natal monetary ecosystem accounts aimed to include ecosystem services from all types of cultivated areas, tree plantations, urban areas and man-made waterbodies, as well as natural (or semi-natural) terrestrial, freshwater and estuarine ecosystems within the accounting area, which excluded marine ecosystems.

While the concept of ecosystem services is well established (Ehrlich and Mooney 1983), the development of a standardised approach to classify ecosystem services remains a serious challenge (United Nations et al. 2014a, Potschin et al. 2016, La Notte et al. 2017). Inconsistency across concepts and terminology has resulted in ambiguity and the SEEA Technical Recommendations (United Nations 2017) flagged the “definition and classification of ecosystem services" as a key area for further research. In this study, a list of services was generated, based on a range of existing classification systems, such as CICES (Haines-Young and Potschin-Young 2017) and knowledge of the study area (Table 1). This is similar to the "reference list" subsequently published in the SEEA EA (United Nations 2021). The study only considered biotic services. Water was not included as a provisioning service, since it is not produced by ecosystems and is accounted for separately as a resource account. Rather, we regard ecosystem services pertaining to water supply as being those that regulate the timing and location of water flows and those that affect water quality, both of which affect the costs of collecting and producing potable water for use. Unlike CICES, within crop and animal production (eco)systems, we considered the ecosystem service to be the *in situ* environmental input to production, rather than the value of crop and animal production. This also means that we could account for pollination and pest control services as an input from surrounding ecosystems. While broad coverage of inland ecosystem services was attempted and key services were prioritised, not all services could be fully covered. The study also excluded estuary inputs to marine ecosystems (see Turpie et al. 2017b).

Table 1.

Ecosystem service classification used. Services with an asterisk were not included in this study.

Broad category	Ecosystem service	Physical measure	Valuation method
Provisioning services	Harvested **wild biomass products**	kg or m^3/ha/yr	Resource rent, based on market prices
	In situ ecosystem inputs to **reared animal** production	Large Stock Units per ha#	Resource rent, based on market prices
	In situ ecosystem inputs to **crop** production	Crop production as proxy, in kg/ha/yr	Resource rent of agri/silvicultural commercial and subsistence production, based on market or imputed prices, after deducting contribution of pollination service to production
	In situ ecosystem inputs to **plantation forestry** production	Forestry production as proxy, in m^3/ha/yr	
	Genetic resources*	-	-
Cultural services	**Experiential value** associated with active or passive use	Monetary only	Resource rent for nature-based tourism; Hedonic pricing method for property value; Local recreation not valued
	Existence value*	-	-
Regulating services	**Flood attenuation**	Monetary only	Avoided conveyance infrastructure costs (metro only)
	Seasonal flow regulation	Monetary only	Annualised avoided costs of water supply infrastructure for existing supply systems plus avoided costs of purchasing water from vendors for those people who depend on instream flows for their domestic water supplies.

Broad category	Ecosystem service	Physical measure	Valuation method
	Sediment retention	m^3/ha/yr	Annualised avoided cost of replacement of lost storage capacity
	Water quality amelioration	Monetary only	Water treatment costs avoided, based on a cost function
	Carbon retention	tC/ha	Annualised avoided damage costs using social cost of carbon
	Agricultural support services	Monetary only	Contribution to agricultural resource rent, based on benefit transfer of a production function
	Critical habitat for fisheries and wildlife*	-	-

Treatment of intermediate services

While many authors argue that one should only value final services, ignoring intermediate services (the provision of a service from one ecosystem type to another, such as crop pollination) would lead to a spatial bias in the valuation of ecosystems. Our approach was to estimate the contribution of the intermediate service and attribute that value to the habitat providing the service. Thus, the pollination contribution to agricultural production was subtracted from the estimated value of ecosystem inputs in agricultural land to avoid double counting.

Quantification and Valuation

For each ecosystem service, we selected valuation methods that are conceptually valid and that produce values that are consistent with the SNA. We attempted to value actual use (rather than capacity to supply). We expressed the value of ecosystems in terms of exchange values (consistent with the SNA) rather than welfare values, but point out that these go a large part of the way to providing information for welfare values. The benefits derived from ecosystem services were expressed in terms of annual flows. These were then summed across all benefit flows to estimate a total annual flow of value from each spatial unit. This total value flow was then used to estimate the asset value of that spatial unit in terms of its net present value (NPV). We used a social discount rate of 3.66% (Addicott et al. 2020) and a time period of 25 years, noting the high level of uncertainty in projecting values into the future (see review by Badura et al. 2017) and that discounting mitigates this concern to some extent. In most cases, it was assumed that ES flows were constant, but for provisioning services, future ES flows were modelled, based on estimated levels of offtake relative to their stocks and productivity. All values are presented in 2010 Rands, which was the most recent national accounting base at the time of the study.

Spatial framework, accounting period and data

We used the national 100 x 100 m (1 ha) Basic Spatial Unit (BSU) grid, constructed by Statistics South Africa for the purpose of ecosystem accounting (Stats SA, see Anderson

2019). Base raster layers (e.g. land use, biomes, census areas) were first projected and then snapped to this grid, ensuring consistency across all ecosystem services and no overlaps for any given area per land-cover class or ecosystem type. We used the 2005 and 2011 KwaZulu-Natal Land Cover datasets, which have 47 classes (including a measure of condition for major natural land-cover classes) and a nominal resolution of 20 m.

Accounting

The supply and use tables only account for ecosystem services used, such that the sum of supply of a particular service must equal the sum of use. For wild biomass, the amount used would also include illegal use and amounts exceeding sustainable yield. In the case of some regulating services, accounting only for the service used is easier to achieve in monetary than physical terms because of the spatio-dynamic complexity of the service and, thus, for certain services, the physical accounts have reported on the service *capacity* , irrespective of whether it is demanded. For certain cultural services, only the monetary accounts are provided, since physical measures were not available (see Table 1). The ecosystem monetary asset account records the monetary value of opening and closing stocks of all ecosystem assets within an ecosystem accounting area and any additions or reductions in these stocks.

Quantifying and valuing ecosystem services and benefits

Wild resources

Hundreds of wild plant and animal species are harvested in the wild by large numbers of households who rely on harvesting natural resources on a subsistence or small-scale basis (Dovie et al. 2002, Shackleton et al. 2002a, Shackleton et al. 2002b, Shackleton et al. 2007 , Twine et al. 2003, Kaschula and Shackleton 2009, Turpie et al. 2010, Turpie et al. 2014). These were grouped into ten broad types of resources (Table 2). Their stocks were estimated, based on land cover, vegetation type (South African National Biodiversity Institute 2018) and corresponding information from literature and availability was based on land tenure. Demand was estimated at the census sub-place (~ village) level, based on household survey data (mainly from Turpie et al. (2010), Dovie et al. (2002), Shackleton et al. (2002a), Shackleton et al. (2002b), Twine et al. (2003), Cocks and Wiersum (2003) Turpie et al. (2010)). Household use was estimated using a purpose-built spatial model, under the assumption of a 5-10 km range of collection, limited by the availability of stocks (see Turpie et al. in prep). Resource was mapped in physical terms (see example for fuelwood (Fig. 4). Values were based on prices reported in the surveys and collection costs were assumed to be negligible. The asset value was calculated as the net present value over 25 years taking sustainability into account where harvesting was compared to the corresponding sustainable yield at the level of the BSU. Where harvesting exceeded the estimated sustainable use, stocks were eroded at the corresponding rate, affecting future use and values. In some cases, this effectively resulted in the asset life being less than 25 years.

Table 2.

Wild biomass groupings, based on the CICES framework and resource characteristics.

