Towards a method for accounting for ecosystem services and asset value:

Pilot accounts for KwaZulu-Natal South Africa, 2005-2011

Updated Final Report January 2021

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Citation and reproduction

Citation: Turpie, J.K., Letley, G., Schmidt, K., Weiss, J., O'Farrell and 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: https://seea.un.org/content/knowledge-base

PREFACE AND ACKNOWLEDGEMENTS

This report was commissioned by the United Nations Environment Programme (UNEP) as part of the South African component of the international, EU-funded, Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) project. The NCAVES project is being carried out as a collaboration between UN Environment, United Nations Statistics Division (UNSD), the South African National Biodiversity Institute (SANBI) and Statistics South Africa (Stats SA).

UNEP commissioned Jane Turpie of Anchor Environmental Consultants (Anchor) and the Environmental Policy Research Unit of the School of Economics, University of Cape Town to assist with the compilation of pilot monetary ecosystem accounts at regional scale, as one of five test countries. Anchor also assisted with the compilation of the physical land and ecosystem accounts at national scale, metro scale and for protected areas, rhinoceroses and cycads, under contract to SANBI. All of this related work has been a collaborative effort involving a number of players. The work is of an exploratory nature, using simple assumptions where need be, in order to test approaches for compiling accounts; the results are therefore preliminary estimates to be improved on with time.

Acknowledgements go to the European Union for funding the NCAVES Project and the Delegation of the European Union to South Africa for supporting its implementation in South Africa and the UNSD and UN Environment for leading the NCAVES Project globally and supporting its management and implementation in South Africa.

This compilation of pilot monetary accounts was led by Jane Turpie, who devised the methodological approaches for both the physical and monetary aspects. Anchor Environmental staff Gwyneth Letley assisted with the economic valuation and write up, Kevin Schmidt undertook the hydrological modelling, Patrick O'Farrell undertook the InVEST modelling and Joshua Weiss assisted with the spatial analyses and mapping. The work was carried out using spatial land cover data compiled and supplied by Debbie Jewitt of Ezemvelo KZN Wildlife.

The study benefitted from the inputs of Gerhardt Bouwer and Robert Parry of Stats SA, Jeanne Nel of the University of Wageningen, Netherlands, and Amanda Driver and Aimee Ginsburg of SANBI. William Speller of UNEP, Julian Chow and Bram Edens of UNSD also reviewed an earlier draft.

The views, thoughts and opinions expressed in the text are not necessarily those of the United Nations or European Union or other agencies involved. The designations employed and the presentation of material including on any map in this work do not imply the expression of any opinion whatsoever on the part of the United Nations or European Union concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

EXECUTIVE SUMMARY

Introduction

Countries monitor their economic performance through the System of National Accounting (SNA), a standardised international methodology which delivers widely used indicators. While the SNA keeps track of man-made capital and goods and services, it does not keep track of natural capital. This has an important bearing for long term sustainability if natural capital is being depleted in the achievement of economic growth. Natural capital accounting applies national accounting principles to systematically measure and monitor ecosystems for decision making and planning. The primary purpose is to integrate information on ecosystem condition and ecosystem services with information in the standard national accounts and 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.

This study forms part of the Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) Project which involves the development of pilot physical and monetary ecosystem accounts. The NCAVES Project was launched in 2017 by the United Nations Statistics Division (UNSD) and United Nations Environment Programme (UNEP) with funding from the European Union (EU) with the aim to advance the knowledge agenda on environmental and ecosystem accounting and initiate pilot testing of System of Environmental-Economic Accounting (SEEA) Experimental Ecosystem Accounting (EEA).

The main aim of this study was to provide a first set of monetary ecosystem accounts at a sub-national scale in South Africa, following SEEA EEA guidelines. The accounts were compiled for the province of KwaZulu-Natal, focusing on inland terrestrial and aquatic ecosystems, including agricultural systems and urban green space, but not including marine ecosystems. Spatial models were developed for a predetermined set of ecosystem services in order to quantify and value the supply of ecosystem services from various ecosystem assets across the province.

Study Area

KwaZulu-Natal is one of the nine provinces of South Africa and occupies the sub-tropical north-eastern portion of the country covering 8% of the country's land area. It encompasses full catchment areas from source to sea, is home to several important water source areas and has the highest mountains in the country. The province has three main types of land tenure – Ingonyama Trust land (communal trust land), state protected areas, and land under private tenure. The Ingonyama Trust owns approximately 30% of the land area and in 2011, 8.7% of the province was under formal protection. KwaZulu-Natal has one metropolitan municipality, namely eThekwini, 10 district municipalities and, within those, 43 local municipalities.

KwaZulu-Natal has the among the highest diversity of ecosystem types in the country and supports a wealth of biodiversity. The province includes representation of most major terrestrial biomes. The six biomes include freshwater ecosystems, grassland, savanna, forests, Indian Ocean Coastal Belt and estuaries. The KwaZulu-Natal Land Cover series (2005-2011) classifies land cover into 47 classes and includes a measure of condition for major natural land cover classes. In 2011, urban areas and cultivation covered 6.1% and 25.3% the province, respectively, while the remainder was under natural vegetation and natural or man-made waterbodies.

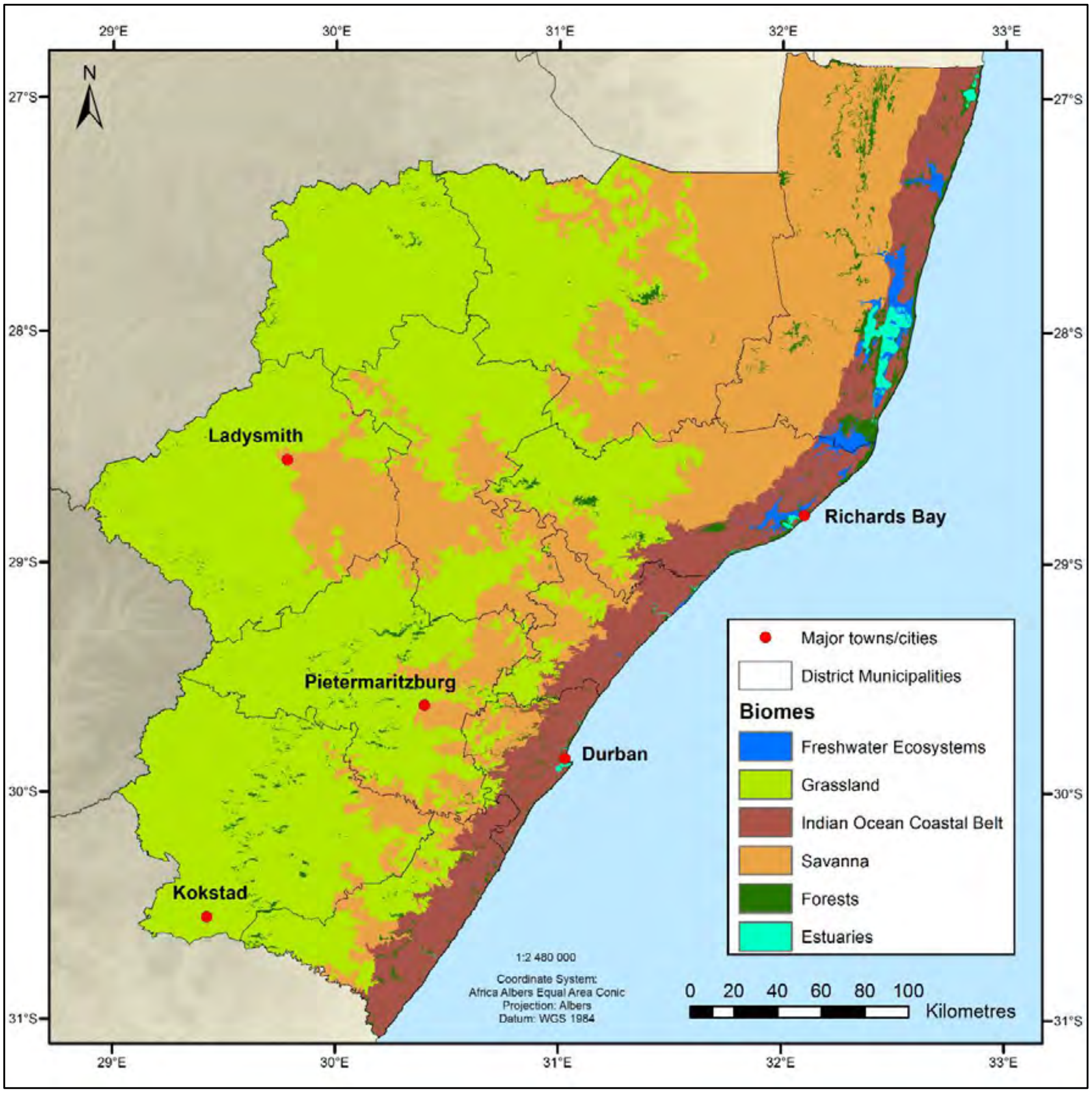

Figure 1. Map of the study area showing the main towns, district municipality boundaries and the biomes.

KwaZulu-Natal is the second largest contributor to South Africa's economy (after Gauteng) contributing 15.8% of GDP in 2011. Economic activity is concentrated in the metropolitan areas of Durban, Pietermaritzburg and Richards Bay. Manufacturing and tertiary industries (trade, business services and transport and communications) are the dominant sectors of the provincial economy. KwaZulu-Natal is the second most populous province in the country with a population of 10.3 million in 2011 and has a youthful population with high birth rates and lower-than-average life expectancy. Low working-age populations and high numbers of children and elderly give rise to large dependency ratios. Unemployment rates were at 33% in 2011 and were highest in northern KwaZulu-Natal.

KwaZulu-Natal contributes the largest share of adult poverty in the country, has the highest percentage share of households living in poverty and the highest share of child poverty in the country.

The main environmental issues facing KwaZulu-Natal include loss of natural habitat due to land use change such as intensive agriculture and urban expansion and land degradation through invasive alien plants, bush encroachment and erosion through loss of vegetative cover, hydrological alteration, overexploitation and poaching of endangered species, and pollution. Drivers of change include expansion of human settlements, changes in patterns of production and consumption, poor land management, poor spatial planning, poverty, and climate change.

Methodological Framework

These accounts were developed based on the System of Environmental Economic Accounting – Experimental Ecosystem Accounts (SEEA EEA). In this analysis, the accounts were developed using spatially-explicit estimates of the supply of ecosystem services in physical terms and their benefits in monetary terms. While some of the information is presented in mapped form, the accounts take the form of tables. In this study we present ecosystem supply and use accounts in physical terms; ecosystem supply and use accounts in monetary terms; and a monetary ecosystem asset account.

We estimated the value of most broad types of ecosystem services: production 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 selected valuation methods that are conceptually valid and that produce values that are consistent with the SNA. We proposed a viable way to deal with “intermediate ecosystem services” (from one ecosystem type to another). We valued actual use (rather than capacity to supply), but also developed a method to take future capacity to supply into account. We expressed the value of ecosystems in terms of exchange values (consistent with the principles of the SNA) rather than welfare values, but point out that these go a large part of the way to informing 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% and a time period of 25 years.

The accounts are presented at the scale of the province, disaggregated by biome (the broadest aggregation of ecosystem types). A spatial framework was created using data on land cover, land use and ecosystem extent. This spatial framework was supported through defining a basic spatial unit (BSU) that is internally homogenous in terms of its biophysical properties. A 100 x 100 m (1 ha) BSU grid, constructed by Statistics South Africa (Stats SA) that covers the entire South African land area, was used for this analysis. In this analysis, base raster layers (e.g. land use, biomes, census areas) were first projected and then snapped to the South African BSU grid, ensuring consistency across all ecosystem services and ensuring no overlaps for any given area per land cover class or ecosystem type.

Ecosystem services and benefits

Wild resources

Millions of South Africans harvest wild plant and animal resources for nutrition, health, energy and raw materials, particularly where there are limited economic opportunities. This is a major benefit in KwaZulu-Natal where resources are predominantly harvested by poorer households on a subsistence basis or to generate some cash income. There are large numbers of species involved, grouped here based on function. The value of wild resources was estimated based on information on habitat productive capacity, actual harvests from comparable areas, habitat condition, land ownership/tenure, accessibility and proximity to main sources of demand.

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
Wild animal resources	Nutrition	Bush meat
		Fisheries

The availability of wild resources was mapped in physical units per hectare based on land cover class, average stocks per hectare from the literature and land tenure. Demand for resources was based on household survey and census data and mapped to residential areas. Actual use (amount harvested) 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. Values were based on market prices per unit 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. Areas of expected overharvesting were also mapped.

The production of wild resources was estimated to be worth some **R3.7 billion** in 2005 and **R3.1 billion** in 2011 (in 2010 prices). Fuelwood was the most valuable resource harvested across the province followed by thatching grass and wild foods and medicines. The change in value of R541 million over the 6-year period suggests an annual rate of decline of 2.4% per year. The most significant loss in value was from the grassland and savanna biomes. This is likely due to degradation of these biomes through overgrazing, bush encroachment and expansion/densification of settlements into natural areas. Overharvesting of wild resources is a major concern and threatens the sustainability of the resource base which could have significant implications on household livelihoods in the future.

Reared animal production

A large proportion of KwaZulu-Natal is under rangeland with the mesic conditions favouring the production of cattle. Certain areas of the province also favour the commercial production of sheep and goats, and large tracts have been developed for wildlife ranching. Generally, there are high input production systems associated with private lands and ‘low input-low output’ systems on communal lands. The ecosystem service is the land’s contribution to production, which includes fodder provision, etc. This was not quantified, but as a proxy, we quantified the amount of production supported in terms of large stock units. The service was valued in terms of resource rent, which is the gross income from livestock production and livestock products less intermediate expenditure, labour costs, and user costs of fixed capital. This excluded non-consumptive wildlife enterprises, which were valued in terms of tourism value.

Information relating to both commercial and communal livestock production was inconsistent and patchy. We relied on the census of commercial agriculture (2002, 2007) at the level of magisterial district and long term quarterly provincial statistics on commercial livestock numbers to estimate commercial production. For communal livestock we used the agricultural household survey (2011) by census ward, provincial level data and information from household surveys to generate estimates of communal production. Wildlife production was calculated using information from the literature on offtake per hectare.

The resource rent value of commercial livestock production in KwaZulu-Natal was **R846 million** in 2005 and **R810 million** in 2011 and for communal livestock production was estimated to be **R824 million** in 2005 and **R658 million** in 2011 (all 2010 prices). Over the six-year study period there was a loss in production of R35 million in the commercial sector and R166 million in the communal sector. This loss in production was associated with the grassland and savanna biomes and is likely due to the losses in carrying capacity of rangelands due to poor grazing and fire management which is further exacerbated by changing climatic conditions (i.e. drought). Production on private wildlife ranches increased over the six-year period but was significantly lower on these farms, as many focus on tourism activities, the value of which is captured elsewhere.

Cultivation

In 2011, roughly a quarter of the province’s land cover comprised cultivated land types (croplands, orchards and forestry plantations). The service is the land contribution to crop production. As a proxy, the service was mapped in physical terms as production (tonnes) per hectare supported. It was valued in terms of resource rent, less the contribution of pollination services from adjacent natural ecosystems where these were valued (for small scale/subsistence production areas).

Commercial crop production and prices were from the 2002 and 2007 Agricultural Census and aligned to land cover classes within each district based on an average production value per crop grouping. Commercial silviculture production and prices were from Forestry South Africa (2011 data) as a single average value per hectare for the province. Communal crop production and prices were taken from studies in Northern KwaZulu-Natal and used as a single average value per hectare for the province. The low spatial resolution of the statistical data and the very limited data on communal farming was a major limitation.

The estimated value of *in situ* ecosystem inputs to crop production in KwaZulu-Natal was **R6.5 billion** in 2005 and **R7.5 billion** in 2011 (2010 prices). The most noticeable change over the six-year period saw sugarcane production in KwaZulu-Natal decrease by some 3.5 million tonnes, while subsistence production increased by 2.5 million tonnes. High input prices, drought and weak protection against imports not only deterred small-scale farmers from farming sugar but had a significant negative effect on production of existing sugarcane farms.