	Purpose	Group
Wild plant resources	Nutrition and health	Wild plant foods and medicines
	Energy	Wood fuel
	Raw materials	Grass
		Reeds and sedges
		Palm leaves
		Poles and withies
		Timber
		Wood for carving/curios
Wild animal resources	Nutrition	Terrestrial birds and animals
		Fish and other aquatic organisms

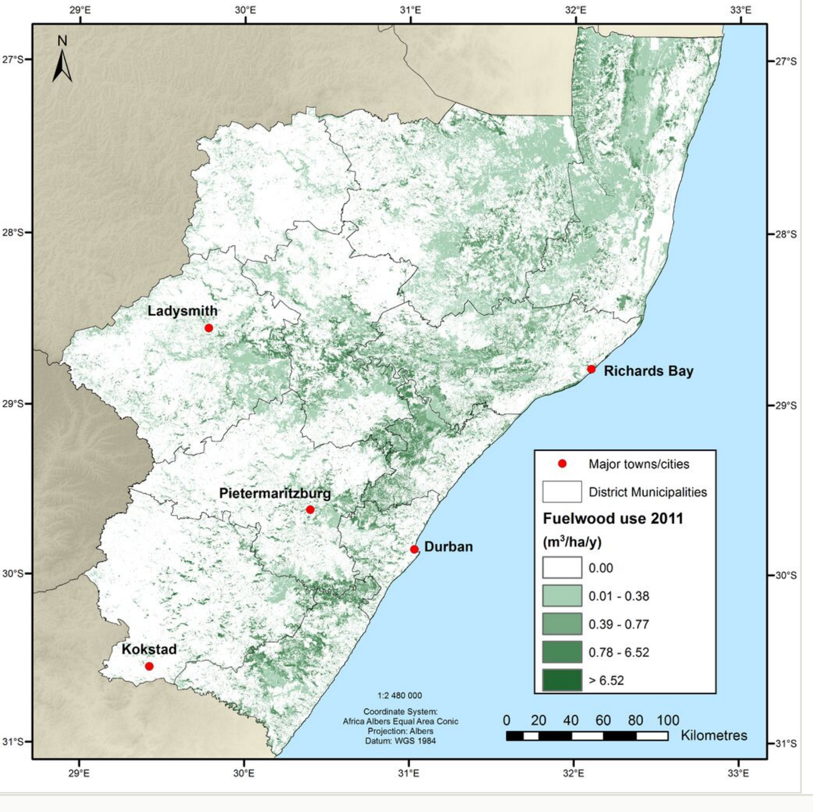

Figure 4.

Estimated spatial variation in the informal harvesting of fuelwood across KwaZulu-Natal.

Land inputs to reared animal production

KwaZulu-Natal accounts for about 20% of cattle in the country (Meissner et al. 2013). These are found in both high input production systems on private lands and 'low input-low output' systems on communal lands. The ecosystem service is the land's contribution to livestock or wildlife production (for meat, live sales or hunting), which includes natural fodder provision. As a proxy for the physical measure, we quantified the amount of livestock supported in standardised large stock units (LSUs, Mokolobate et al. 2017). District level stocking rates, production and value on private and communal lands were derived from the Census of Commercial Agriculture 2007 (Statistics South Africa 2011), quarterly provincial statistics, the agricultural household survey (Statistics South Africa 2012) and other studies (Kunene and Fossey 2006, Turpie et al. 2010, Turpie et al. 2014, Mahlobo 2016, Nkosi 2017). Wildlife stocking and offtake rates were not available, but production value was calculated using information from Ezemvelo KwaZulu-Natal Wildlife and literature (Taylor et al. 2015). Reared animal production was valued using the resource rent method (gross income less intermediate expenditure, labour costs and user costs of fixed capital), based on the agricultural census.

Land inputs to cultivated production

We used production in tonnes of produce or m^3 of timber as a proxy for the physical measure of land inputs to cultivated production. The service was valued in terms of resource rent, less the contribution of pollination services from adjacent natural ecosystems. Commercial crop production, prices and input costs were taken from the Census of Commercial Agriculture (Statistics South Africa 2006, Statistics South Africa 2011), using groupings that could be aligned to land-cover classes. Silviculture production and value were only available at provincial level (Forestry South Africa 2017). Communal crop production, prices and input costs were taken from household studies in northern KwaZulu-Natal (Turpie et al. 2014) and used as a single average value per hectare.

Experiential value

While cultural values are generally understood to comprise both use and non-use values, the SEEA EA only accounts for use values, which we term "experiential value". We developed a framework for the consideration of experiential benefits, as accruing in three ways: to people who live close to the site used (herein characterised as "locals"), to people who come from nearby ("visitors") and to people who travel relatively far to visit the site ("tourists"), with methods of valuation typically being different for each (Fig. 5Fig. 6). This study only covered value to locals as manifest in property investment and value to tourists. There were no data or valuation studies (e.g. travel cost studies) on which to estimate the value to nearby visitors.

The contribution of ecosystems to tourism value was estimated using tourism statistics and spatial data on activity (Fig. 6). First, the tourism expenditure attributed to visiting attractions, as opposed to other activities, such as visiting family and friends, was estimated for different categories of domestic and foreign tourists, based on information collated from the South African Tourism (SAT) annual performance reports (South African Tourism 2005, South African Tourism 2006, South African Tourism 2011) and from data collected in regional tourist offices. Resource rent was estimated using ratios from the SAT Satellite Accounts (Statistics South Africa 2010, Statistics South Africa 2015). This value was spatially allocated to the BSU grid in proportion to photo user density using the InVEST Recreation Model 3.5.0 which obtains data on geotagged photographs uploaded to *flickr.com*. Geotagged photographs are a reliable proxy for visitation rates (Wood et al. 2013, Turpie et al. 2017a, Turpie et al. 2017b, Lee and Tsou 2018, Barros et al. 2019).

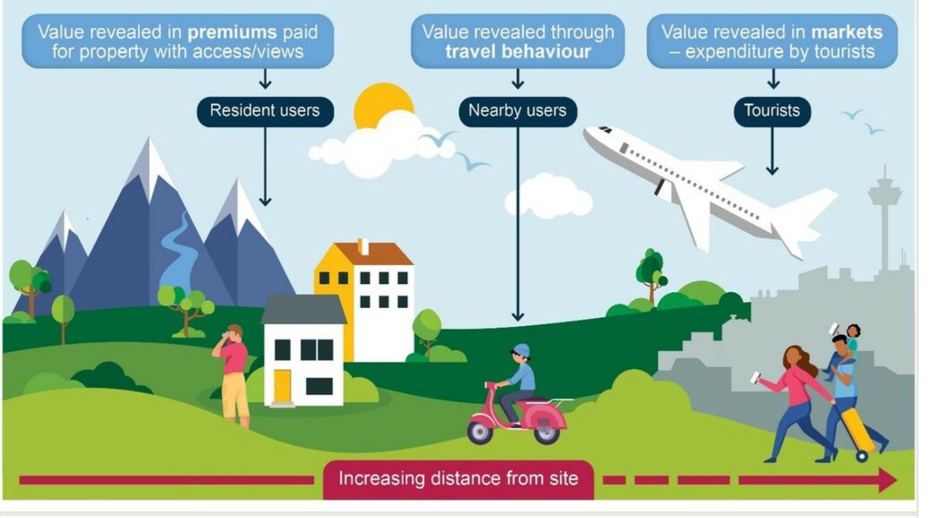

Figure 5.

A typology of values associated with experiential uses of ecosystems (source: authors).

The amenity value of ecosystems to locals was estimated in terms of the contribution of urban green open space areas to property value. The property value of urban green open space areas in KwaZulu-Natal was estimated, based on the hedonic pricing study of eThekwini Municipality which was derived from very detailed property and open space data (see Turpie et al. 2017b). Such data were not available for other urban areas in the Province. Thus, a simple benefits transfer model was derived for the latter areas, based on the relationship between suburb-level census data on household income and premiums paid for open space in eThekwini. This was applied to the ten urban centres identified using the Functional Town Typology by van Huyssteen et al. (2018). The aggregated premium value was annualised for the supply and use tables.

Carbon retention

In South Africa, total ecosystem carbon was mapped at national scale in 2015 (Department of Environmental Affairs 2015). This was used to estimate the 2005 and 2011 carbon stocks, based on average carbon values per land cover type. We sought to value the service in terms of the avoided climate change damage costs, both to South Africa and the rest of the world. This was considered preferable to using market values, since there is very little trade in ecosystem carbon in South Africa (Remme et al. 2015). However, estimates of the global social cost of carbon (SCC)- the net present value of avoided costs from the release of 1 t of CO_2 - are numerous and vary greatly (for example, see Tol 2008). Estimates have also been increasing over time, as the more recent studies have tended to be more comprehensive. Estimates now range from US$10 to US$1000/tCO_2 (Ricke et al. 2018). In their critical review of literature, van den Bergh and Botzen (2014) suggested a lower bound value of US$125/t$CO_2$. Disaggregated estimates have also started emerging. For example, Nordhaus (2017) provided an updated median estimate of global SCC as US$31/t$CO_2$ (in 2010 US$) and estimated that 3% of this would be borne in Africa. Ricke et al. (2018) produced a far higher median estimate of global SCC (US$417/t$CO_2$ in 2018 US$) and disaggregated this to country-level, yielding a unit cost of US$3.31 for South Africa. In this study, we used the more conservative estimate from Nordhaus (2017) with a global SCC of US$31/t$CO_2$ and an estimate of US$3.31 for South Africa's SCC, which is 0.8% of the global SCC estimate produced by Ricke et al. (2018).

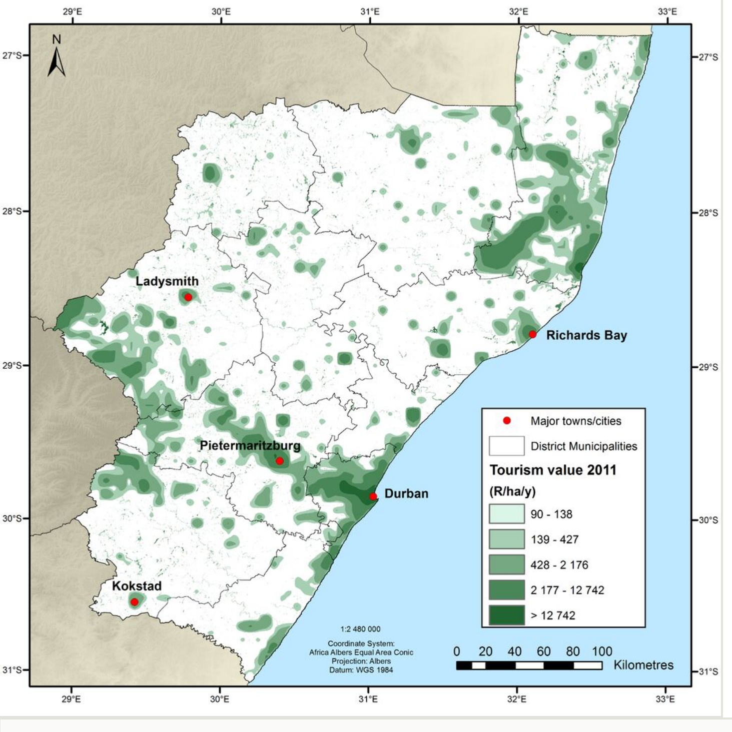

Figure 6.

Nature-based tourism value for the year 2011 across KwaZulu-Natal, based on the distribution of geo-referenced photographs uploaded to Flickr.

The value of SCC is expected to increase over time as populations and per capita incomes grow and should correspond to the year of the account, as ecosystem carbon retained will increase in real value over time. Therefore, the SCC estimates from the literature were escalated at a rate of 3% per year (Nordhaus 2017) to derive different estimates for 2005 and 2011. The annualised social cost of carbon was estimated using a social rate of discount of 3.24%.

Pollination

Crop pollination by insects increases both yield and quality of crops (Melin et al. 2014). In KwaZulu-Natal, most commercial crops are wind pollinated and it is assumed that vegetable and fruit farmers tend to actively pollinate their crops. We, therefore, focused on the likely benefits to communal land farmers. The location and extent of vegetable and fruit gardens was estimated using census data (Statistics South Africa 2012), community survey data (Statistics South Africa 2016) and information from literature (Shisanya and Hendriks 2011, Ogundiran et al. 2014). We used land-cover data to calculate the amount and type of natural vegetation surrounding each of the settlement areas and we used a value function transfer approach, based on the panel model of Tibesigwa et al. (2019) to predict the value added to income from pollinator-dependent crops by natural pollinators.

Flow regulation

Ecosystems can reduce seasonal variation in downstream river flows through infiltration and temporary storage in catchment areas (relative to the variation in rainfall), reducing the built storage capacity needed to achieve a given yield through the year (Vogel et al. 1999, Vogel et al. 2007, Guswa et al. 2017). Therefore, water supply infrastructure and reservoir capacity, in particular, can be treated as a substitute for the service provided by ecosystems.

For this study, a hydrological model was set up for all of the catchments of KwaZulu-Natal using the Soil and Water Assessment Tool (SWAT) model. The service was mapped in physical terms as the difference in infiltration relative to a bare landscape, in m^3 per ha. The benefits generated from the service were considered in terms of the avoided additional storage capacity required to meet the yield of the existing supply systems, which was estimated, based on the theoretical relationship between storage, yield and reliability for a standardised reservoir (Kuria and Vogel 2015) and costed, based on data from a national inventory of reservoirs. We also estimated the avoided costs of obtaining water for people who depend on instream flows for their domestic water supplies, based on monthly water demands by these households within each sub-catchment (derived from Statistics South Africa 2012).

Sediment retention

Erosion and sedimentation within watersheds can become a major issue as it causes structural damage to reservoirs, causes flooding, affects the quality of drinking water and increases water treatment costs (Pimentel et al. 1995, Basson 2009). Natural vegetation and crops can reduce erosivity by stabilising soils and intercepting rainfall (de Groot et al.

2002). Vegetated areas also capture eroded sediments transported in surface flows, preventing them from entering rivers (Blumenfeld et al. 2009, Conte et al. 2011). While some level of sedimentation of dams is expected and planned for under natural conditions, elevated catchment erosion either incurs dredging costs or shortens the lifespan of dams and related infrastructure.

The extent to which ecosystems retained and/or captured sediments relative to a bare landscape was estimated and mapped using the InVEST Sediment Delivery Ratio model. Due to the potentially large and costly damages of sedimentation, we assumed that the service would be fully demanded. We used the replacement cost of lost storage capacity to estimate its value.

Water quality amelioration

The impacts of natural vegetation and cultivated land on water quality were estimated using the SWAT hydrological model. The model was set up to estimate changes in phosphorus loads at raw water treatment extraction points relative to a bare landscape in which the retention/absorption capacity of the vegetated areas was reduced. The value of the service was then estimated in terms of the avoided costs to water treatment works using a water treatment cost model developed by Turpie et al. (2017b).

Results

The ecosystem service supply and use accounts were developed in both physical and monetary terms for 2005 and 2011. The monetary supply and use accounts for 2011 are presented in Table 3 and Table 4 and the ecosystem monetary asset account in Table 5. The aggregate values for 2005 and 2011 are compared in Table 6.