Nature-based tourism

The year-round warm weather and numerous outdoor activities make KwaZulu-Natal a leading tourism destination, both domestically and internationally. Nature-based tourism is an important component of the overall tourism sector in the province. It encompasses all tourist activities related to nature, both on land, along the coast and on inland waters. This study used a combination of tourism data, patterns of geotagged photographs uploaded to the internet, and spatial data on land cover and land ownership to estimate ecosystem contribution to nature-based tourism value in 2005 and 2011 in KwaZulu-Natal.

The proportion of tourism expenditure attributed to tourist attractions, as opposed to activities such as visiting family and friends, attending conferences, etc. was estimated for different types of domestic and foreign tourists based on information collated from the South African Tourism annual performance reports and from data collected in regional tourist offices. The estimated tourism expenditure on visiting attractions was converted into resource rent using conversion factors for 2005 and 2011 extracted from the South African Tourism Satellite Accounts and converted into 2010 prices. The resource rent of tourism spend on attractions in KwaZulu-Natal was R727 million in 2005 and R1.2 billion in 2011 (excluding the marine component). This value was spatially allocated in proportion to photo density (using the density of geotagged photos uploaded to Flickr) and apportioned based on land cover data using KwaZulu-Natal Land Cover 2005, 2011. The resource rent attributed to natural areas was estimated to be **R448 million** in 2005 and **R637 million** in 2011 – an increase of R266 million over six years. Natural areas contributed 64% and 57% of the total terrestrial tourism value in 2005 and 2011, respectively. Most of the nature-based tourism comes from the savanna and grassland biomes which are the dominant biomes within the main protected areas of the province.

Amenity value to property owners

Green open space areas in cities provide several benefits, such as opportunities for recreation and tourism, attractive views, habitat for wildlife, improved air quality and biodiversity conservation. The value that residents place on open space is reflected, to an extent, in private property and real estate markets. The property value of urban green open space areas in KwaZulu-Natal was estimated based on data used in the hedonic pricing study of eThekwini Municipality. The hedonic model from this detailed study was used in conjunction with census data to produce a simple property model that estimated the likely magnitude of premiums paid for green open space in other urban areas of KwaZulu-Natal.

The property model was applied to the census sub-places located within the urban residential areas of ten urban centres in KwaZulu-Natal identified using the CSIR Functional Town Typology. The model related the average property premium associated with urban green open space (natural open space areas and parks) to average household income. The total premium value was annualised and converted into 2010 Rands. The total property premium associated with urban green open space in KwaZulu-Natal in 2011 was estimated to be in the order of **R1 328 million per year.** eThekwini Municipality accounts for some 68% of this value. Using the South African real (inflation adjusted) property growth rate for the period 2005-2011, the property premium associated with urban green open space in 2005 was in the order of **R1 165 million** per year.

Carbon storage and sequestration

Ecosystems can make a significant contribution to global climate regulation through the sequestration and storage of carbon. When these systems are degraded or cleared, much of this carbon is released into the atmosphere. These emissions contribute to global climate change, which is expected to lead to changes in biodiversity and ecosystem functioning, changes in water availability, more frequent and severe droughts and floods, increases in heat-related illness and mortality, and impacts on agriculture and energy production.

Natural capital accounts will keep track of carbon stored in ecosystems (= carbon stocks) and the changes over time as a result of sequestration of carbon from the atmosphere by plants and releases of carbon back into the atmosphere that occur as a result of ecosystem disturbance (= carbon flows). Using the South African National Carbon Sink Assessment, total ecosystem carbon in KwaZulu-Natal was estimated for 2005 and 2011 and valued from both a South African perspective and a global perspective. Estimates of the global social cost of carbon vary greatly, with estimates now ranging from \$10 to \$1000/tCO_2. In this study we used the more conservative estimate from Nordhaus (2017) with a global SCC of US\$31/ tCO_2 and an estimate of US\$0.25 for South Africa's SCC, which is 0.8% of the global SCC estimate. The value of SCC is expected to increase over time as populations and per capita incomes grow and should ideally correspond to the year of the account as carbon retained in the environment will increase in real value over time. Therefore, the SCC estimate for 2020 was adjusted at a rate of 3% per year to derive different estimates for 2005 and 2011.

KwaZulu-Natal had an estimated 1237 Tg of carbon in 2005 and 1197 Tg of carbon in 2011. In 2005, the retained carbon stocks had an annualised global value of some **R29.9 billion** of which national benefits amount to **R236 million per year**. In 2011, these values were **R34.6 billion**, and **R273 million**, respectively.

Pollination

Agricultural support services include pollination of crops and control of crop pests by animals living in surrounding environments. Our analysis only includes pollination to crops and is restricted to pollination inputs to "home gardens" in the low-density settlements of communal areas of KwaZulu-Natal.

Crop pollination by insects is an essential ecosystem service that increases both the yield and the quality of crops. Of the crops grown in KwaZulu-Natal, many are wind-pollinated, including sugar and maize. However, several crops are directly dependent on insect pollination, including subtropical fruit crops such as mangoes, papayas, avocados and litchis, and nut trees such as macadamia, cashews and almonds. These crops are likely to benefit from wild colonies of bees occurring in natural or semi-natural vegetation surrounding home gardens. Because the wild pollination service is primarily provided by adjacent plots of land and not by the cropland itself and because this service is measured as the difference in output of service areas, this value can be attributed to surrounding natural habitat rather than the land under crops. Therefore, we account for pollination here as an input from surrounding ecosystems.

We used census data and community survey data and information from the literature to estimate the number of households in KwaZulu-Natal with home gardens and the average extent of these. We use land cover data to calculate the amount and type of natural vegetation surrounding each of the settlement areas. We used a benefit transfer approach to predict crop revenue from pollinator-dependent crops.

The percentage share of natural vegetation (forest, woodland, wooded grassland, dense bush and bushland) surrounding home gardens decreased by 2.6 percentage points (or 50 000 hectares).

Bushland and woodland were the most severely affected, with decreases in area of 2.7 and 0.9 percentage points, respectively. The value of wild pollination services to nature dependent subsistence home gardens in KwaZulu-Natal was estimated to be **R51.3 million** in 2005 and **R47.7 million** in 2011. Savanna ecosystems contribute the most to these values. The loss in natural vegetation surrounding these settlements is likely due to the expansion/densification of settlement areas and the impacts of overgrazing.

Flow regulation

Ecosystems can reduce variation in downstream river flows over the longer duration through infiltration and temporary storage in the catchment areas, reducing the need for built storage to achieve a given yield through the year. This service is likely to be more important where there is high seasonality in rainfall patterns, and especially where demand is strongly seasonal. Ecosystems can reduce temporal variation in water flows, particularly on an intra-annual basis, relative to the variation in rainfall. Without this service, dry season flows would be expected to be lower, increasing the need for storage. 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 model was run using rainfall data for 1979 to 2015, with monthly outputs generated for 1985 to 2015. Flow outputs were generated for a total of 565 sub-basins in the study area. The model was calibrated manually using flow data from gauging stations in the province as well as using SWAT-CUP. Simulations were run using each of the 2005 and 2011 KZN Land Cover data sets, and for corresponding land cover datasets that were generated with natural and cultivated land cover classes being converted to a barren state. The infiltration and temporary storage that is facilitated by ecosystems has the effect of changing the seasonal pattern of surface flows lower in the catchment. The service was measured in physical terms as the difference in infiltration relative to a barren scenario, in m^3 per ha. The benefits generated from the service were considered in terms of the avoided costs of water supply infrastructure for existing supply systems based on the theoretical relationship between storage, yield and reliability (the S-R-Y relationship) for a standardized reservoir, and in terms of the avoided costs of obtaining water for people that depend on instream flows for their domestic water supplies, based on monthly water demands by these households within each sub-catchment.

The value of this service in terms of infrastructure cost savings was estimated to be **R3.25 billion** in 2005 and **R3.12 billion** in 2011. The biggest change in the estimated average increment in water retention by ecosystems was observed in the grassland and forest biomes. This value is very preliminary and requires more sophisticated modelling. In addition, it was estimated that the flow regulation service performed by catchment ecosystems contributed an annual cost savings to poor households of some **R3 million** in 2005, and **R2.6 million** in 2011, which is significant in terms of the income levels of the beneficiary households. The most hard-hit areas, with more than 60% of the total instream value, were in the Mfolozi primary catchment in northern KwaZulu-Natal.

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 and maintenance costs at water treatment works. Natural vegetation and crops can reduce erosivity by stabilising soils and intercepting rainfall, thereby preventing erosion. Vegetated areas also capture the sediments that have been eroded from agricultural and degraded lands and transported in surface flows, preventing them from entering rivers. 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 InVEST Sediment Delivery Ratio model was used to estimate the average annual soil loss from the quaternary catchments of KwaZulu-Natal and the extent to which natural vegetation and cultivated land retains and captures sediment. Total sediment loss for each quaternary catchment was calculated in 2005 and 2011 relative to a barren landscape scenario in which the retention capacity of the natural vegetation and cultivated land was reduced. The difference in the sediment loss between the baseline and barren scenario provided the total amount of sediment being retained by the vegetated areas in each catchment. Due to the potentially large and costly damages of sedimentation we assumed that the service would be fully demanded, and we used the replacement cost of lost storage capacity (e.g. through raising the dam wall, constructing a substitute dam at a new site to make up the reduction in capacity or constructing check dams) to estimate its value. 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.

The hypothetical total loss of vegetative cover would increase sediment yields by an average of 1947% (0.23-45.92 tons/ha/y) in 2005 and 1538% (0.15-44.03 tons/ha/y) in 2011. Sediment retention varied between 0.30 and 233.90 tons/ha/y (mean = 24.94 tons/ha/y) and between 0.17 and 233.06 tons/ha/y (mean = 17.52 tons/ha/y) in 2005 and 2011, respectively. The value of erosion control by natural vegetation and cultivated land was estimated to be **R435.8 million** in 2005 and **R330.4 million** in 2011. The average per ha value in 2005 was R109.56 (R1.31-R1 027.44) compared to R88.61 per ha in 2011 (R0.80-R1 011.86). This difference was due to the net loss in natural vegetation over this time period, largely from the grassland and savanna biomes. The upper sub-catchments of the uThukela catchment and the sub-catchments of the Mvoti River north of Durban were found to be particularly important for retaining sediments**.**

Water quality amelioration

Anthropogenic introduction of nutrients into the landscape can lead to reduced water quality and the eutrophication of freshwater and marine ecosystems. This reduces the capacity of these systems to supply ecosystem services and increases water treatment costs. Natural vegetated systems can play an important role in the trapping of sediments and absorption and breakdown of organic and inorganic pollutants in surface and sub-surface water runoff. Wetlands are particularly well known for their capacity for water quality amelioration, but the service is also provided by terrestrial landscapes. Phosphorus is removed through sediment trapping and plant uptake, nitrogen is removed through denitrification and plant uptake, and pathogens are destroyed by UV radiation.

In this study, the impacts of natural vegetation and cultivated land on water quality were estimated using the SWAT hydrological model which was set up for KwaZulu-Natal. The model was set up to estimate changes in phosphorous loads at raw water treatment extraction points relative to a barren landscape scenario 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.

A total of just under 9800 tonnes of phosphorous was retained by the natural vegetation in the water supply catchments of KwaZulu-Natal in 2005 and 7876 tonnes were retained in 2011. The average annual phosphorous loadings increased by 31% over the six-year period, presumably due to increasing upstream agricultural inputs. The value of water quality amelioration was estimated to be a saving of **R20.4 million** (~59%) in 2005 and **R16.0 million** (~46%) in 2011, in the production cost of 667 000 ML provincially. The average per ha value ranged from < R1 to R352 in 2005 (mean = R9.56/ha) and from < R1 to R379 in 2011 (mean = R8.06/ha). This service was found to be particularly important in the uThukela catchment.

Overall results and discussion

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 in those years if global carbon values are used, and R17.6 billion and R18.2 billion or 5% and 4% of provincial GDP if the social cost of carbon to South Africa is used (Table I). Because of the large difference between the global and national values, and because the global carbon values dwarf the other ecosystem services, the aggregate ecosystem service flow and asset value table was compiled using each of these values. However, the following discussion is based on the results associated with global carbon values.

In 2011, the bulk of the value of ecosystem services was produced by regulating services (73%). Provisioning services and cultural services accounted for 23% and 4% of the total value, respectively. The global value of carbon storage dominated the estimated value of ecosystem services, accounting for 66% of the total value in 2011. This was followed by the land contribution to crop production (14%), the provisioning of wild resources (6%), flow regulation (6%) and experiential value (4%). The other hydrological services accounted for just 1% of the total value of ecosystem service flows in 2011. It is possible that these values are underestimated due to the very conservative methods used.

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%), savanna biome (27%) and cultivated land (26%). The Indian Ocean Coastal Belt biome accounted for 4% which was mainly due to the importance of forest and dense savanna vegetation in this biome for carbon storage and pollination services. Landscaped urban parks produced 48% of the value of cultural ecosystem services. Grassland and savanna 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.

Table I: Value of ecosystem service flows and associated asset values in 2005 and 2011; values in 2010 R millions. Note that the table shows both the global carbon values as well as national carbon values and the respective total flows and asset values associated with each.

Class	Ecosystem service	2005		2011	
		Annual flow R millions	**Asset value R millions**	**Annual flow R millions**	**Asset value R millions**
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 (global value)	29 922.56	484 745.42	34 579.34	560 185.33
	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**
Value of flows and asset values in 2005 and 2011 when using national carbon values					
Regulating	Carbon storage (national)	236.39	3 829.49	273.18	4 425.46
Total		**17 572.38**	**256 391.56**	**18 172.74**	**271 303.59**

The asset value of ecosystems, as derived from the value of annual flows using the net present value approach, was estimated at **R737 billion** and **R827 billion**, respectively (Table I), an increase in value of 12.2% over six years. The net change is 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. The effect of increased demand is reduced by decreased capacity through reduction in ecosystem extent and/or ecosystem degradation. Natural areas have been reduced by the expansion of cultivation and settlements. Of the remaining natural areas, degradation has been driven largely by poor grazing management and poor agricultural practices, particularly in the communal areas. Poor land management has exacerbated bush encroachment and the spread of invasive alien plants. These processes are being exacerbated by poverty and the adverse impacts of climate change.

Provisioning services were the most comprehensively valued services, although they did not include the legal commercial harvest of natural resources (likely to be small), or the illegal harvesting of high value, endangered species (likely to be large but unsustainable). We also did not have an estimate for the value, if any, of provision of genetic resources of use in horticulture, medicine or other areas. Little, if any, research has been carried out in this regard.

Our valuation of cultural services focused on the use value aspect, which we termed experiential value. Non-use values are not included in the SEEA EA although allowance is made for recording relevant physical information related to non-use flows in the physical supply-use tables, under a separate flow "ecosystem and species appreciation." Both the aggregate tourism estimates and the estimated contribution of urban green space to property value were considered reliable and relatively complete estimates.

While this study included a broad coverage of regulating services in order to pilot these methods, it has not captured all aspects and all locations. In some cases, such as the control of agricultural pests by animals living in neighbouring natural ecosystems, there was no information at all. In the case of pollination, a lack of detailed data, including spatial data, on both commercial and subsistence crop production meant limiting the estimate of crop pollination services to the benefits to household subsistence cultivation. There is likely to be some additional pollination benefit to commercial and small-scale agricultural production. Our estimate of pollination value is therefore highly conservative. There is still much debate within the SEEA with regards to the framing of the carbon service and a consistent approach to its valuation. This requires further attention. Three of the four hydrological services were only considered for natural land, and not agricultural or urban green space. Further work will be needed to estimate where and to what extent cultivated land contributes to seasonal flow regulation, nutrient and sediment retention. In addition, the maintenance of low flows was valued in terms of formal water supply and the availability of water for households that collect their water from rivers, but did not include an estimate of the value to commercial irrigators, which could be substantial, especially given the growth in irrigated crop area over time. Flood attenuation services were only considered for green open space within eThekwini municipality, so further work will be needed to extend this to all areas where the service might be of value. The catchment areas upstream of this, which stretch all the way to the inland border of KwaZulu-Natal, are likely to have a much higher value in this regard. There are also other large urban areas that are likely to benefit from flood attenuation. We have also excluded critical habitat value, including nursery value of the province's large number and area of estuaries.