Table 3.

Total supply per ecosystem type 2011 in monetary values (R millions). Note: Built includes man-made parks, value pertains to parks, area to all built area.

Biome (ha) Resource	**Freshwater ecosystems**	**Grassland**	**Indian Ocean Coastal Belt**	**Savannah**	**Forests**	**Estuaries**	**Cultivated**	**Built**	**Total**
54 901	3 354 881	362 944	2 292 315	181 604	39 425	2 361 582	682 874	9 330 526	
Wood products	3.27	520.67	179.74	612.69	216.18	0.16	2513.45		**4 046.16**
Non-wood products	18.11	866.56	175.23	537.16	49.95	0.54			**1 647.54**
Livestock production	2.9906	984.9509	95.0889	384.2992	5.0088	0.5349			**1 472.87**

Biome (ha) Resource	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savannah	Forests	Estuaries	Cultivated	Built	Total
Crop production							5 021.98		**5 021.98**
Experiential value	21.1	326.0	193.9	297.4	80.9	36.3	161.9	1 009.1	**2 126.60**
Carbon storage	133.26	13 261.20	1 421.88	9 010.02	909.21	4.40	9 839.37		**34 579.34**
Pollination	0.06	11.09	5.03	29.73	1.77	0.00			**47.69**
Flow regulation	23.29	2 014.08	22.61	1 020.55	85.19	1.06			**3 166.78**
Flood attenuation								23.50	**23.50**
Sediment retention	5.99	167.75	22.28	94.58	39.50	0.30			**330.40**
Water quality amelioration	-	12.89	0.08	2.65	0.41	-			**16.03**
Total R millions	**208.04**	**18 165.17**	**2 115.85**	**11 989.10**	**1 388.14**	**43.29**	**17 536.70**	**1 032.61**	**52 478.90**
Value R/ha	**3 789.37**	**5 414.55**	**5 829.68**	**5 230.13**	**7 643.78**	**1 098.11**	**7 425.83**	**1 512.15**	**5 624.43**

Table 4.

Total use per economic user (2011) in monetary values. R millions.

Economic users Ecosystem service	Agric, Forestry and Fisheries	Water supply	Trade, catering & accommodation	Other sectors	Households	Government	Rest of world	Total
Wood products	2 513.45				1 532.71			**4 046.16**
Non-wood products					1 647.54			**1 647.54**
Livestock production	815.45				657.43			**1 472.88**
Crop production	3 441.24				1 580.74			**5 021.98**
Experiential value			798.83	1 327.78				**2 126.60**
Carbon storage						273.18	34 306.16	**34 579.34**

Economic users Ecosystem service	Agric, Forestry and Fisheries	Water supply	Trade, catering & accommodation	Other sectors	Households	Government	Rest of world	Total
Pollination					47.69			**47.69**
Flow regulation	3 166.78							**3 166.78**
Flood attenuation					23.50			**23.50**
Sediment retention		330.40						**330.40**
Water quality amelioration		16.03						**16.03**
Total	**9 936.91**	**346.43**	**798.83**	**1 327.78**	**5 489.61**	**273.18**	**34 306.16**	**52 478.90**

Table 5.

Ecosystem monetary asset account 2005-2011. NPV calculated using an asset lifespan of 25 years and a discount rate of 3.66%. All values expressed in 2010 prices.

	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savannah	Forests	Estuaries	Cultivated	Urban green space	TOTAL
Opening stock (2005)	**2 797.05**	**269 912.28**	**33 383.63**	**181 813.62**	**18 792.00**	**566.46**	**215 197.79**	**14 844.65**	**737 307.48**
Change due to change in ecosystem extent	-121.74	-25 359.56	-5 845.08	-19 719.94	-466.86	-1.70	64 233.38	3 017.71	**15 736.21**
Change due to change in ecosystem capacity and/or service demand	641.72	37 104.20	4 200.92	25 701.99	2 715.82	134.74	4 655.54	-1 135.15	**74 019.77**
Net change	519.97	11 744.64	-1 644.16	5 982.05	2 248.96	133.04	68 888.92	1 882.55	89 755.98
Closing stock (2011)	**3 317.03**	**281 656.92**	**31 739.47**	**187 795.67**	**21 040.96**	**699.50**	**284 086.71**	**16 727.21**	**827 063.46**
Net change %	18.6%	4.4%	-4.9%	3.3%	12.0%	23.5%	32.0%	12.7%	12.2%

Table 6.

Value of ecosystem service flows and associated asset values in 2005 and 2011; in 2010 R millions.

Class	**Ecosystem service**	**2005**		**2011**	
		Annual flow	**Asset value**	**Annual flow**	**Asset value**
Provisioning	Wild resources	3 722.16	32 032.23	3 180.25	28 440.48
	Animal production	1 672.99	27 100.67	1 472.87	23 859.03
	Cultivation	6 456.70	104 591.91	7 535.43	122 066.22
Cultural	Nature-based tourism	532.83	8 631.31	798.83	12 940.22
	Property	1 164.97	18 871.27	1 327.78	21 508.60
Regulating	Carbon storage (value to SA)	236.39	3 829.49	273.18	4 425.46
	Carbon storage (value to ROW)	29 686.17	480 915.93	34 306.16	555 759.87
	Pollination	51.26	830.33	47.69	772.50
	Flow regulation	3 247.87	52 612.12	3 166.78	51 298.55
	Flood attenuation	31.02	502.49	23.50	380.68
	Sediment retention	435.79	7 059.28	330.40	5 352.18
	Water quality amelioration	20.40	330.46	16.03	259.67
Total		**47 258.53**	**737 307.48**	**52 478.90**	**827 063.46**
Total excluding Carbon value to ROW		**17 572.38**	**256 391.56**	**18 172.74**	**271 303.59**

The combined value of the annual flow of ecosystem services was R47.3 billion in 2005 and R52.5 billion in 2011, which was equivalent to 13% and 12% of provincial GDP. Of this, R17.6 billion and R18.2 billion of the benefits accrued to South Africa (Table 6) and only R8.4 billion and R8.9 billion (about 17% of ecosystem services value) was recorded within the SNA. In other words, the ecosystem service accounts extend the 2005 and 2011 GDP estimates by R38.9 and R43.6 million, respectively. Note that this will increase when the accounts are extended to the marine economic exclusion zone (EEZ) boundary and to all services.

The bulk of the value of ecosystem services was produced by regulating services (73% in 2011). Provisioning services and the cultural services valued accounted for 23% and 4% of the total value in 2011, respectively. Regulating value was dominated by carbon retention, which accounted for 65% of total value. Flow regulation accounted for 6%, while sediment retention and water quality amelioration only made up 1% of value. Provisioning service value was mostly crop production, which accounted for 14% of the value.

Just under two thirds of the provisioning services value in 2011 was produced by cultivated land (62%). Most of the value of regulating services was produced in the grassland biome (41%), savannah biome (27%) and cultivated land (26%). Landscaped urban parks produced 48% of the value of the partial estimate of cultural ecosystem services. Grassland and savannah ecosystems were important for nature-based tourism. Within forest ecosystems, cultural services (in particular, nature-based tourism) accounted for the highest percentage share of the value followed by regulating services.

The main users of the ecosystem services quantified were the rest of the world (66%; carbon storage as an exported service in the form of avoided damage costs to the rest of the world)*[2], followed by the agriculture, forestry and fisheries sectors (19%) and households (11%). Approximately 2% of the total value flows to the trade, catering and accommodation sectors, which are also an important source of employment in the Province.

The asset value of ecosystems was estimated at R737 billion and R827 billion in 2005 and 2011, respectively (Table 5, Table 6), an increase in value of 12.2% over six years. The net change in asset value between 2005 and 2011 was the result of a 2% overall loss of value due to reduction in the extent of ecosystems, combined with a net increase of 10% of value which is attributed to the changes in capacity for supply or the demand for services.

In physical terms, all service volumes apart from crop production and cultural services, decreased from 2005 to 2011. The aggregate value of all services also decreased from 2005 to 2011, except for crop production, cultural services and carbon retention (Table 6). The annual value of harvested wild resources decreased by over R500 million, ecosystem contribution to livestock production by just over R200 million and hydrological services by just under R200 million. These reductions are due to decreases in extent and condition of natural ecosystems and/or decreases in the demand for services. The aggregate increase in value of crop production was due to the combination of a 29.5% increase in cultivated area and a 0.7% increase in production per unit area. While the carbon retention value increased between 2005 and 2011, this was due to the changing price of carbon and not an overall increase in the change of total ecosystem carbon stored. In fact, ecosystem carbon decreased by 40.1 TgC (3.2%) over the six-year period. Increases in experiential value were due to increased numbers of users and/or price.

Discussion

Ecosystem values and changes over time

This study found that ecosystem services made a significant contribution when compared to GDP. Only a fraction of this value is currently recorded in the national accounts, primarily associated with formal agriculture and forestry production and ecosystem contributions to property value and tourism. The value of the additional service flows valued in the ecosystem accounts is significant and includes informal use of provisioning services, all regulating services and the recreational value not estimated in this study.

The study also showed, however, that the volumes of all provisioning and regulating services from natural landscapes decreased over the accounting period. These losses in services were likely due to a combination of the overharvesting of resources, overgrazing leading to denudation in some areas and bush encroachment in other areas, the spread of invasive alien plants and the loss of habitat due to expanding cultivation and human settlements. While these concerns have been well noted (Driver et al. 2015), this study has shown that their aggregate economic impact can be substantial. Furthermore, the losses were not fully portrayed in the asset valuation. While the effects of overexploitation on provisioning services were taken into account, it was implicitly assumed that the future ecosystem capacity to supply regulating services and reared animal production would remain unchanged. This is unrealistic given current rates of degradation. Future studies would also need to consider the sustainability of crop production. Given the significant losses in value of ecosystem services from natural ecosystem types over only six years, it is clear that further research is required to validate these findings and to seek urgent solutions. Indeed, the degradation of natural ecosystems could have significant impacts for the most vulnerable communities in the Province, who are reliant on them for their livelihoods, water and food security.

The interpretation of value changes is important. In spite of decreases in most of their services, the values of most natural systems increased as a result of the increased demand for tourism and carbon. In the case of nature-based tourism, value increased in spite of general evidence of a decline in the extent and condition of natural areas. Over time, it would be useful to consider the counterfactual or what tourism value might have been in the absence of the negative ecological trends. Similarly, for carbon, the increase in service value would have been greater if carbon retention had not decreased.

Completeness and reliability of estimates

This study has estimated the value of a range of ecosystem services, covering most broad types. We did not include all ecosystem services, some are only partially valued and the geographic coverage excludes the marine environment. Future iterations should expand these accounts to include other services such as local recreation, local climate regulation and air quality amelioration, as well as expanding the area to include coastal and marine ecosystems and their services. In addition, some of the methods used in this study are innovative and require further refinement and validation. For some services, compiling the biophysical aspects are the most limiting factor, while for others, economic data are limiting. Nevertheless, the study provides a solid beginning from which to progress.

In many cases, data were not ideal from a temporal or spatial perspective, especially for provisioning services. For example, the low spatial resolution and commercial focus of agricultural data, as well as lack of regularly updated data, created difficulties. There were very little data on wildlife ranching and forestry and none on bioprospecting. These types of data issues will be relatively straightforward to resolve once countries start planning for ecosystem accounting. Addressing other data shortcomings may require considerable effort, such as ecosystem condition, ecosystem capacity for resource provision, illegal offtake of endangered species and the sustainability of various types of ecosystem use. Our study showed that, taking sustainability of resource use into account, had a significant effect on asset value. It is easy to see that this could produce a more appropriate policy response than an account that assumes that values can be sustained in perpetuity.

Our valuation of cultural services focused on the use value aspect, which we termed experiential value. Both the aggregate tourism estimates and the estimated contribution of urban green space to property value were considered reliable and relatively complete estimates. However, we missed an entire component pertaining to the relatively local use of ecosystems, such as recreation, religious or cultural ceremonies. Such values can be estimated in future, based on travel cost surveys (e.g. Ezebilo 2016) or mobile phone or other big data (e.g. Jaung and Carrasco 2020) and would add value to ecosystems close to any rural or urban settlements, especially where inhabitants are wealthier.

The valuation of hydrological services involved modelling at a far greater scale than is typically the case. Clarification of these services is critical since they are widely interpreted in literature. We value the role that ecosystems play in saving the costs of water supply to people, including their influence on climate, but not as a source of water *per se* (see further comment below). Since the role that tropical forests play in influencing local or regional rainfall (Duku and Hein 2021) does not apply in the study area, we focused on the timing and quality of flows. We, therefore, developed a relatively rapid method for quantifying the flow regulation service which obviated the need for detailed water resources modelling in each water supply area (Turpie et al. in prep). Nevertheless, scaling the modelling up to national scale will likely be onerous and may require development of simpler hydrological models. Not all benefits were quantified in this study, including flow regulation for irrigation supply and flood attenuation outside eThekwini Municipality. Furthermore, the SEEA EA (United Nations 2021) now recommends that water supply is included as a provisioning service. Although not all authors see water itself as being supplied by ecosystems, its inclusion will greatly increase the overall asset value of ecosystems.

Data limitations meant that pollination had to be valued using a benefits transfer method, using a relationship developed elsewhere on the continent, which was far from ideal. It is almost certain that many of these estimates will eventually be replaced by better estimates, based on better data and better models. As this happens, it will be important to update the earlier estimates as best as possible in order to ensure continuity of the accounting dataset. While this may require an adjustment of policy responses as better information comes to light, it is still preferable to begin with some estimate than with none. Where it comes to natural ecosystems for which a change in land cover or use could lead to permanent damage, preliminary estimates should probably have been less conservative.

Value of carbon retention

The valuation of carbon stored in ecosystems is a critical concern in monetary ecosystem accounting. There has been a long-standing debate within the SEEA with regards to the framing and treatment of the carbon service and a consistent approach to its valuation (Remme et al. 2015, Edens et al. 2019, Keith et al. 2021). Accounting for the climate regulation service in monetary terms commonly involves using one of two approaches: the carbon trading price or the social cost of carbon, as recommended in the updated SEEA EA (United Nations 2021). Both of these represent a measure of avoided damage, a cost-based method which assumes there is a willingness to pay to avoid the associated damage (United Nations 2021). While using the carbon price seems preferable over the SCC because it comes from actual market transactions (Horlings et al. 2020,United Nations 2021), many countries (including South Africa) do not yet have mature carbon trading systems and the SCC is the only suitable alternative.

The SCC, used in this study, is an estimate of the current marginal damage cost of a tonne of carbon emitted. Applying this at scale to the gigatonnes of carbon in the landscape makes the assumption that this cost would still apply to the last tonne in the landscape. In aggregate, this value can rival the GDP of a country and is, hence, unrealistic in terms of proxy for exchange value. In reality, the technological replacement cost for this service, which is currently too high to be considered in valuation studies, may well decrease to well below this level by the time the last tonne of carbon is lost to the atmosphere. Thus, the carbon retention value in this study could be a gross overestimate and is one of the methods that needs a thorough review.