Conclusions and recommendations

The results of this study are incomplete and preliminary, and so need to be interpreted with due caution. We have demonstrated the compilation of monetary accounts for ecosystems on a large scale using various statistical data sources and valuation methods, and produced a useful starting point for monetary ecosystem accounting at a national scale in South Africa. However, important challenges remain in achieving this, especially with regards to refinement and standardisation of land cover and ecosystem condition data, agreeing on functional vegetation groups as a level in the ecosystem classification, standardising ecosystem types used for summarising ecosystem service values, and in the refinement of assumptions, modelling techniques and valuation methods. Extending the analysis to include the gaps in ecosystem service types and in geographic coverage of certain services is also an important challenge that needs to be addressed going forward.

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. While this is a significant contribution, it is apparent that the values of many of the services have decreased over time, particularly the grassland and savanna biomes which dominate the landscape. The annual value of harvested wild resources decreased by over R500 million in these two biomes, ecosystem contribution to livestock production by just over R200 million, and hydrological services by just under R200 million. While the carbon storage 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 over the six-year period. Nature-based tourism increased by some R189 million over the same period. Cultivated land also increased in extent and aggregate value over the six-year period.

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), followed by the agriculture, forestry and fisheries sector (19%) and households (11%). Approximately 2% of the total value flows to the trade, catering and accommodation sector, which is also an important source of employment in the province. Reductions in ecosystem stocks and the associated loss in ecosystem services will have the highest impact for these economic users. This is an important result to consider given that a significant number of households across KwaZulu-Natal are reliant on natural ecosystems for maintaining livelihoods and food security.

The losses in the value of ecosystem services from natural ecosystems were 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, human settlements and other activities such as mining. While these trends are generally well-known, this study has shown that their aggregate economic impact can be substantial. Furthermore, these losses were not fully portrayed in this study, since the sustainability of use of provisioning services was only accounted for in the case of the informal harvesting of natural resources. Future studies would also need to consider the sustainability of reared animal and crop production. Habitat degradation and loss, which largely comes about in the poorly-managed pursuit of provisioning services, has had a measurable negative effect on the supply of every type of regulating service, including carbon storage which is of global concern. 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.

We also note that, while there are theoretical differences in the values used for accounting (measuring changes in production) and economic analysis (measuring changes in societal welfare), there is a substantial overlap in the approaches used, and in general, the work undertaken in compiling ecosystem service accounts is likely to be very useful in feeding into economic analysis. The latter will require augmentation, however, particularly for the valuation of cultural services.

This study has estimated the value of a range of ecosystem services, covering most broad types. While the scope is not yet comprehensive due to both data and time constraints, it provides a solid platform from which to progress. This study does not include all ecosystem services, and some are only partially valued, and the geographic coverage is incomplete. The study also does not extend in the marine environment and does not include some important estuarine services. Some of the methods used in this study are innovative and require further refinement and validation. In many cases, the data used in the study have not been ideal in terms of quality, time or spatial location. In some cases, time consuming work is needed to refine the data and assumptions in models. In addition, reliable spatial information to produce or validate estimates of ecosystem condition and sustainability of harvesting, grazing and cultivation practices is largely lacking.

Setting up monetary ecosystem accounts therefore requires a considerable effort in collating appropriate monitoring data as well as in compiling reliable modelling frameworks for the estimation of values. Further discussion is also needed to refine the way in which the accounting tables are compiled and summarised in order to be useful for decision and policy makers. Finally, there will be some considerations in terms of land cover data should this provincial-scale pilot be extended to a national-scale effort. The following recommendations are made:

1. Produce an **enhanced national land cover data series**, which is detailed and consistent, and incorporates non-satellite derived data on wetlands and ecosystem condition, at 5 year intervals in sync with census data, focusing on quality over frequency and applicable to all provinces for sub-national use;
2. Produce better **agricultural and resource use statistics** at a high spatial resolution at 5-year intervals in sync with census data, including small scale and subsistence activities, and augmented with non-census derived data on livestock and crop areas, as well as co-ordinated data on resource harvesting from protected areas;
3. Produce nationally-consistent, **fine scale tourism statistics** on visitor activities, as well as statistics for major paying natural attractions;
4. Produce centrally collated **statistics from water supply managers**, including data on water treatment plants and reservoir sedimentation;
5. Undertake **further research and modelling** to improve methods and estimates and fill gaps, including improving on and extending the hydrological modelling; filling gaps on the value of critical habitats and marine ecosystem services, undertaking empirical studies to validate model estimates, and having a think tank to review the novel methods used;
6. **Explore useful ways to summarise the findings**, for example in terms of ecosystem types.
7. **Explore key policy messages** that may emerge from the monetary values associated with particular ecosystem services.

ABBREVIATIONS AND ACRONYMS

BSU	Basic spatial unit
CICES	Common International Classification of Ecosystem Services
CPI	Consumer Price Index
CSIR	Council for Scientific and Industrial Research
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
D'MOSS	Durban Metropolitan Open Space System
EEA	Experimental Ecosystem Accounting
EPCPD	Environmental Planning and Climate Protection Department
FEGS-CS	Final Ecosystem Goods and Services Classification System
GDP	Gross Domestic Product
HRU	Hydrologic Response Unit
IAP	Invasive Alien Plant
IPCC	Intergovernmental Panel on Climate Change
KZN	KwaZulu-Natal
LSU	Livestock Unit
LULC	Land Use Land Cover
MEA	Millennium Ecosystem Assessment
MUSLE	Modified Universal Soil Loss Equation
NCAVES	Natural Capital Accounting and Valuation of Ecosystem Services
NESCS	National Ecosystem Services Classification System
NIAPS	National Invasive Alien Plant Survey
NPV	Net Present Value
SA	South Africa
SANBI	South African National Biodiversity Institute
SAPECS	Southern African Program on Ecosystem Change and Society
SEEA	System of Environmental-Economic Accounting
SNA	System of National Accounting
Stats SA	Statistics South Africa
SWSA	Strategic Water Source Area
SWAT	Soil and Water Assessment Tool
TEEB	The Economics of Ecosystems and Biodiversity
UN	United Nations
UNE	United Nations Environment
UNSD	United Nations Statistics Division
VFR	Visiting Friends and Relatives
WSA	Water Source Area

TABLE OF CONTENTS

1 INTRODUCTION 1

1.1 ECOSYSTEM ACCOUNTING 1

1.2 THE NCAVES PROJECT 1

1.3 KZN PILOT MONETARY ECOSYSTEM ACCOUNTS 2

1.4 STRUCTURE OF THE REPORT 3

2 STUDY AREA 4

2.1 EXTENT, TOPOGRAPHY AND DRAINAGE 4

2.2 LAND TENURE AND ADMINISTRATIVE SUBDIVISIONS 5

2.3 NATURAL VEGETATION, LAND USE AND LAND COVER 8

2.4 WATER SUPPLY CONTEXT 11

2.5 ECONOMY 13

2.6 DEMOGRAPHIC AND SOCIOECONOMIC STATISTICS 16

2.7 ENVIRONMENTAL ISSUES 19

2.7.1 Loss of natural habitat due to land use change 19
2.7.2 Loss of vegetation and soil cover 20
2.7.3 Bush encroachment 21
2.7.4 Invasive alien plants (IAPs) 23
2.7.5 Hydrological alteration 24
2.7.6 Poaching and overexploitation of species 24
2.7.7 Solid waste, air and water pollution 25

3 METHODOLOGICAL FRAMEWORK 26

3.1 OVERVIEW 26

3.2 ECOSYSTEM SERVICES 28

3.3 VALUATION 31

3.4 SPATIAL FRAMEWORK 34

3.5 ACCOUNTING TABLES 35

4 ECOSYSTEM SERVICES AND BENEFITS 37

4.1 WILD RESOURCES 37

4.1.1 Overview of the service 37
4.1.2 Data and methods 37
4.1.3 Results and discussion 46

4.2 *IN SITU* INPUTS TO REARED ANIMAL PRODUCTION 57

4.2.1 Overview of the service 57
4.2.2 Data and methods 58
4.2.3 Results and discussion 62

4.3 *IN SITU* INPUTS TO CROP PRODUCTION 68

4.3.1 Overview of the service 68

4.3.2 Data and methods 68
4.3.3 Results and discussion 71

4.4 EXPERIENTIAL VALUE (RECREATIONAL AND RELATED USE) 74

4.4.1 Ecosystem contribution to tourism 74
4.4.2 Ecosystem contribution to property value 83

4.5 CARBON STORAGE AND SEQUESTRATION 87

4.5.1 Overview of the service 87
4.5.2 Data and methods 87
4.5.3 Results and discussion 90

4.6 CROP POLLINATION 93

4.6.1 Overview of the service 93
4.6.2 Data and methods 94
4.6.3 Results and discussion 96

4.7 FLOW REGULATION (MAINTENANCE OF BASE FLOWS) 98

4.7.1 Overview of the service 98
4.7.2 Data and methods 101
4.7.3 Results and discussion 107

4.8 SEDIMENT RETENTION 112

4.8.1 Overview of the service 112
4.8.2 Data and methods 113
4.8.3 Results and discussion 115

4.9 WATER QUALITY AMELIORATION 119

4.9.1 Overview of the service 119
4.9.2 Data and methods 120
4.9.3 Results and discussion 125

4.10 FLOOD ATTENUATION (ETHEKWINI ONLY) 130

4.10.1 Overview of the service 130
4.10.2 Data and methods 130
4.10.3 Results and discussion 133

5 ECOSYSTEM SERVICE AND ASSET ACCOUNTS 134

5.1 ECOSYSTEM SERVICE SUPPLY AND USE ACCOUNTS (IN PHYSICAL TERMS): SUPPLY ACCOUNTS 135

5.2 ECOSYSTEM SERVICE SUPPLY AND USE ACCOUNTS (IN PHYSICAL TERMS): USE ACCOUNTS 136

5.3 ECOSYSTEM SERVICE SUPPLY AND USE ACCOUNTS (IN MONETARY TERMS): SUPPLY ACCOUNTS 137

5.4 ECOSYSTEM SERVICE SUPPLY AND USE ACCOUNTS (IN MONETARY TERMS): USE ACCOUNTS 138

5.5 ECOSYSTEM MONETARY ASSET ACCOUNT 139

6 DISCUSSION 140

6.1 COMPLETENESS AND RELIABILITY OF ESTIMATES 140

6.1.1 Provisioning services 140
6.1.2 Cultural services 141
6.1.3 Regulating services 142

6.2 COMPARISON WITH WELFARE VALUE ESTIMATES 144

6.3 AGGREGATE VALUES 145
6.4 SENSITIVITY TO DISCOUNTING AND TIME HORIZON 146
6.5 ATTRIBUTING VALUE TO ECOSYSTEM TYPES 146
6.6 TRENDS AND RELATIVE EFFECTS OF ECOSYSTEM EXTENT VS CAPACITY AND DEMAND 149

7 CONCLUSIONS AND RECOMMENDATIONS 151

7.1 KEY FINDINGS AND THEIR IMPLICATIONS 151
7.2 RECOMMENDATIONS FOR FURTHERING NATURAL CAPITAL ACCOUNTING 153
7.2.1 Produce an enhanced land cover data series 153
7.2.2 Produce better agricultural and resource use statistics at a high spatial resolution 154
7.2.3 Produce nationally-consistent, fine scale tourism statistics 154
7.2.4 Produce centrally collated statistics from water supply managers 155
7.2.5 Undertake further research and modelling to improve methods and estimates and fill gaps 155
7.2.6 Maintain a flexible approach 156
7.2.7 Explore useful ways to summarise the findings 156

8 REFERENCES 157

A1 APPENDIX 1. ABBREVIATED SUMMARY OF CICES 5.1 174

A2 APPENDIX 2. ASSUMPTIONS USED TO ESTIMATE HOUSEHOLD DEMAND FOR WILD RESOURCES 176

A3 APPENDIX 3. ASSUMPTIONS ON THE STOCKS OF NATURAL RESOURCES 178

A3.1 FUELWOOD, POLES AND TIMBER 178
A3.2 THATCHING GRASS, REEDS, SEDGES AND PALM LEAVES 179
A3.3 WILD PLANT FOODS AND MEDICINES 179
A3.4 WILD ANIMAL RESOURCES 180

A4 APPENDIX 4. DETAILED DATA SOURCES FOR LIVESTOCK 182

A4.1 COMMERCIAL FARMLAND 182
A4.2 COMMUNAL AREAS 183

A5 APPENDIX 5. MODELLING OF HYDROLOGICAL SERVICES 186

A5.1 INTRODUCTION 186
A5.2 OVERVIEW OF THE SWAT MODEL 186
A5.3 INPUT DATA 187
A5.3.1 History 188
A5.3.2 Climate data 189
A5.4 WATERSHED DELINEATION 190
A5.5 DEFINITION OF HYDROLOGIC RESPONSE UNITS (HRUS) 190
A5.6 SIMULATION AND MODEL CALIBRATION 192
A5.6.1 Manual calibration of model 192
A5.6.2 SWAT-CUP calibration 198
A5.7 LIMITATIONS 200

1 INTRODUCTION

1.1 Ecosystem accounting

Countries monitor their economic performance through the System of National Accounting (SNA), a standardised international methodology which delivers widely used indicators such as the Gross Domestic Product (GDP). While the SNA keeps track of man-made capital and goods and services, it does not keep track of natural capital. This has an important bearing for long term sustainability if natural capital is being depleted in the achievement of economic growth. In response to this, the UN has embarked on the development of methods to keep track of natural capital as an extension of the SNA. This began with the development of natural resource accounts, which accounted for biotic and abiotic resource stocks and flows, such as fisheries, forestry, minerals and water. These accounts have already been compiled in many countries, including South Africa. More recently, attention has been turned to accounting for ecosystems in their entirety, and the full range of ecosystem services that they supply.

Ecosystem accounting is an element of natural capital accounting that is grounded in the System of Environmental-Economic Accounting (SEEA). It applies national accounting principles to systematically measure and monitor ecosystems for decision making and planning (UN 2017, Remme *et al.* 2018). In natural capital accounting, ecosystems are considered as assets that provide ecosystem services to people, measured in both physical and monetary terms (Hein *et al.* 2016). Ecosystem accounting therefore encompasses four main areas: ecosystem extent, condition, ecosystem services and valuation.

The primary purpose of valuation in monetary terms is to integrate information on ecosystem condition and ecosystem services with information in the standard national accounts (UN 2017). Indeed, the SEEA ecosystem accounting framework allows data on ecosystems and biodiversity to be integrated directly with economic data contained within the System of National Accounts (SNA). Therefore, one of the main aims of the framework 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 (UN 2017). Recognising ecosystem services as outputs produced by ecosystem units allows for them to be recorded as being transacted within an accounting system.

1.2 The NCAVES Project

This study forms part of the Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) Project which involves the development of pilot physical and monetary ecosystem accounts in five countries, including South Africa. The NCAVES Project was launched in 2017 by the United Nations Statistics Division (UNSD) and United Nations Environment Programme (UNEP) with funding from the European Union (EU). It aims to advance the knowledge agenda on environmental and ecosystem accounting and initiate pilot testing of System of Environmental-Economic Accounting (SEEA) Experimental Ecosystem Accounting (EEA), with a view to improving the management of natural biotic resources, ecosystems and their services at the national level as well as mainstreaming biodiversity and ecosystems in national level policy, planning and implementation.

In South Africa, the NCAVES Project is being led by Statistics South Africa (Stats SA) and the South African National Biodiversity Institute (SANBI). Funding for this component (the development of pilot monetary accounts in South Africa) is from the European Union channelled via the United Nations Environment Programme (UNEP). Deliverables of the overall NCAVES project in South Africa include:

- Pilot ecosystem service and monetary accounts at sub-national scale (KwaZulu-Natal province; this study);
- Physical ecosystem accounts at national scale (national land and terrestrial ecosystem accounts) and subnational scales (protected areas, metropolitan areas);
- Pilot species accounts for selected plants and animals;
- Contributing to the global research agenda of the SEEA EEA;
- Testing selected SEEA EEA indicators in the context of the 2030 Sustainable Development Agenda, Aichi Targets or other international indicator initiatives;
- A national forum and national training workshop to enhance capacity and enlarge the ecosystem accounting community of practice; and
- A national strategy for advancing environmental-economic accounting.