Will accounting values be useful for economic decision-making?

The SEEA-EA methods align with the SNA, which produce measures such as Gross Domestic Product (GDP). These are measures of production value, but are often misused as measures of welfare (Jorgenson 2018). Economic analysis used to guide project, programme or policy decisions often involve the estimation of changes in welfare for the gainers and losers involved. These welfare measures, which comprise the sum of producer and consumer surplus, tend to be larger than contributions to GDP, which are more closely aligned to incomes generated in production. Ecosystem accounting requires that values are expressed in terms of exchange values as per the SNA, so called since they are the incomes generated in the exchange of goods and services. This raises the concern that ecosystem accounting could be used incorrectly and lead to distorted decision-making with regard to the environment. However, it is worth noting firstly that in many cases, exchange values of ecosystem services will align closely with welfare values and, for the rest, that ecosystem accounting at a national scale will go a long way towards producing welfare estimates.

The valuation methods used in accounting are largely based on methods developed for cost-benefit analysis and, in reality, many estimates of the value of ecosystem services intended for cost-benefit analysis have, in fact, been exchange values, since they are often easier to compute. Based on the current state of the art, there would be little distinction between exchange value and welfare value estimates in the values of provisioning and regulating services. Provisioning services, as for this study, are typically estimated by subtracting costs from the value of production, focusing on either resource rents or producer surplus, but not consumer surplus. Regulating services, as for this study, tend to be valued in much the same way in both the accounts and for cost-benefit analysis, using an avoided costs approach. This has the same impact on production values and welfare values.

Cultural services are where value estimates are likely to differ most, since valuation methods for economic analysis have focused on deriving consumer surplus, especially for cases where access to (or viewing) nature is free or merely priced to cover costs. This study estimated the direct value added from domestic and international tourism expenditure (as reflected in the national accounts), as well as that from property value premiums attributed to green open space. An economic analysis would also be interested in the consumer surplus of domestic users. Estimates of international tourism value, therefore, need little or no adjustment. For the rest, revealed preference valuation studies (travel cost and hedonic pricing) can be adapted to provide welfare estimates through second stage analysis (for example, see Wolf and Klaiber 2021). More importantly, an economic analysis would also be expected to include non-use value, which is estimated using stated-preference surveys. Thus, in general, the work undertaken in compiling ecosystem service accounts is likely to be very useful in feeding into economic analysis, but will require augmentation, particularly for cultural services. Ultimately, we suggest that both should be derived during the accounting process, with the welfare values provided in supplementary tables. Meanwhile, it is important that the difference is clearly communicated to policy-makers. The monetary accounts should not be interpreted as being “the value of nature” (Hein et al. 2020).

Will monetary ecosystem accounts send the right message?

Related to the above, there are also concerns that monetary accounting of ecosystems may send the wrong policy message since anthropogenic landscapes are often more valuable, on average, than natural landscapes, as was found in this study. Accounting tables report the aggregate and average values of ecosystems, but do not report on marginal values. Although agricultural value may be higher than that of neighbouring ecosystems, subsequent conversions are likely to return decreasing values as they expand into less suitable areas. Conversely, the marginal value of natural ecosystems will increase as they contract into critical areas. For all else being equal, the optimal allocation of land use is the point where marginal values of each become equal. The analysis of potential policy impacts, therefore, involves projection of these non-linear area-value relationships in conjunction with the conversion of accounting values to welfare values. While accounting alone does not provide the full information required for such analyses, it goes a long way to providing information for them and will become increasingly valuable as long term datasets start to emerge in the process. It will also be important for future iterations of this work to draw on additional data inputs to capture changes in the capacity of anthropogenic, as well as natural landscapes, in the estimation of future flows and asset values.

Acknowledgements

This study was funded by the United Nations Environment Programme as part of the South African component of the international, EU-funded, Natural Capital Accounting and Valuation of Ecosystem Services project. Thanks to Gerhardt Bouwer and Robert Parry of Statistics South Africa and Ezemvelo KwaZulu-Natal Wildlife for assistance with data. We are grateful to William Speller and Julian Chow of UNEP, Bram Edens of United Nations Statistics Division and Mandy Driver of the South African National Biodiversity Institute for their valuable inputs. Thank you to Carl Obst and Rocky Harris for their constructive comments on an earlier version of the manuscript.

Ethics and security

Not applicable.

Author contributions

JKT: Conceptualisation and writing; GL: Analysis; JW: GIS, KS: Hydrology

Conflicts of interest

None.

References

- Addicott E, Fenichel E, Kotchen M (2020) Even the Representative Agent Must Die: Using Demographics to Inform Long-Term Social Discount Rates. Journal of the Association of Environmental and Resource Economists 7 (2): 379-415. https://doi.org/10.1086/706885
- Anderson R (2019) Basic Spatial Unit. Version 2019_01. April 2019. Statistics South Africa, Pretoria.
- Badura T, Ferrini S, Agarwala M, Turner K (2017) Valuation for Natural Capital and Ecosystem Accounting. Synthesis report for the European Commission. Centre for Social and Economic Research on the Global Environment. University of East Anglia, Norwich.
- Barros C, Moya-Gómez B, Gutiérrez J (2019) Using geotagged photographs and GPS tracks from social networks to analyse visitor behaviour in national parks. Current Issues in Tourism 23 (10): 1291-1310. https://doi.org/10.1080/13683500.2019.1619674
- Basson GR (2009) Management of siltation in existing and new reservoirs. General Report Q. 89. Proc. of the 23rd Congress of the Int. Commission on Large Dams CIGBICOLD (vol. 2).
- Blumenfeld S, Lu C, Christophersen T, Coates D (2009) Water, Wetlands and Forests. A Review of Ecological, Economic and Policy Linkages. Secretariat of the Convention on Biological Diversity and Secretariat of the Ramsar Convention on Wetlands, Montreal and Gland. CBD Technical Series No. 47.
- Cocks ML, Wiersum KF (2003) The significance of plant diversity to rural households in the Eastern Cape province of South Africa. Forests, Trees and Livelihoods 13: 39-58. https://doi.org/10.1080/14728028.2003.9752443
- Conte M, Ennaanay D, Mendoza G, Walter MT, Wolny S, Freyberg D, Nelson E, Solorzano L (2011) Chapter 6: Retention of nutrients and sediment by vegetation. In: Kareiva P, Tallis H, Ricketts TH, Daily GC, Polasky S (Eds) Natural Capital: theory and

practice of mapping ecosystem services. Oxford University Press Inc., New York. https://doi.org/10.1093/acprof:oso/9780199588992.003.0006