1.3 KZN pilot monetary ecosystem accounts

The main aim of this study was to provide a first set of monetary ecosystem accounts at a subnational scale in South Africa, following SEEA EEA guidelines. The accounts were compiled for the province of KwaZulu-Natal, building on the KZN physical land an ecosystem extent and condition accounts that have been compiled for 2005, 2008 and 2011 by Driver *et al.* (2015), as well as recent ecosystem service valuation studies carried out at national scale (Turpie *et al.* (2017a) and for the eThekwini Municipality in KwaZulu-Natal (Turpie *et al*. 2017b).

This study focused on terrestrial and inland aquatic ecosystems, including agricultural systems, but did not include the marine ecosystems of this coastal province. Spatial models were developed for a predetermined set of ecosystem services in order to quantify and value the supply of ecosystem services from various ecosystem assets across the province. The spatial models were used to highlight the spatial variability in the supply and use of different ecosystem services even within a given ecosystem type. Using these spatial models and the biophysical supply tables, monetary supply and use tables for different economic units (use of ecosystem services and their products by different economic sectors) were generated. Finally, the ecosystem monetary asset accounts were created to take account of changes in stocks of ecosystem assets across the accounting periods.

1.4 Structure of the report

The document is structured as follows:

- Section 2 provides context by describing the study area in terms of topography, geography, environment and socioeconomics. The main environmental issues in KwaZulu-Natal are also outlined here.
- Section 3 outlines the methodological framework, providing an overview of the spatial framework and ecosystem service classification framework used in this study, the ecosystem services included in the valuation, the valuation approach and the time frame and accounting framework.
- Section 4 presents an explanation of each of the ecosystem services that are accounted for in this study, followed by the methods used for quantification and valuation and the physical and monetary accounting tables generated for each of the two time periods (2005 and 2011). In some cases the results also include graphical outputs.
- Section 5 presents an overall summary and discussion of the valuation results, including the completeness and reliability of the estimates. It also touches on the computation of asset values, the comparison with welfare value estimates, and the way in which the data are summarised to ecosystem type.
- Section 6 presents the ecosystem supply and use accounts
- Section 7 presents the ecosystem monetary asset account.
- Section 8 highlights the key findings of the study and provides recommendations for the way forward.
- Appendix 1 provides an abbreviated summary of CICES 5.1; Appendix 2 outlines assumptions used in estimating household demand for wild resources; Appendix 3 outlines the assumptions on the stocks of natural resources; Appendix 4 presents more detail on the data used in estimating livestock and ranched wildlife production; and Appendix 5 provides the detailed methodology for the hydrological modelling.

2 STUDY AREA

2.1 Extent, topography and drainage

KwaZulu-Natal is one of the nine provinces of South Africa. It occupies the sub-tropical north-eastern portion of the country and covers approximately 94 000 km^2 or 8% of South Africa's land area. It is bounded to the north by Mozambique and Swaziland, to the west by Lesotho and the Free State Province, to the south by the Eastern Cape Province and to the east by the Indian Ocean. It encompasses full catchment areas from source to sea. The Drakensberg range in the west has the highest mountains in the country, with several peaks reaching over 3000 metres (Figure 2.1).

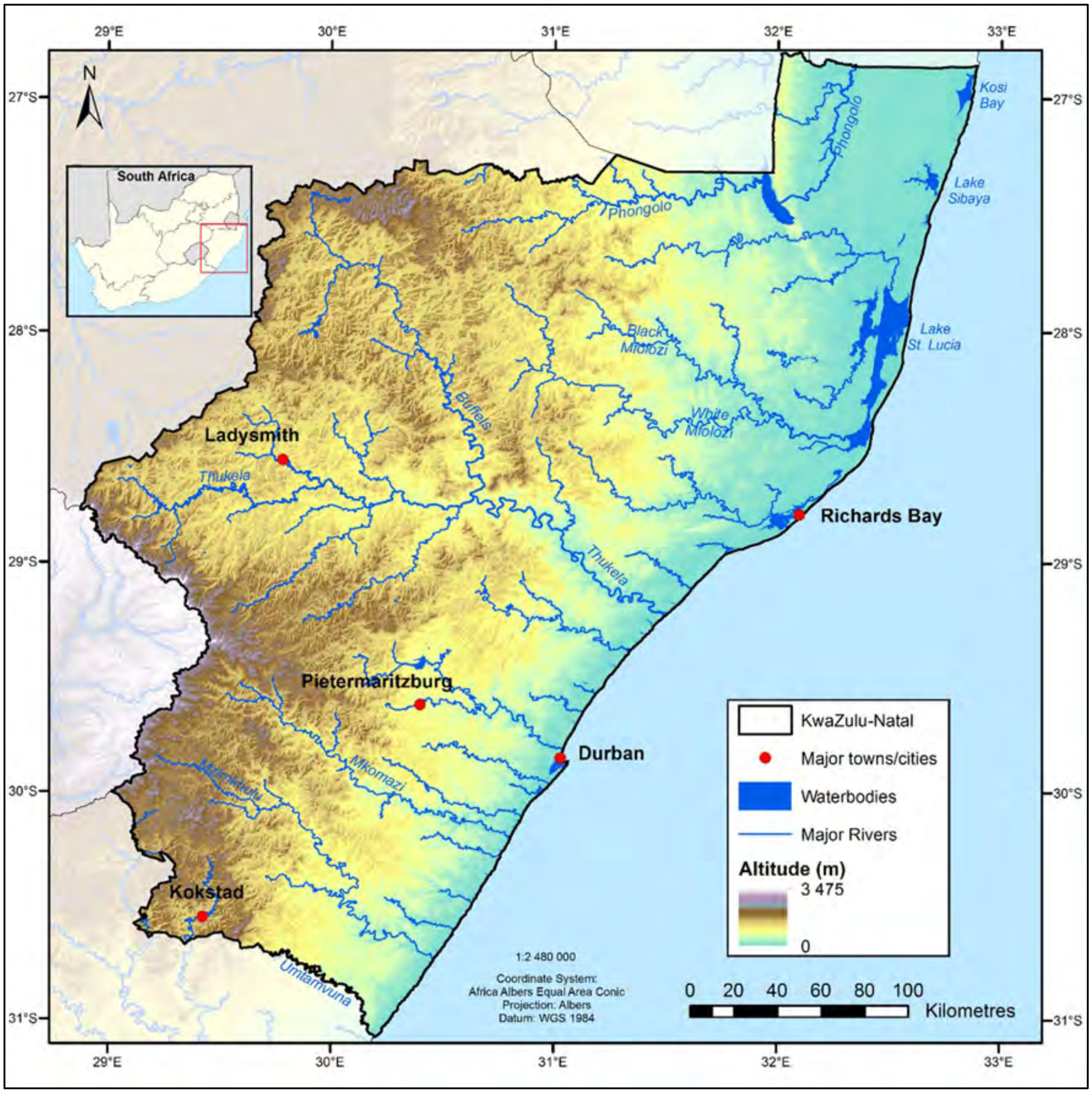

Figure 2.1. Topographical map of KwaZulu-Natal showing the main rivers, lakes and estuaries. The inset map shows KwaZulu-Natal's location within South Africa.

There are approximately 60 estuaries along the Indian Ocean coast, most of which are small and fed by small rivers. There are six major river systems which are also important for water supply to urban centres, agriculture, forestry, local communities and industry: the Phongola, uMfolozi, Thukela, uMngeni, Mkomazi and the uMzimkulu.

2.2 Land tenure and administrative subdivisions

The province has three main types of land tenure – Ingonyama Trust land, state protected areas, and land under private tenure (Figure 2.3). Almost 30% of the land area is owned by the Ingonyama Trust, which was established to administer the land owned by the Zulu people, and is managed by a board which is chaired by the Zulu King. This land was formerly the self-governing former "homeland" area of *KwaZulu* and is largely under communal tenure.

The province has a long history of formal nature conservation dating back to the 1890s (Carruthers 1995). By 1940, 227 564 ha (2.44% of the total area) was protected. The largest additions to the protected area estate came about in the 1970s, such that by 1980 over 5% of the province was conserved (Figure 2.2). In 2005, approximately 7.9% of the land was under formal protection (736 823ha), and this had increased to 8.7% by 2011 (Figure 2.3). These mostly fall under the provincial conservation authority, Ezemvelo KZN Wildlife. Exceptions include some smaller protected areas under municipal protection or private ownership, and the iSimangaliso Wetland Park, which encompasses the St Lucia and Kosi estuarine lake systems. iSimangaliso was listed as South Africa's first World Heritage Site in 1999. It is managed by the iSimangaliso Wetland Park Authority, in which conservation management is subcontracted to Ezemvelo KZN Wildlife. This, as well as many other protected areas in the province, are now under (finalised or pending) community ownership agreements following a lengthy land restitution process, but their protected status remains firm.

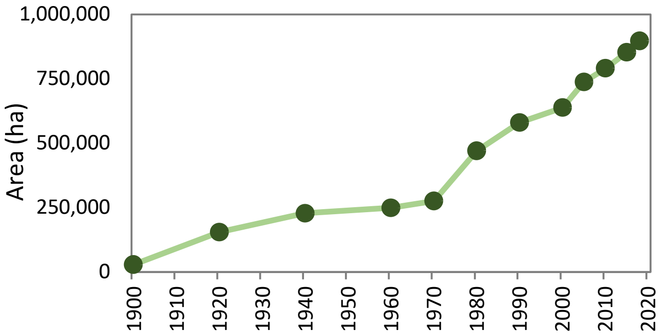

Figure 2.2. Time-series of the extent of area formally conserved in KwaZulu-Natal between 1900 and 2018. Source: SANBI protected areas GIS dataset 2020.

Unlike other provinces in South Africa which changed when the country moved from four to nine provinces, the provincial boundary of KwaZulu-Natal has remained relatively stable over time. However, the boundaries of the magisterial districts and municipalities within the province have changed over time. Earlier statistics, including census data up to 1996, were reported by magisterial district, of which there were 52 in KwaZulu-Natal (Figure 2.4). The magisterial districts have undergone some name changes and were realigned to the municipalities in 2014. More recent statistics, such as Census 2001 and Census 2011, have been reported by municipality. KwaZulu-Natal has one metropolitan municipality, namely eThekwini, 10 district municipalities and, within those, 43 local municipalities (Figure 2.4). These boundaries have not historically aligned with the magisterial districts. These changes have a bearing on any analysis of change, including ecosystem accounting, since this means that many government statistics have not been collected from consistent areas over time (e.g. see Weir-Smith 2016). They also render different datasets difficult to compare or combine.

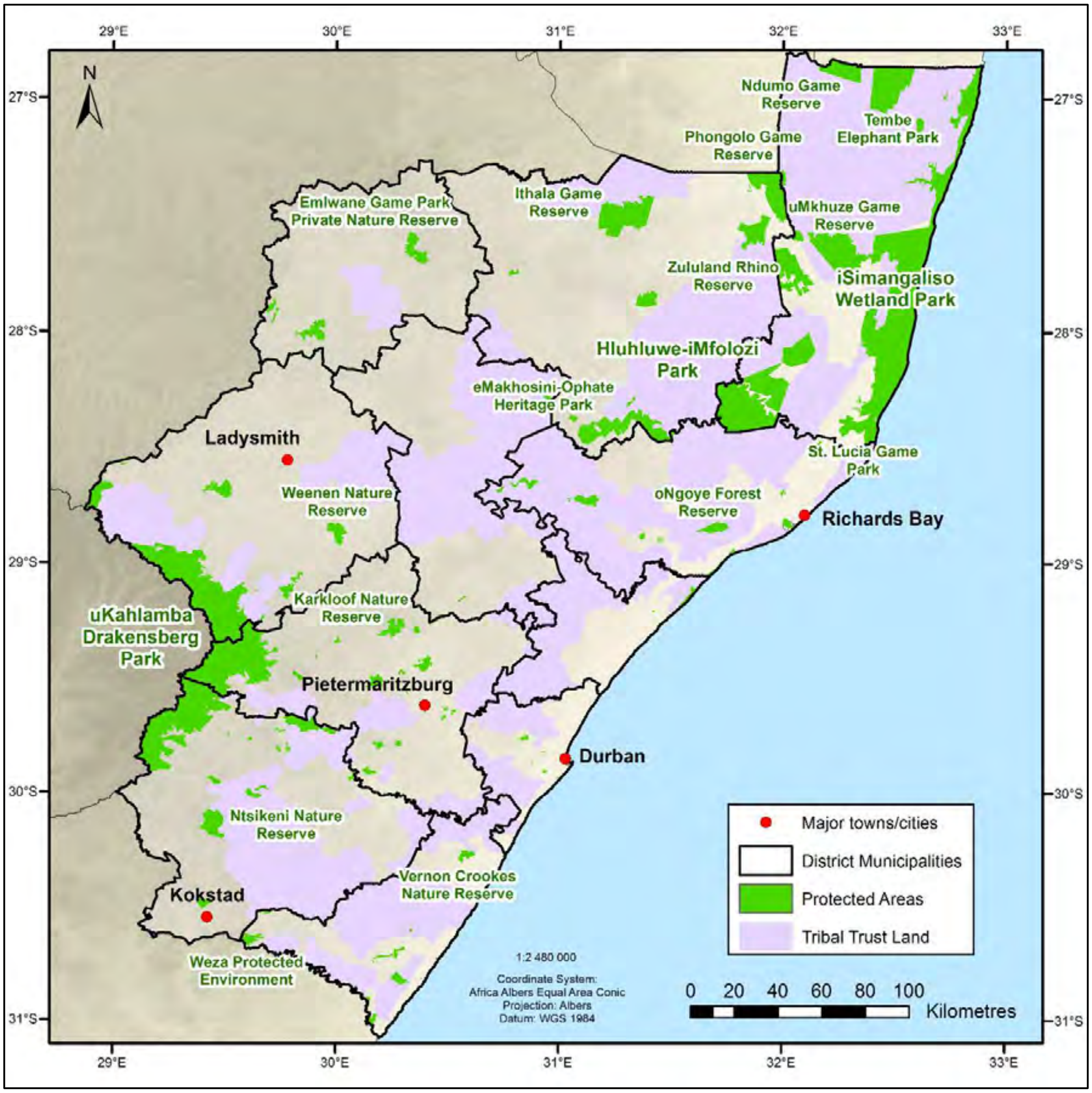

Figure 2.3. Map of KwaZulu-Natal showing proclaimed protected areas (largely state-owned) as at 2011, Ingonyama Tribal Trust land (largely communal) and land under private tenure.