- de Groot RS, Wilson MA, Boumans RJ (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41 (3): 393-408. https://doi.org/10.1016/s0921-8009(02)00089-7
- Department of Environmental Affairs (2015) The South African National Terrestrial Carbon Sink Assessment. Pretoria, South Africa.
- Dovie DB, Shackleton CM, Witkowski ET (2002) Direct-use values of woodland resources consumed and traded in a South African village. International Journal of Sustainable Development & World Ecology 9 (3): 269-283. https://doi.org/10.1080/13504500209470122
- Driver A, Nel JL, Smith J, Daniels F, Poole CJ, Jewitt D, Escott BJ (2015) Land and ecosystem accounting in KwaZulu-Natal, South Africa. Discussion document for Advancing SEEA Experimental Ecosystem Accounting Project, October 2015. South African National Biodiversity Institute, Pretoria.
- Duku C, Hein L (2021) The impact of deforestation on rainfall in Africa: a data-driven assessment. Environmental Research Letters 16 (6). https://doi.org/10.1088/1748-9326/abfcfb
- Edens B, Elsasser P, Ivanov E (2019) Discussion paper 6: Defining and valuing carbon related services in the SEEA EEA. Paper submitted to the Expert Meeting on Advancing the Measurement of Ecosystem Services for Ecosystem Accounting, New York, 22-24 January 2019 and subsequently revised. Version of 15 March 2019. URL: https://seea.un.org/events/expert-meeting-advancing-measurement-ecosystem-services-ecosystem-accounting
- Edens B, Maes J, Hein L, Obst C, Siikamaki J, Schenau S, Javorsek M, Chow J, Chan JY, Steurer A, Alfieri A (2022) Establishing the SEEA Ecosystem Accounting as a global standard. Ecosystem Services 54 https://doi.org/10.1016/j.ecoser.2022.101413
- Ehrlich P, Mooney H (1983) Extinction, Substitution, and Ecosystem Services. BioScience 33 (4): 248-254. https://doi.org/10.2307/1309037
- Ezebilo EE (2016) Economic value of a non-market ecosystem service: an application of the travel cost method to nature recreation in Sweden. International Journal of Biodiversity Science, Ecosystem Services & Management 12 (4): 314-327. https://doi.org/10.1080/21513732.2016.1202322
- Forestry South Africa (2017) Industry Info: Statistical Data. Forestry South Africa.. URL: https://forestry.co.za/statistical-data/.
- Guswa AJ, Hamel P, Dennedy-Frank PJ (2017) Potential effects of landscape change on water supplies in the presence of reservoir storage. Water Resources Research 53 (4): 2679-2692. https://doi.org/10.1002/2016wr019691
- Haines-Young R, Potschin-Young M (2017) Common International Classification of Ecosystem Services (CICES) V5.1. Guidance on the Application of the Revised Structure.
- Hein L, Bagstad K, Obst C, Edens B, Schenau S, Castillo G, Soulard F, Brown C, Driver A, Bordt M, Steurer A, Harris R, Caparrós A (2020) Progress in natural capital accounting for ecosystems. Science 367 (6477): 514-515. https://doi.org/10.1126/science.aaz8901

- Horlings E, Schenau S, Hein L, Lof M, de Jongh L, Polder M (2020) Experimental monetary valuation of ecosystem services and assets in the Netherlands. CBS Den Haag and Wageningen University & Research..
- Jaung W, Carrasco LR (2020) Travel cost analysis of an urban protected area and parks in Singapore: a mobile phone data application. Journal of Environmental Management 261 https://doi.org/10.1016/j.jenvman.2020.110238
- Jorgenson D (2018) Production and Welfare: Progress in Economic Measurement. Journal of Economic Literature 56: 867-919. https://doi.org/10.1257/jel.20171358
- Kaschula SA, Shackleton CM (2009) Quantity and significance of wild meat off-take by a rural community in the Eastern Cape, South Africa. Environmental Conservation 36: 192-200. https://doi.org/10.1017/s0376892909990282
- Keith H, Vardon M, Obst C, Young V, Houghton RA, Mackey B (2021) Evaluating nature-based solutions for climate mitigation and conservation requires comprehensive carbon accounting. Science of The Total Environment 769 https://doi.org/10.1016/j.scitotenv.2020.144341
- Kunene N, Fossey A (2006) A survey on livestock production in some traditional areas of northern Kwazulu-Natal. Livestock Research for Rural Development. URL: http://www.utafoundation.org/lrrd1808/cont1.808 .htm
- Kuria FW, Vogel RM (2015) Global Storage-Reliability-Yield Relationships for Water Supply Reservoirs. Water Resources Management 29: 1591-1605. https://doi.org/10.1007/s11269-014-0896-4
- La Notte A, D'Amato D, Mäkinen H, Paracchini ML, Liquete C, Egoh B, Geneletti D, Crossman ND (2017) Ecosystem services classification: A systems ecology perspective of the cascade framework. Ecological Indicators 74: 392-402. https://doi.org/10.1016/j.ecolind.2016.11.030
- Lee JY, Tsou M (2018) Mapping spatiotemporal tourist behaviours and hotspots through location-based photo-sharing service (Flickr) data. In: Kiefer P, Huang H, Van de Weghe N, Raubal M (Eds) Progress in Location Based Services. Springer International Publishing, Cham. [ISBN 978-3-319-71470-7]. https://doi.org/10.1007/978-3-319-71470-7_16
- Le Maitre DC, Seyler H, Holland M, Smith-Adao L, Nel JL, Maherry A, Witthuser K (2018) Identification, Delineation and Importance of the Strategic Water Source Areas of South Africa, Lesotho and Swaziland for Surface Water and Groundwater. Report No. TT 743/1/18, Water Research Commission, Pretoria.
- Mahlobo BT (2016) Multi–criteria livestock assessment for sustainability of smallholder farms in Kwa-Zulu Natal. MSc Thesis in Sustainable Agriculture, Stellenbosch University.
- Meissner HH, Scholtz MM, Palmer AR (2013) Sustainability of the South African Livestock Sector towards 2050 Part 1: Worth and impact of the sector. South African Journal of Animal Science 43 (3): 282-297. https://doi.org/10.4314/sajas.v43i3.
- Melin A, Rouget M, Midgley J, Donaldson J (2014) Pollination ecosystem services in South African agricultural systems. South African Journal of Science 110: 1-9. https://doi.org/10.1590/sajs.2014/20140078
- Mokolobate MC, Scholtz MM, Calitz FJ (2017) Explaining the principle of large stock units and its implications on grazing capacity. Applied Animal Husbandry & Rural Development 10: 17-20.

- Nel J, Le Maitre D, Roux D, Colvin C, Smith J, Smith-Adao L, Maherry A, Sitas N (2017) Strategic water source areas for urban water security: Making the connection between protecting ecosystems and benefiting from their services. Ecosystem Services 28: 251-259. https://doi.org/10.1016/j.ecoser.2017.07.013
- Nkosi NZ (2017) Level of access to agricultural extension and advisory services by emerging livestock farmers in uThungulu district municipality, KwaZulu-Natal province. MSc Thesis in Agriculture, University of South Africa.
- Nordhaus W (2017) Revisiting the social cost of carbon. Proceedings of the National Academy of Sciences 114 (7): 1518-1523. https://doi.org/10.1073/pnas.1609244114
- Ogundiran OA, Monde N, Agholor I, Odeyemi AS (2014) The Role of Home Gardens in Household Food Security in Eastern Cape: A Case Study of Three Villages in Nkonkobe Municipality. Journal of Agricultural Science 6 (1): 129-136.
- 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 (5201): 1117-1123. https://doi.org/10.1126/science.267.5201.1117
- Potschin M, Haines-Young R, Fish R, Turner RK (2016) Routledge Handbook of Ecosystem Services. Routledge, Taylor & Francis Group, London; New York. https://doi.org/10.4324/9781315775302
- Remme R, Edens B, Schröter M, Hein L (2015) Monetary accounting of ecosystem services: A test case for Limburg province, the Netherlands. Ecological Economics 112: 116-128. https://doi.org/10.1016/j.ecolecon.2015.02.015
- Remme R, Lof M, de Jongh L, Hein L, Schenau S, de Jong R, Bogaart P (2018) The SEEA EEA biophysical ecosystem service supply-use account for the Netherlands. Wageningen University. URL: https://www.cbs.nl/-/media/_pdf/2018/23/psu_ess_nl.pdf
- Ricke K, Drouet L, Caldeira K, Tavoni M (2018) Country-level social cost of carbon. Nature Climate Change 8 (10): 895-900. https://doi.org/10.1038/s41558-018-0282-y
- Shackleton CM, Shackleton SE, Ntshudu M, Ntzebeza J (2002a) Direct use values of non-timber forest products from three rural villages in the Kat River Valley, Eastern Cape Province, South Africa. Journal of Tropical Forest Products 8: 45-65.
- Shackleton CM, Hassan R, De Wit M, Shackleton SE, Beukman R (2002b) Natural woodlands and forests: Contribution to national income and economic welfare. In: Hassan R (Ed.) Accounting for stock and flow values of woody land resources: Methods and results from South Africa. Centre for Environmental Economics and Policy (CEEPA), University of Pretoria, Pretoria, 53-72 pp.
- Shackleton CM, Timmermans HG, Nongwe N, Hamer N, Palmer NR (2007) Direct-use Values of Non-Timber Forest Products from two areas on the Transkei Wild Coast. Agrekon 46: 113-134. https://doi.org/10.1080/03031853.2007.9523764
- Shisanya SO, Hendriks SL (2011) The contribution of community gardens to food security in the Maphephetheni uplands, determined by the Household Food Insecurity Access Scale. Development Southern Africa 28 (4): 509-526. https://doi.org/10.1080/0376835x.2011.605568
- South African National Biodiversity Institute (2018) The Vegetation Map of South Africa, Lesotho and Swaziland 2006-2018. Mucina, L., Rutherford, M.C. and Powrie, L.W. (Eds). URL: http://bgis.sanbi.org/SpatialDataset/Detail/18
- South African Tourism (2005) 2005 Annual Tourism Report. Pretoria, South Africa.