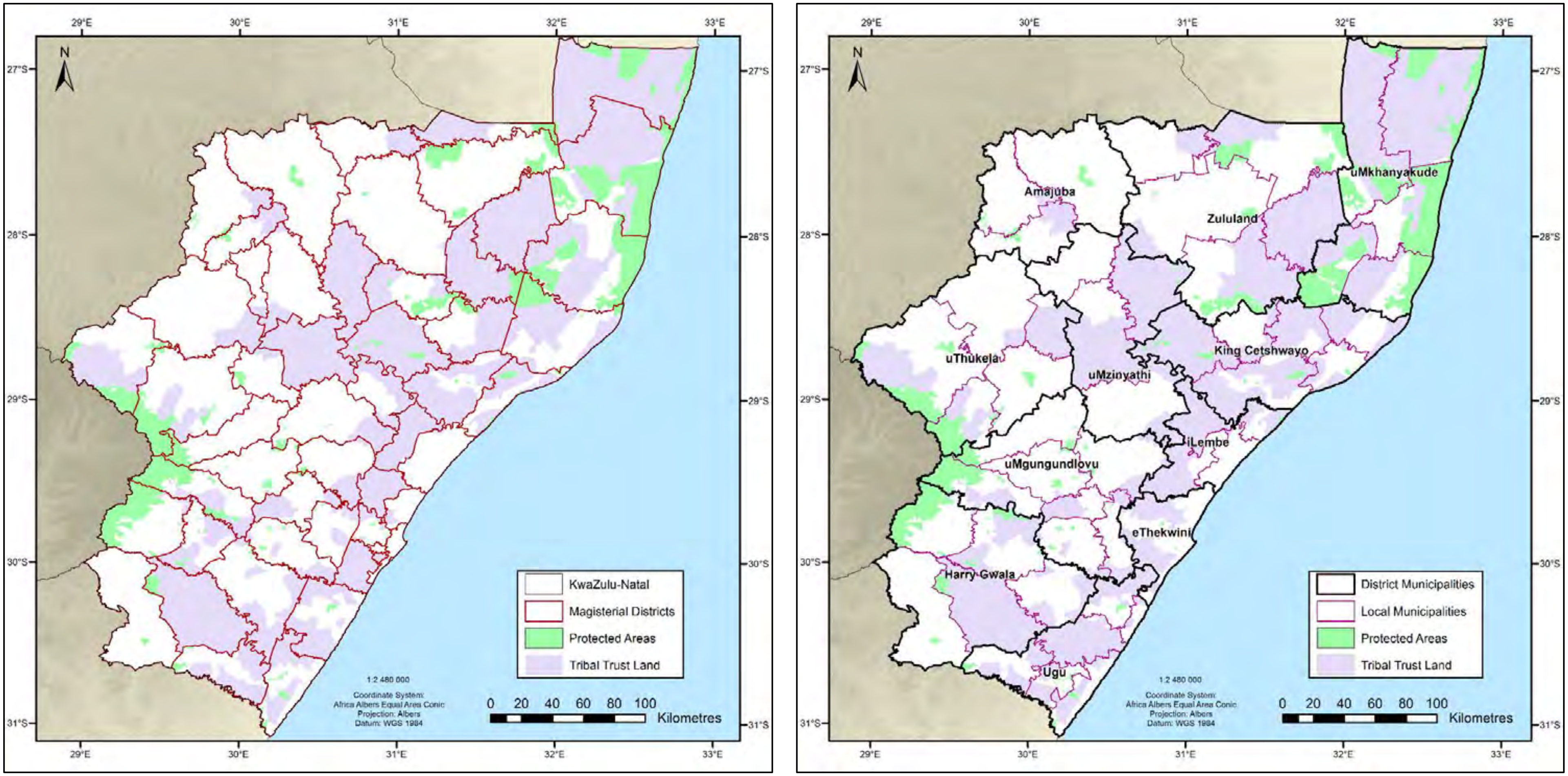

Figure 2.4. Map of KwaZulu-Natal showing (a) the magisterial districts as at 2007 (corresponding to agricultural census data used in the study) and (b) the metropolitan (eThekwini), district and local municipalities as at 2011, with names of the district municipalities shown. These are shown in relation to the tribal trust land and protected areas.

2.3 Natural vegetation, land use and land cover

Due to its topographical variation and subtropical and coastal location, KwaZulu-Natal has a high diversity of ecosystem types and supports a wealth of biodiversity (Figure 2.5). Most major terrestrial biomes are presented, namely grassland, savanna, forests, Indian Ocean coastal belt, as well as estuaries, freshwater ecosystems and azonal vegetation (mainly comprises hydrophilic and riverine vegetation associated with freshwater wetlands and riparian zones). The last two have been combined as "freshwater ecosystems" for summary purposes in this study. Some biomes are quite diverse. For example the Indian Ocean coastal belt comprises coastal dunes, dune forest and coastal grassy plains.

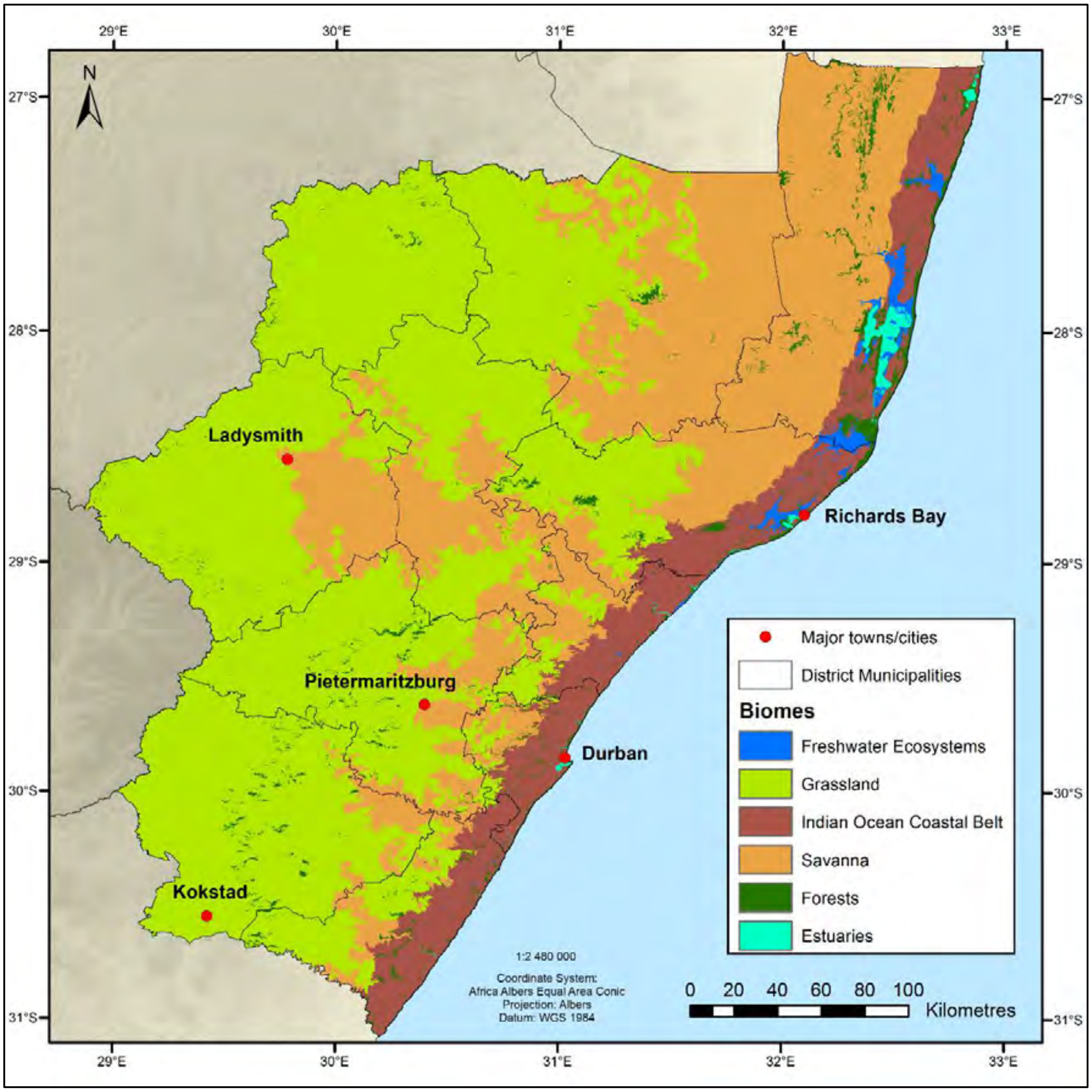

Figure 2.5. Representation of different vegetation biomes in KwaZulu-Natal. Source: SANBI 2018 Vegetation Map. For comparison purposes, see Figure 2.7 for the broad land cover classes.

Various land cover maps have been developed for KwaZulu-Natal in the past, but these have not been consistent in the way that land cover has been classified and determined. In recent years, two major efforts have led to consistent classifications which allow for analysis of changes over time. These are (a) the National Land Cover, commissioned by the then Department of Environmental Affairs (DEA; now Department of Environment, Forestry and Fisheries - DEFF), for which maps using consistent methods have been produced at 30m resolution for 1990, 2013/14 and 2017, and (b) the KwaZulu-Natal Land Cover, commissioned by Ezemvelo KZN Wildlife, for which maps have been produced at 20 m resolution for 2005, 2008, 2011 (Figure 2.6). According to the latter, built-up and cultivated areas covered 6.1% and 25.3% the province, respectively, in 2011 (Figure 2.7).

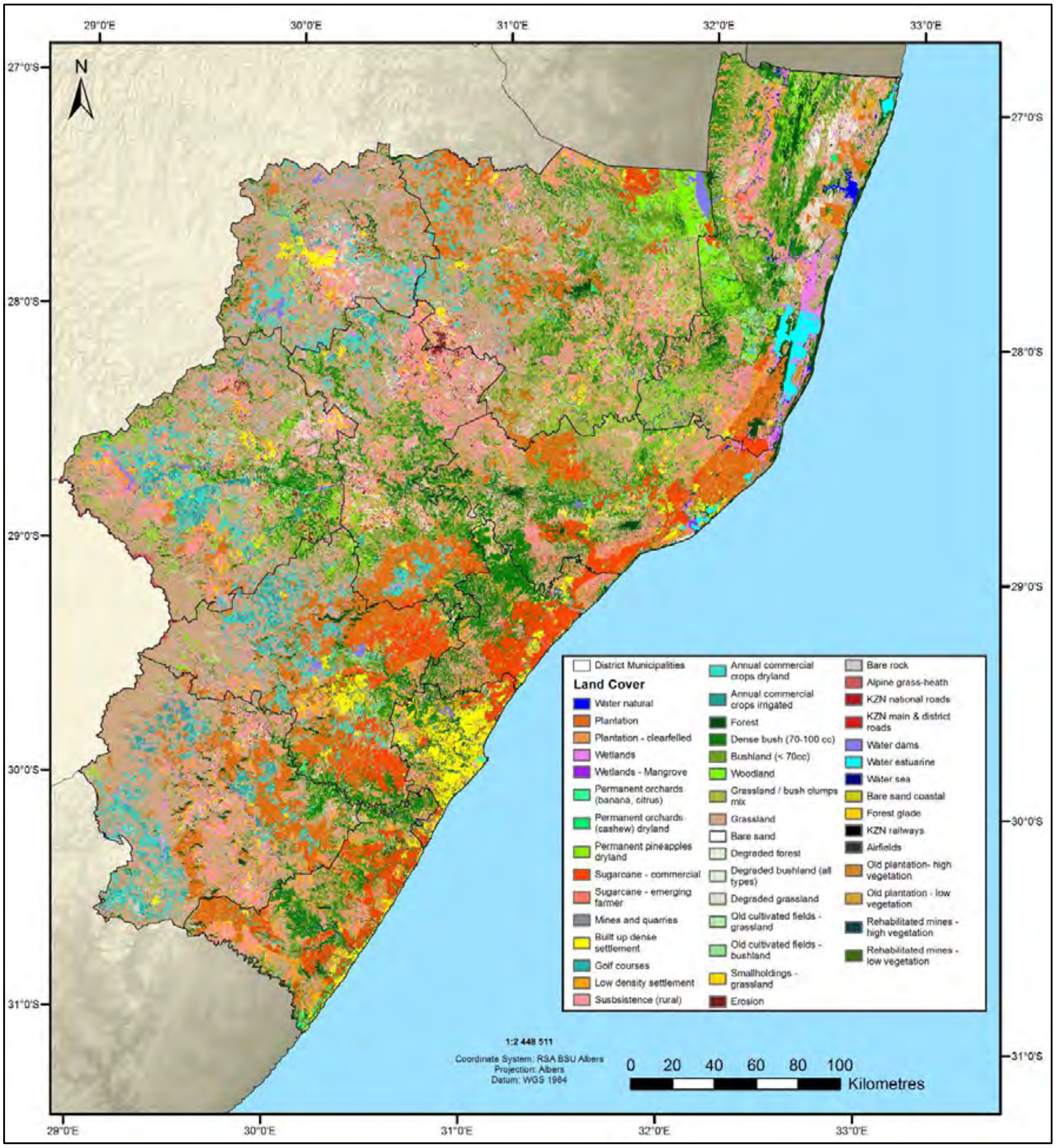

Figure 2.6. KwaZulu-Natal Land Cover map for 2011 (Source: Ezemvelo KZN Wildlife)

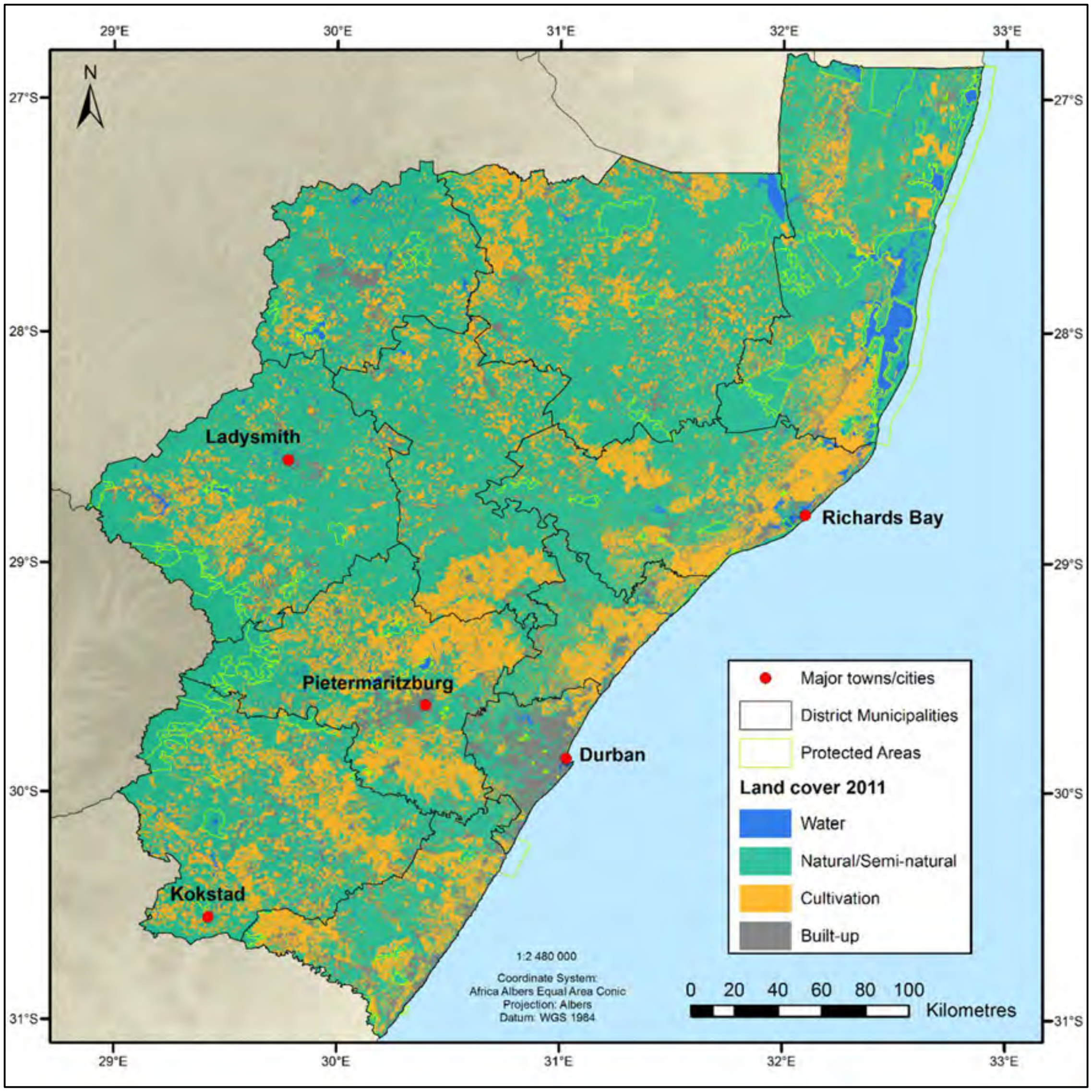

Figure 2.7. Map of KwaZulu-Natal showing four major categories of land cover – water, natural/semi-natural, cultivated and built up areas. Outlines of protected areas area superimposed in light green.

Whereas the National Land Cover series has more classes (72 in total, with more differentiation in the urban classes), the KwaZulu-Natal Land Cover series, which classifies land cover into 47 classes, includes a measure of condition for major natural land cover classes and has been much more committed to time series integrity with back-corrections being done as new information has come in. Ezemvelo KZN Wildlife's KwaZulu-Natal Land Cover series is also considered to be more accurate than the National Land Cover due to ground-truthing efforts that were made in the compilation process.

As was done for the KwaZulu-Natal physical land accounts compiled by Driver *et al.* (2015) for 2005 to 2011, this study has made use of the KwaZulu-Natal Land Cover series 2005 to 2011. In contrast, the land and ecosystem accounts that have recently been compiled at national scale have used the National Land Cover. Future extensions of these methods will need to use National Land Cover data, in an improved form that incorporates a measure of condition.

2.4 Water supply context

Rainfall tends to be highest in the highest parts of the landscape, and these areas, are important catchment areas for water supply reservoirs that serve the rest of the county as well as for sustaining river flows to downstream areas. KwaZulu-Natal contains a large share of South Africa's Strategic Water Source Areas (SWSAs; Le Maitre *et al.* 2018, Nel *et al*. 2017, Figure 2.8). SWSAs cover 10% of the land and deliver 50% of South Africa's water (Le Maitre *et al.* 2018). When linked to downstream urban centres, these areas support at least 51% of South Africa's population and 64% of its economy (Nel *et al*. 2017). The main threats to these areas within the province are land degradation, large-scale plantations, coal mining, large-scale cultivation and invasive alien plants (WWF-SA 2013, Le Maitre *et al.* 2018).

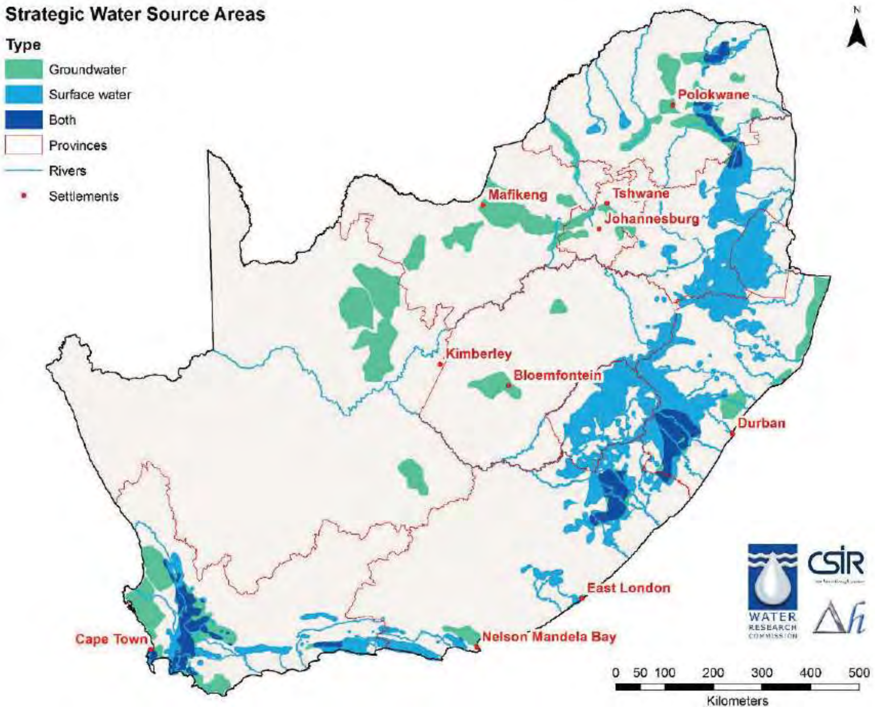

Figure 2.8. South Africa's Water Source Areas. Source: Le Maitre et al. (2018).

An extensive network of engineered infrastructure supplies towns and cities with water via dams, pipelines, inter-basin transfers and pumping schemes. The province has more than 1000 reservoirs (known as 'dams' in South Africa), ranging in storage capacity from 0.002 to 2445 million m^3. More than 800 of these are smaller farm dams used predominantly for irrigation or stock watering. The larger reservoirs are used for domestic water supply, industrial use, recreation and hydroelectricity. Figure 2.9 shows the location of the larger reservoirs across the province that are multi-use or used for domestic water supply only. The largest water supply reservoirs are situated on the uMgeni and Thukela rivers which are used to supply treated drinking water to the towns and cities across the province through a network of pipes and pumping schemes. The water utility, Umgeni Water, is the largest supplier of bulk potable water in KwaZulu-Natal providing water services to the municipalities of Durban and Pietermaritzburg as well as smaller settlements in the corridor of these two cities. uMhlathuze Water, overseen by the Department of Water and Sanitation (DWS), provides water services to Richards Bay and smaller municipalities along the Zululand Coast. uThukela Water and uThukela District Municipality manage water supply services in the interior of the province, supplying water to the settlements of Ladysmith, Colenso, Weenen, Winterton, Greytown and Estcourt.

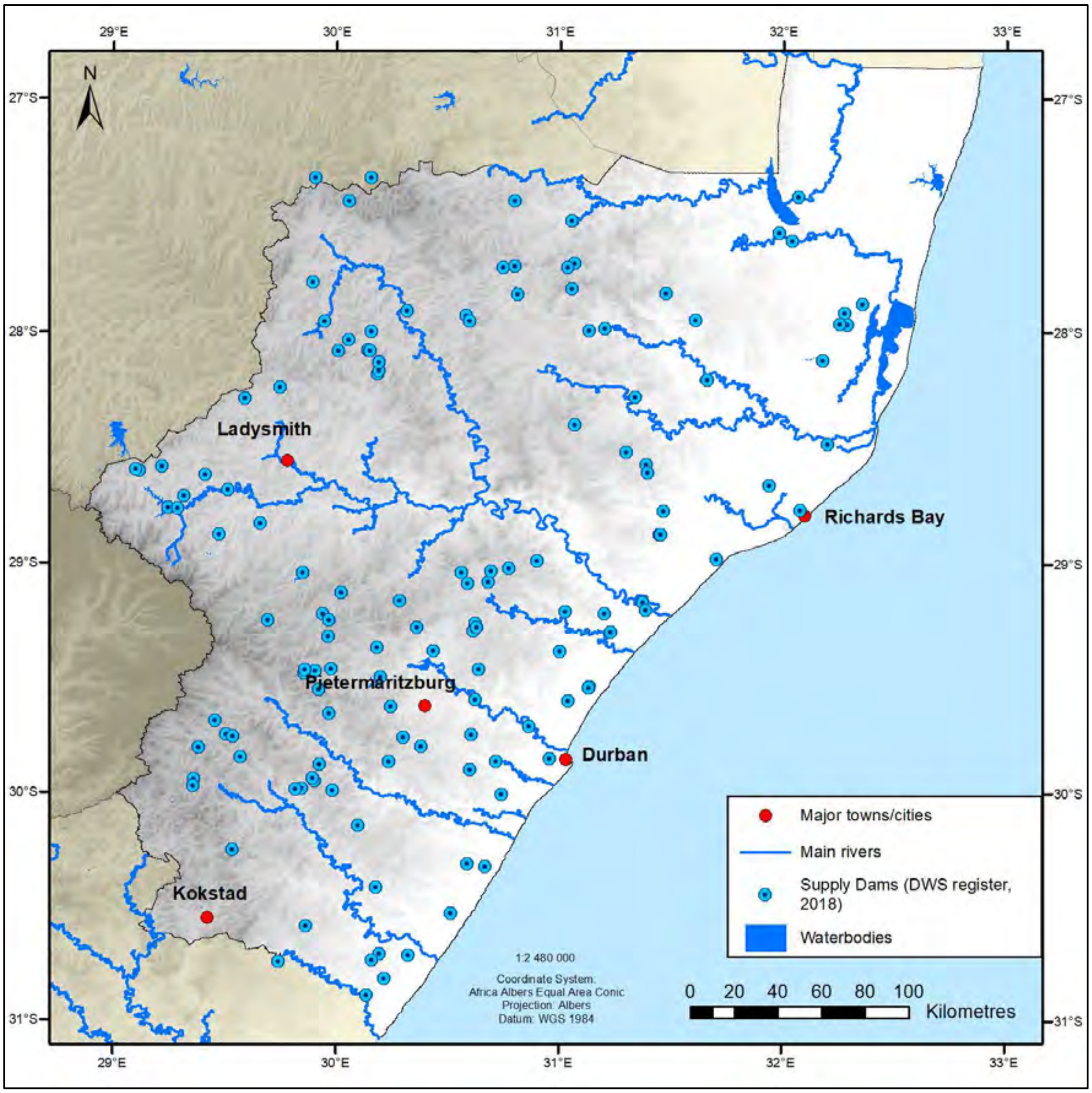

Figure 2.9. Location of the main water supply reservoirs (domestic water supply and irrigation) larger than 1000 m^3 capacity in KwaZulu-Natal.

2.5 Economy

The period under review (2005-11) followed a long period of healthy growth in the KwaZulu-Natal regional economy from 1999. However, the economy was badly affected by the global recession of 2008 (Figure 2.10). By 2011, growth rates had recovered somewhat, although this preceded a subsequent period of slowing growth rates.

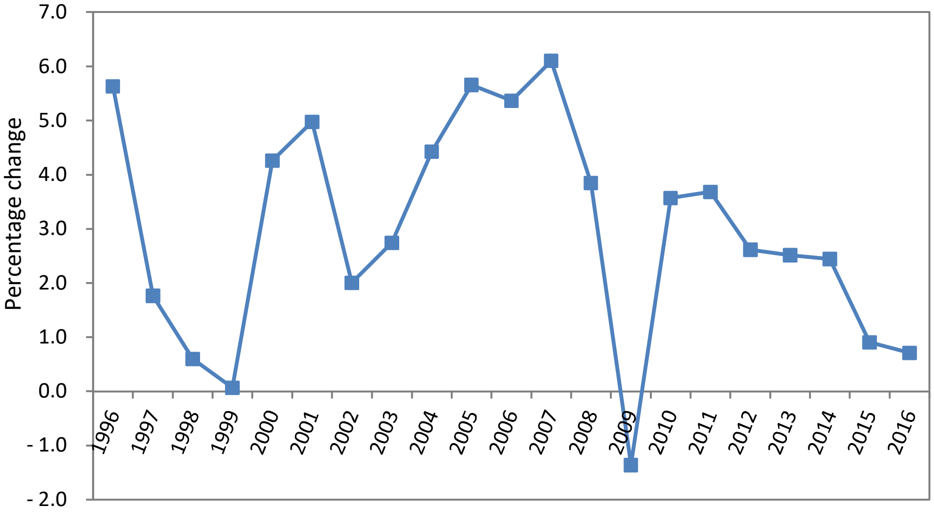

Figure 2.10. KwaZulu-Natal's share of Gross Domestic Product (GDP) year on year growth, 1996 – 2016 percentage change in constant 2010 prices. Source: Stats SA 2014a (Statistical release PO441).

South Africa's national accounts are updated approximately every five years to reflect a new reference year and simultaneously benchmark estimates against new datasets. At the time of this study, the most recent benchmark and rebasing had been done in November 2014, in which the reference year was updated to 2010. The regional GDP statistics for KwaZulu-Natal for the years 2004 to 2013 are given in Table 2.1 in current and constant 2010 prices, with the information for 2005 and 2011 summarised in the figures below (Figure 2.11, Figure 2.12).

KwaZulu-Natal is the second largest contributor to South Africa's economy (after Gauteng) contributing 15.5% and 15.8% towards GDP in 2005 and 2011, respectively. Economic activity is concentrated in the metropolitan areas of Durban, Pietermaritzburg and Richards Bay. Two of South Africa's major seaports, Durban and Richards Bay, are located in KZN. Manufacturing and tertiary industries (trade, business services and transport and communications) are the dominant sectors of the provincial economy. Growth in the manufacturing sector is driven by the paper and paper products industry, ferroalloys (such as aluminium) and other chemicals (Trade & Investment KwaZulu-Natal 2019). Primary industries make a relatively small contribution to the province's GDP, with the Agriculture, forestry and fishing sector contributing 4% in both 2005 and 2011 (Figure 2.11, Figure 2.12).

Table 2.1. Regional Gross Domestic Product for KwaZulu-Natal for 2004 to 2013, in current and constant 2010 prices. Source: Stats SA 2014a (Statistical release PO441).

a. Current prices - Rand million

Industry	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Primary Industries	**13 915**	**14 232**	**15 722**	**19 778**	**24 933**	**25 012**	**25 676**	**26 607**	**27 431**	**29 058**
Agriculture, forestry and fishing	10 764	10 558	11 059	14 286	17 758	18 235	17 714	18 391	18 410	19 578
Mining and quarrying	3 151	3 674	4 663	5 492	7 175	6 778	7 962	8 216	9 020	9 480
Secondary Industries	**63 245**	**67 627**	**69 477**	**78 786**	**93 109**	**98 753**	**103 840**	**112 551**	**119 116**	**130 019**
Manufacturing	52 596	56 416	56 399	63 127	71 611	72 404	75 045	76 133	80 016	86 431
Electricity, gas and water	4 715	4 899	5 277	5 689	6 043	8 562	10 544	15 073	18 477	20 075
Construction	5 934	6 312	7 800	9 970	15 454	17 787	18 251	21 345	20 622	23 513
Tertiary industries	**143 177**	**161 471**	**183 553**	**209 616**	**237 039**	**248 557**	**264 974**	**294 120**	**323 830**	**349 174**
Trade, catering and accommodation	31 506	35 310	43 145	51 653	60 810	57 234	60 988	69 911	75 559	78 759
Transport, storage and communication	31 653	35 410	39 764	43 416	46 118	46 027	48 277	54 511	62 560	71 155
Finance, real estate and business services	37 358	43 351	48 847	57 255	63 159	69 377	70 713	75 886	83 995	88 386
Personal services	14 064	15 563	17 613	19 081	20 533	22 773	24 558	27 217	29 554	31 425
General government services	28 595	31 838	34 183	38 212	46 419	53 147	60 439	66 594	72 163	79 450
All industries at basic prices	**220 336**	**243 331**	**268 752**	**308 179**	**355 081**	**372 322**	**394 490**	**433 277**	**470 376**	**508 251**
Taxes less subsidies on products	23 645	27 411	31 697	36 030	37 666	36 365	39 356	46 792	50 015	55 671
GDPR at market prices	**243 981**	**270 741**	**300 448**	**344 209**	**392 747**	**408 687**	**433 846**	**480 069**	**520 391**	**563 921**

b. Current prices - percentage contributions

Industry	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Primary Industries	**5.7**	**5.3**	**5.2**	**5.7**	**6.3**	**6.1**	**5.9**	**5.5**	**5.3**	**5.2**
Agriculture, forestry and fishing	4.4	3.9	3.7	4.2	4.5	4.5	4.1	3.8	3.5	3.5
Mining and quarrying	1.3	1.4	1.6	1.6	1.8	1.7	1.8	1.7	1.7	1.7
Secondary Industries	**25.9**	**25.0**	**23.1**	**22.9**	**23.7**	**24.2**	**23.9**	**23.4**	**22.9**	**23.1**
Manufacturing	21.6	20.8	18.8	18.3	18.2	17.7	17.3	15.9	15.4	15.3
Electricity, gas and water	1.9	1.8	1.8	1.7	1.5	2.1	2.4	3.1	3.6	3.6
Construction	2.4	2.3	2.6	2.9	3.9	4.4	4.2	4.4	4.0	4.2
Tertiary industries	**58.7**	**59.6**	**61.1**	**60.9**	**60.4**	**60.8**	**61.1**	**61.3**	**62.2**	**61.9**
Trade, catering and accommodation	12.9	13.0	14.4	15.0	15.5	14.0	14.1	14.6	14.5	14.0
Transport, storage and communication	13.0	13.1	13.2	12.6	11.7	11.3	11.1	11.4	12.0	12.6
Finance, real estate and business services	15.3	16.0	16.3	16.6	16.1	17.0	16.3	15.8	16.1	15.7
Personal services	5.8	5.7	5.9	5.5	5.2	5.6	5.7	5.7	5.7	5.6
General government services	11.7	11.8	11.4	11.1	11.8	13.0	13.9	13.9	13.9	14.1
All industries at basic prices	**90.3**	**89.9**	**89.5**	**89.5**	**90.4**	**91.1**	**90.9**	**90.3**	**90.4**	**90.1**
Taxes less subsidies on products	9.7	10.1	10.5	10.5	9.6	8.9	9.1	9.7	9.6	9.9
GDPR at market prices	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