- South African Tourism (2006) Annual Domestic Tourism report 2005. Pretoria, South Africa.
- South African Tourism (2011) 2011 Annual Tourism Report. Pretoria, South Africa.
- Statistics South Africa (2006) Census of commercial agriculture, 2002 – KwaZulu-Natal. Financial and production statistics. Report 11-02-03 (2002). Statistics South Africa, Pretoria, 109 pp.
- Statistics South Africa (2010) Tourism Satellite Account. Statistics South Africa, Pretoria.
- Statistics South Africa (2011) Census of commercial agriculture, 2007 – KwaZulu-Natal. Provincial statistics for selected products. Report 11-02-02 (2007). Statistics South Africa, Pretoria, 17 pp.
- Statistics South Africa (2012) National Census 2011. Statistics South Africa, Pretoria.
- Statistics South Africa (2014) Gross domestic product: Annual estimates 2004 – 2013, Regional estimates 2004 – 2013, Third quarter 2014. Statistical Release P0441. Statistics South Africa, Pretoria, 86 pp.
- Statistics South Africa (2015) Tourism Satellite Account. Statistics South Africa, Pretoria.
- Statistics South Africa (2016) Statistics South Africa Community Survey 2016. Statistics South Africa, Pretoria.
- Statistics South Africa (2018) Men, Women and Children. Findings of the Living Conditions Survey 2014/15. Statistics South Africa, Pretoria.
- Taylor WA, Lindsey PA, Davies-Mostert H (2015) An assessment of the economic, social and conservation value of the wildlife ranching industry and its potential to support the green economy in South Africa. The Endangered Wildlife Trust, Johannesburg.
- Tibesigwa B, Siikamäki J, Lokina R, Alvsilver J (2019) Naturally available wild pollination services have economic value for nature dependent smallholder crop farms in Tanzania. Scientific Reports 9 https://doi.org/10.1038/s41598-019-39745-7
- Tol RJ (2008) The Social Cost of Carbon: Trends, Outliers and Catastrophes. *T*he Open-Access, Open-Assessment E-Journal 2: 2008-2025. https://doi.org/10.5018/economics-ejournal.ja.2008-25
- 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. iSimangaliso Wetland Park Authority. Report.
- Turpie JK, de Wet J, Clark B, Orr K, Brown C, Joubert A, Reinecke K, Magoba R, Beuster H, Clarke T, Kotze D (2010) The nature, distribution and value of aquatic ecosystem services of the Olifants, Inkomati and Usutu to Mhlathuze Water Management Areas. Contract Report for Department: Water Affairs and Forestry, Pretoria, 378 pp.
- Turpie JK, Letley G, Chrystal R, Corbello S (2017a) The value of Durban's natural capital and its role in Green Urban Development. Part 1: A spatial valuation of the natural and semi-natural open space areas in eThekwini Municipality. World Bank Report. https://doi.org/10.1596/26765
- Turpie JK, Forsythe KJ, Knowles A, Blignaut J, Letley G (2017b) Mapping and valuation of South Africa's ecosystem services: A local perspective. Ecosystem Services 27: 179-192. https://doi.org/10.1016/j.ecoser.2017.07.008
- Turpie JK, Letley G, Schmidt K, Weiss J, O'Farrell, Jewitt D (2021) Towards a method for accounting for ecosystem services and asset value: Pilot accounts for KwaZulu-

Natal, South Africa, 2005-2011. NCAVES project report. URL: https://seea.un.org/content/knowledge-base

- Turpie JK, Weiss J, Letley G (in prep) Novel spatial modelling method for determining sustainable wild harvested resource use with regards to ecosystem service and asset value in an ecosystem accounting framework.
- Twine WC, Moshe D, Netshiluvhi TR, Siphungu V (2003) Consumption and direct-use values of savanna bioresources used by rural households in Mametja, a semi-arid area of Limpopo Province. South African Journal of Science 99: 467-473.
- United Nations, European Commission, Food and Agricultural Organization of the United Nations, Organisation for Economic Co-operation and Development, The World Bank (2014a) System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting. United Nations, New York.
- United Nations, European Commission, Food and Agricultural Organization of the United Nations, International Monetary Fund, Organisation for Economic Co-operation and Development, The World Bank (2014b) System of Environmental-Economic Accounting 2012 – Central Framework. United Nations, New York.
- United Nations (2017) SEEA Experimental Ecosystem Accounting: Technical Recommendations. Prepared as part of the joint UNEP / UNSD / CBD project on Advancing Natural Capital Accounting funded by NORAD. URL: https://seea.un.org/sites/seea.un.org/files/Presentations/Training_China_2017/seea_eea_tech_rec_final_v3.2_16oct2017.pdf
- United Nations, et al. (2021) System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing. URL: https://seea.un.org/ecosystem-accounting
- van den Bergh JCJM, Botzen WJW (2014) A lower bound to the social cost of CO2 emissions. Nature Climate Change 4 (4): 253-258. https://doi.org/10.1038/nclimate2135
- van Huyssteen E, Green C, Sogoni Z, Maritz J, McKelly D (2018) South African Functional Town Typology. 2. CSIR. URL: http://stepsa.org/socio_econ.html#Indicator
- Vogel R, Sieber J, Archfield S, Smith M, Apse C, Huber-Lee A (2007) Relations among storage, yield, and instream flow. Water Resources Research 43 (5). https://doi.org/10.1029/2006wr005226
- Vogel RM, Lane M, Ravindiran RS, Kirshen P (1999) Storage reservoir behavior in the United States. Journal of Water Resources Planning and Management 125 (5): 245-254. https://doi.org/10.1061/(ASCE)0733-9496(1999)125:5(245)
- Wolf D, Klaiber HA (2021) Willingness to Pay in Hedonic Pricing Models. Oxford Research Encyclopedia of Economics and Finance https://doi.org/10.1093/acrefore/9780190625979.013.583
- Wood SA, Guerry AD, Silver JM, Lacayo M (2013) Using social media to quantify nature-based tourism and recreation. Scientific Reports 3 (1). https://doi.org/10.1038/srep02976

Endnotes

*1 seea.un.org/file/19398/download?token=bkG5DCit

*2 Note that, for the SEEA EA, it has subsequently been decided to treat all carbon services as used by the government in which the ecosystems are located.