c. Constant 2010 prices - Rand million

Industry	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Primary Industries	**24 412**	**22 950**	**22 747**	**23 442**	**25 453**	**24 542**	**25 676**	**27 362**	**27 978**	**29 321**
Agriculture, forestry and fishing	15 493	14 589	14 666	15 329	17 872	17 303	17 714	19 470	19 920	20 917
Mining and quarrying	8 919	8 361	8 082	8 113	7 581	7 239	7 962	7 892	8 058	8 404
Secondary Industries	**85 509**	**91 600**	**97 025**	**103 272**	**105 996**	**98 872**	**103 840**	**106 260**	**108 401**	**110 355**
Manufacturing	64 931	68 936	73 097	77 062	78 786	70 588	75 045	77 251	78 888	79 868
Electricity, gas and water	9 997	10 648	10 999	11 325	10 814	10 332	10 544	10 660	10 657	10 635
Construction	10 582	12 016	12 928	14 885	16 395	17 952	18 251	18 349	18 856	19 851
Tertiary industries	**204 307**	**217 833**	**230 093**	**245 043**	**255 164**	**258 302**	**264 974**	**275 811**	**283 854**	**291 231**
Trade, catering and accommodation	47 759	50 848	54 103	57 398	58 237	58 359	60 988	63 989	66 356	67 378
Transport, storage and communication	37 698	39 928	42 005	45 492	47 186	47 237	48 277	49 874	51 215	52 729
Finance, real estate and business services	50 805	56 178	60 501	64 929	68 719	69 850	70 713	73 766	75 289	77 189
Personal services	20 557	21 252	22 379	23 589	24 431	24 411	24 558	25 273	25 874	26 594
General government services	47 488	49 627	51 106	53 635	56 591	58 447	60 439	62 908	65 120	67 341
All industries at basic prices	**314 229**	**332 382**	**349 865**	**371 758**	**386 613**	**381 716**	**394 490**	**409 432**	**420 233**	**430 907**
Taxes less subsidies on products	31 950	33 393	35 533	37 152	38 027	37 163	39 356	40 393	41 370	42 334
GDPR at market prices	**346 179**	**365 775**	**385 398**	**408 910**	**424 640**	**418 879**	**433 846**	**449 826**	**461 604**	**473 241**

d. Constant 2010 prices - percentage changes

Industry	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Primary Industries	**0.9**	**-6.0**	**-0.9**	**3.1**	**8.6**	**-3.6**	**4.6**	**6.6**	**2.3**	**4.8**
Agriculture, forestry and fishing	0.3	-5.8	0.5	4.5	16.6	-3.2	2.4	9.9	2.3	5.0
Mining and quarrying	2.0	-6.3	-3.3	0.4	-6.6	-4.5	10.0	-0.9	2.1	4.3
Secondary Industries	**5.6**	**7.1**	**5.9**	**6.4**	**2.6**	**-6.7**	**5.0**	**2.3**	**2.0**	**1.8**
Manufacturing	4.7	6.2	6.0	5.4	2.2	-10.4	6.3	2.9	2.1	1.2
Electricity, gas and water	7.3	6.5	3.3	3.0	-4.5	-4.5	2.0	1.1	0.0	-0.2
Construction	9.4	13.6	7.6	15.1	10.1	9.5	1.7	0.5	2.8	5.3
Tertiary industries	**4.3**	**6.6**	**5.6**	**6.5**	**4.1**	**1.2**	**2.6**	**4.1**	**2.9**	**2.6**
Trade, catering and accommodation	5.4	6.5	6.4	6.1	1.5	0.2	4.5	4.9	3.7	1.5
Transport, storage and communication	4.5	5.9	5.2	8.3	3.7	0.1	2.2	3.3	2.7	3.0
Finance, real estate and business services	7.2	10.6	7.7	7.3	5.8	1.6	1.2	4.3	2.1	2.5
Personal services	1.8	3.4	5.3	5.4	3.6	-0.1	0.6	2.9	2.4	2.8
General government services	1.3	4.5	3.0	4.9	5.5	3.3	3.4	4.1	3.5	3.4
All industries at basic prices	**4.4**	**5.8**	**5.3**	**6.3**	**4.0**	**-1.3**	**3.3**	**3.8**	**2.6**	**2.5**
Taxes less subsidies on products	4.8	4.5	6.4	4.6	2.4	-2.3	5.9	2.6	2.4	2.3
GDPR at market prices	**4.4**	**5.7**	**5.4**	**6.1**	**3.8**	**-1.4**	**3.6**	**3.7**	**2.6**	**2.5**

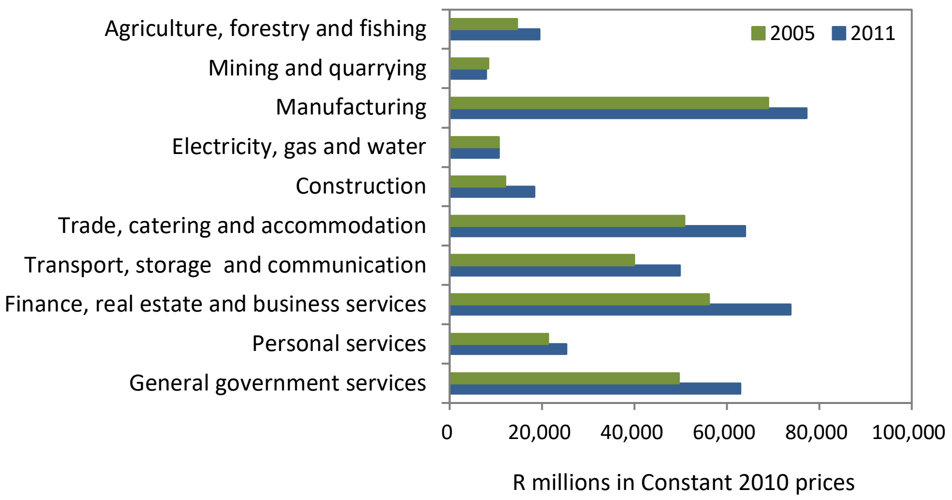

Figure 2.11 Sectoral contribution to Provincial GDP in 2005 and 2011, in constant 2010 prices. Source: Stats SA 2014a (Statistical release PO441)

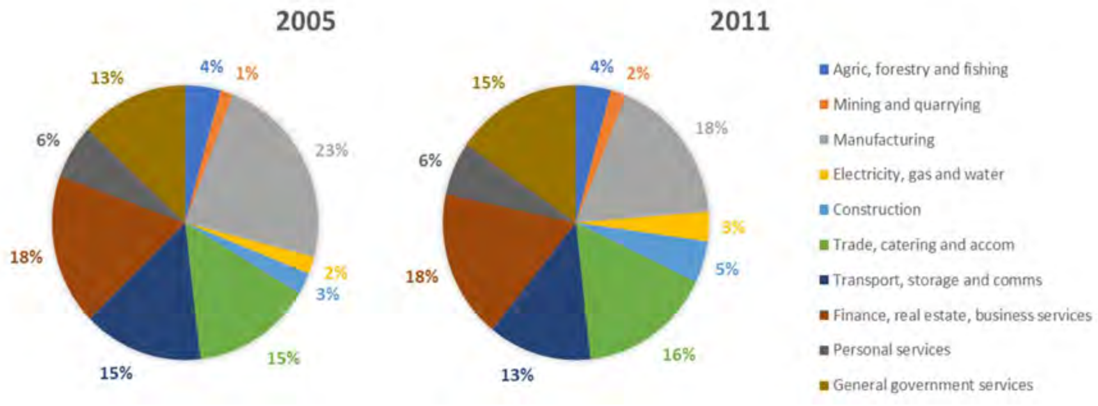

Figure 2.12. Sectoral percentage contribution to Provincial GDP in 2005 and 2011. Source: Stats SA 2014a (Statistical release PO441)

In addition to the Agriculture, forestry and fishing sector, ecosystem services would be expected to make an important contribution to the Trade, catering and accommodation sector, and to the Finance, real estate and business services sector through nature based tourism and property values. Both tertiary sub-sectors make a substantial contribution of 15-16%, and 18%, respectively. While all three sectors grew at a similar rate from 2005 to 2011, the absolute growth in contribution in the two tertiary sectors was much larger. Furthermore, the Trade, catering and accommodation sector, which most closely aligns to tourism, grew faster than the other two sectors. Indeed, KwaZulu-Natal is a popular holiday destination. The province has nine blue flag beaches, is home to two UNESCO World Heritage Sites and boasts numerous state- and privately-owned game reserves. More recently, the wildlife sector, which is centred on game and wildlife farming/ranching activities that relate to the stocking, trading, breeding, and hunting of game, and all the services and goods required to support this value chain, has become an increasingly important contributor to the provincial economy in KwaZulu-Natal. In South Africa, the wildlife economy has been growing consistently faster than the general economy, contributing R3 billion to GDP in 2014 (DEA 2016).

2.6 Demographic and socioeconomic statistics

KwaZulu-Natal is the second most populous province in the country with an estimated population of 10.3 million in 2011. It contained 19.8% of the country's population and was the second most densely populated province with an estimated 120 people per km^2. In 2011, approximately 34% of the provincial population resided in the eThekwini Metropolitan Municipality (Durban and surrounds). eThekwini, iLembe (just north of eThekwini), uMgungundlovu (inland of eThekwini) and King Cetshwayo (formerly uThungulu) Districts were the most densely populated areas (Figure 2.13).

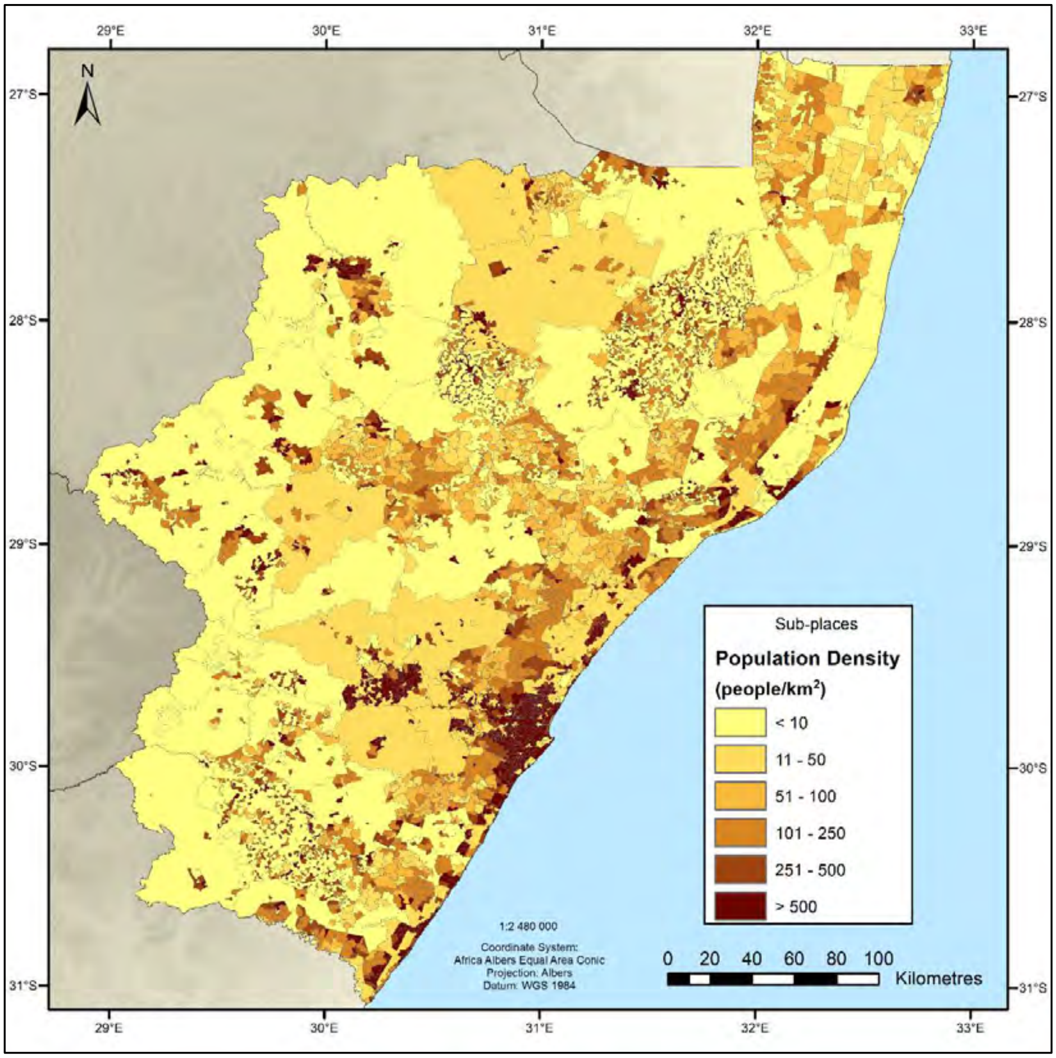

Figure 2.13. Map of KwaZulu-Natal showing population density (people/km^2) per Census 2011 subplace.

Full census data were available for 1996, 2001 and 2011, and official estimates were available for 2007 and 2016. The population grew by 8.9% from 9 426 017 in 2001 to 10 267 300 in 2011, slower than South Africa's overall population growth of 14.4% over the same period (Stats SA 2014b). Indeed, population growth in KwaZulu-Natal slowed from 2.2% p.a. from 1996 to 2011, to 0.7% p.a. for 2001 to 2011. eThekwini and the district municipalities of Umgungundlovu (inland of eThekwini), Umkhanyakude (furthest north) and iLembe (just north of eThekwini), had the highest growth rates, of 1.1%, 0.9%, 0.9% and 0.8%, respectively (Stats SA 2014b).

KwaZulu-Natal has a youthful population. Children aged 0-14 years make up 32% of the population (Table 2.2). The bulk (63%) of the population is aged between 15 and 64 years of age and the elderly make up 5% of the population (Table 2.2). The population pyramid for 2011 in KwaZulu-Natal indicates high birth rates (i.e. lots of children due to high fertility rates) and lower than average life expectancy (i.e. a small elderly population). This is a typical trend seen in many developing countries. Low working-age populations with high numbers of children and elderly indicate large dependency ratios. There are a number of local municipalities in KwaZulu-Natal that have high dependency ratios greater, where the number of children and elderly exceeds the working-age population.

Table 2.2. KwaZulu-Natal population by district municipality and functional age group, 2011. Source: Stats SA 2012

	Children (0-14)		**Youth & Adults (15-64)**		**Elderly (65+)**	
District	**Number**	**%**	**Number**	**%**	**Number**	**%**
Ugu	240 587	33.3	434 213	60.1	47 684	6.6
uMgungundlovu	288 027	28.3	675 795	66.4	53 941	5.3
uThukela	246 136	36.8	391 276	58.5	31 436	4.7
uMkhanyakude	252 216	40.3	346 093	55.3	28 163	4.5
King Cetshwayo	339 412	37.4	527 269	58.1	41 746	4.6
Harry Gwala	174 878	37.9	263 932	57.2	22 610	4.9
uMzinyathi	205 357	40.2	278 918	54.6	26 564	5.2
Amajuba	168 446	33.7	308 401	61.7	23 492	4.7
Zululand	317 412	39.5	448 395	55.8	37 768	4.7
iLembe	205 101	33.8	371 974	61.3	30 340	5.0
eThekwini	867 475	25.2	2 409 653	70.0	165 233	4.8
KwaZulu-Natal	**3 305 047**	**31.9**	**6 455 916**	**63.1**	**508 978**	**4.9**

Literacy rates (reported as the percentage of the population aged 15 years and older with Grade 7 or higher level of education) were above 80% in only 15 of KwaZulu-Natal's 44 municipalities in 2016 (Stats SA 2018a). The municipalities with the lowest literacy rates in the province were Msinga (in the Umzinyathi District, 63.8%), Nkandla (in the uThungulu District, 67%) and Maphumulo (in the iLembe District, 68.1%). All municipalities apart from Umzumbe (in the Ugu District) had more than 80% of children aged 6-13 years enrolled in primary school (Stats SA 2018a).

Overall, approximately 26.7% of the population aged 20 years and older living in KwaZulu-Natal reported to have achieved a matric qualification or higher as their highest level of education (Figure 2.14, Stats SA 2018a). Approximately 16.4% of the population had no schooling and only

25.7% of the population reported having some primary school education (Figure 2.14). In 2011, the percentage of the KwaZulu-Natal population with no schooling was higher than the national average.

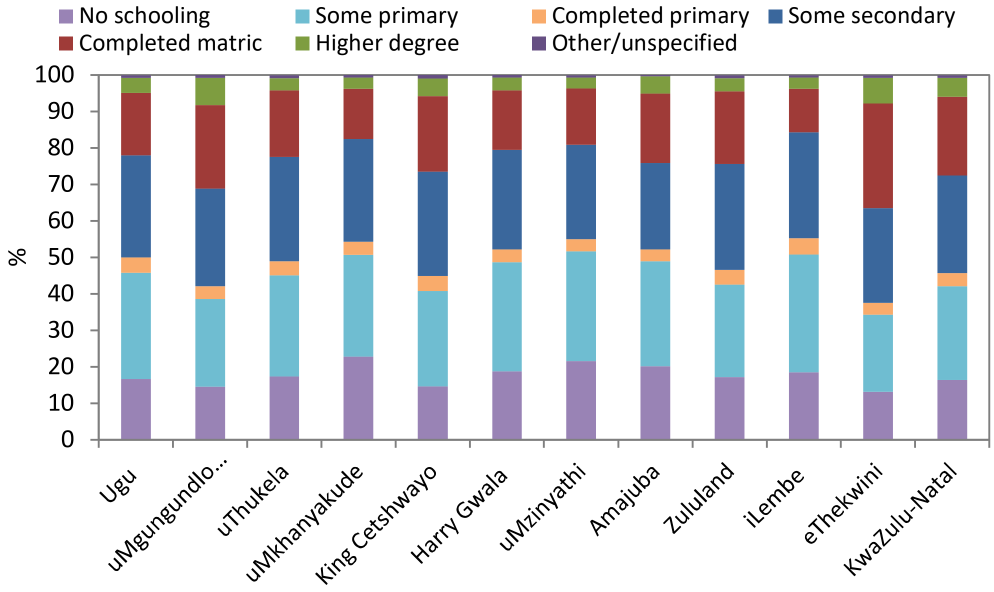

Figure 2.14. Population by highest level of education (percentage share) per district municipality in 2016. Source: Stats SA 2018a.

In 2011, the unemployment rate in KwaZulu-Natal was 33%, higher than the national average of 29.8% (Stats SA 2012). The youth unemployment rate (population aged 15-34 years) was 42.1% in 2011 down from 58.4% in 2001. Unemployment rates were highest in the uMkhanyakude and Zululand Districts of northern KwaZulu-Natal (Stats SA 2012).

According to the Living Conditions Survey (LCS) 2014/15 (Stats SA 2018b), more than half of the adult population were living in poverty in KwaZulu-Natal (60.7%) in 2014, the third highest in South Africa. KwaZulu-Natal also had the highest percentage share of households living in poverty at 20.6%. Approximately six out of every ten (60%) households headed by females in KwaZulu-Natal were living below the upper-bound poverty line (UBPL)[1] compared to less than four out of ten male-headed households (38%, Stats SA 2018b). KwaZulu-Natal also had the highest share of child poverty in the country at 26.6%.

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[1] The Living Conditions Survey uses South Africa's official national poverty lines to profile money metric poverty. These lines are reported in March 2015 prices as follows: - Food poverty line (FPL) = R441 per person per month; - Lower-bound poverty line (LBPL) = R647 per person per month; - Upper-bound poverty line (UBPL) = R992 per person per month.

2.7 Environmental issues

The main environmental issues facing KwaZulu-Natal include:

- Loss of natural habitat due to land use change;
- Loss of vegetation and soil cover in rangelands and cultivated lands, as a result of poor management practices;
- Bush encroachment (increases in woody vegetation) in rangelands as a result of poor grazing and fire management practices;
- Invasive alien plants and other organisms
- Hydrological alteration by dams, water abstraction and transfers;
- Poaching and overexploitation of endangered and important species; and
- Solid waste, air and water pollution

Many of these problems are inter-related and they are also exacerbated by climate change. Different authors group these problems differently, depending on their focus. For example, for a terrestrial ecosystem focus, the problems of loss of vegetation and soil cover, bush encroachment and invasive alien plants can all be grouped as “land degradation”. Land degradation are explored in more detail in the accompanying scenario analysis that follows on from this study. The above problems are outlined briefly below in order to provide further context to this study.

2.7.1 Loss of natural habitat due to land use change

Land cover change is a significant threat to biodiversity in KwaZulu-Natal. Natural habitat loss has averaged 1.2% per year since 1994, with the natural vegetation share of the province changing from 73% to 53% by 2011 (Jewitt *et al.* 2015). Up to 2008, this was primarily due to expansion of agricultural, urban and forest plantation areas. Indeed, subsistence agriculture, which is often associated with low density settlement, has grown exponentially (Driver *et al.* 2015). Other land cover classes that have increased since then include reservoirs, mines and erosion. Natural habitat loss is also due to the expansion of rural settlements, particularly in communal areas (Ingonyama Trust Board land). Natural habitat loss continues to be a major concern. By 2011 the province was already close to the threshold of 50% natural, beyond which the persistence of biodiversity will be under significant threat. The situation for South Africa as at 2013/14 is shown in Figure 2.15. This demonstrates that KwaZulu-Natal has a high proportion of intensively modified land cover relative to most other provinces. Note that this analysis is based on satellite data and does not provide an assessment of change in the quality of the remaining natural habitats. Land cover change is addressed at local, district, metropolitan municipality and provincial scales through the relevant planning departments. However, environmental concerns are not always given the attention they deserve in these planning processes. This is compounded by the fact that much of the land use change happening at present is unplanned (subsistence agriculture and low-density settlements in particular) or informal, and/or illegal.

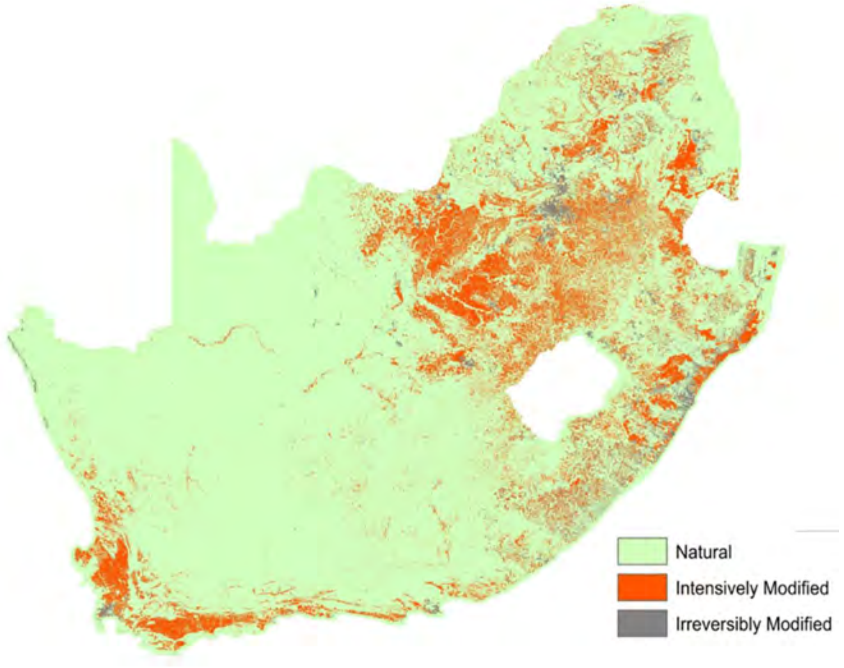

Figure 2.15 Remaining area of natural vegetation, and the area under cultivation and plantations (intensively modified), and under urban or mining land use (irreversibly modified).

2.7.2 Loss of vegetation and soil cover

Land degradation in the form of loss of vegetation and soil cover is a major and widespread problem in KwaZulu-Natal, and is particularly severe in some of the communal land areas where people were forcibly settled in the past in high densities, and where there are still low levels of education and high levels of poverty. There tends to be a high level of reliance on subsistence farming, albeit slightly less so since the introduction of government welfare payments in post-Apartheid South Africa. The land degradation problems are partly the result of subsistence cultivation and gathering of resources such as firewood, but are primarily associated with overgrazing (Sonneveld *et al.* 2005), as livestock keeping for cultural purposes has been a strong tradition in these areas. KwaZulu-Natal has a fairly high veld degradation index and one of the highest indices of soil degradation and susceptibility to donga formation (Hoffman & Todd 2000). This undermines the productive potential of land and water resources in this area and presents serious challenges in terms of resilience to drought. Soil erosion is a serious problem in the upper catchment areas of the province (Figure 2.16). Loss of vegetation cover and resulting erosion is seen as one of the biggest problems in KwaZulu-Natal, but also one of the most difficult to solve. Many projects have been carried out to try and address the source of the problem at local scales, but no major successes have been reported. Meanwhile, the government's Natural Resource Management programmes assist by repairing erosion dongas and rehabilitating damaged wetlands in these landscapes.

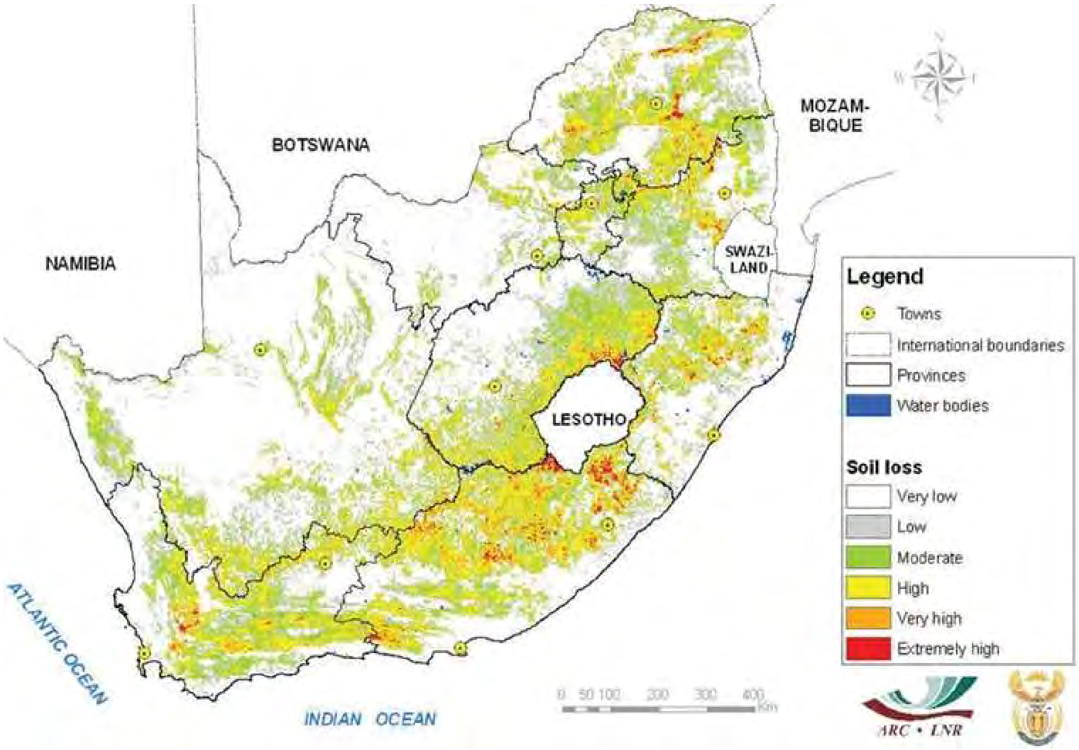

Figure 2.16. Distribution of sheet and rill erosion in South Africa. Source: Agricultural Research Council.

2.7.3 Bush encroachment

Bush encroachment is a problem in many of the rangeland areas of the province, typically in the sub-escarpment grasslands and savannas (in the middle altitudes). It involves the proliferation of indigenous woody species that naturally occur in these ecosystems, especially in areas of higher rainfall and rainfall seasonality (Turpie *et al.* 2018). Bush encroachment is a result of poor land management, including overgrazing and active reduction in fire intensity or frequency. These practices disturb the natural balance between grassy and woody species that is maintained through the seasonal build-up of dry grassy biomass and natural burning regimes that regulate the emergence of woody saplings. Overgrazing limits this fuel, so both overgrazing and fire suppression allow greater survival of woody saplings and the densification of woody cover. Bush encroachment can be reversed by better land management, but only up to a point (about 40% tree cover), beyond which it becomes necessary to use active removal methods to restore the landscape.

Bush encroachment negatively affects ecosystem function which has a negative impact on species diversity, distribution and abundance (i.e. biodiversity). Furthermore, it has negative consequences on agricultural productivity, hydrological budgets and ecotourism. It affects both commercial and communal farming areas as palatable grasses are lost and grazing carrying capacity declines. Bush encroachment can have hydrological impacts through changes in vegetation and soil structure which influences soil infiltration rates, groundwater recharge and surface runoff. The increase in woody cover in protected areas and game reserves can have a significant negative impact on ecotourism as the game viewing experience is affected through poor visibility (i.e. dense bushy vegetation prevents sightings of wild animals). Bush encroachment has a similar impact on habitat and ecosystem services to invasive alien plants (IAPs) in terrestrial landscapes, but is distinct in that it is largely a result of *in situ* management actions, unlike in the case of IAPs which spread onto land as a result of past introductions elsewhere in the landscape (Turpie *et al.* 2018).

In South Africa, there has been a significant increase in tree cover in the grassland and savanna biomes since national-scale aerial photography was first undertaken in the 1940s, although most of this has happened only in the last few decades. A comparison of encroachment studies in the different bioregions showed that the sub-escarpment grassland bioregion had the highest average change in overall woody cover from the start to the end of monitoring period (41%), followed by the Lowveld zone which had an average overall change of 27% (Turpie *et al*. 2018). The other zones had an average overall change in woody cover of about 20%. Thus, bush encroachment is particularly important in KwaZulu-Natal. Nationally, there has been little response to bush encroachment as of yet, but government has recently decided to treat it as a form of land degradation, rather than as a fortuitous means of carbon sequestration (Turpie *et al*. 2018).

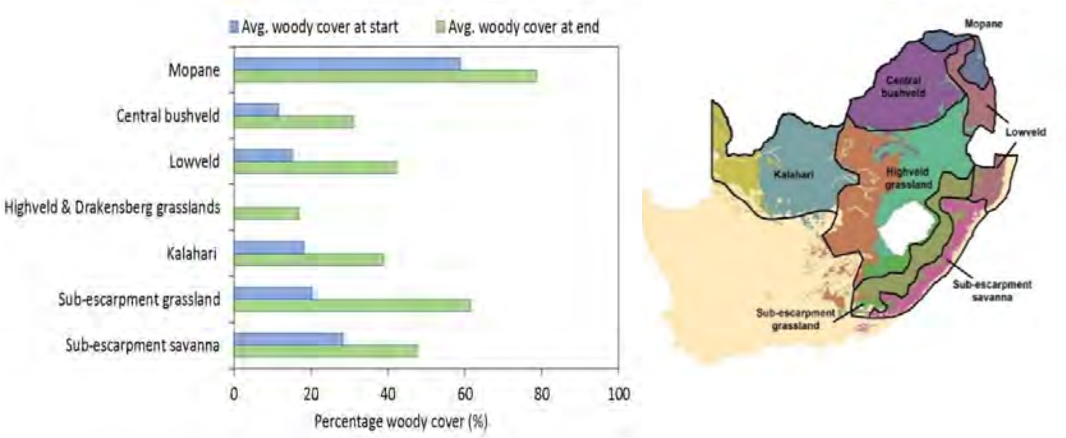

Figure 2.17. The average percentage woody cover at the start and end of monitoring within different bioregional zones. Source: Turpie et al. (2018), based on data in O'Connor et al. (2014).

2.7.4 Invasive alien plants (IAPs)

As in the case of bush encroachment, increases in woody cover due to IAPs can lead to a change in land capability (e.g. decreased grazing capacity, but increased production of fuel wood), and a decrease in biodiversity and water yields. In KwaZulu-Natal, IAPs include a suite of species such as *Eucalyptus* that tend to invade water courses, affecting water flows. Other species such as *Lantana* invade terrestrial areas and displace grazing and have an impact on biodiversity. The maps of IAPs are not particularly accurate but have been updated under the National Invasive Alien Plant Survey (NIAPS) project. In the KwaZulu-Natal catchments, IAPs are estimated to reduce water flows by 2.3-5.0% compared to water use by indigenous vegetation (Le Maitre *et al.* 2016). The government has been tackling the spread of IAPs since the inception of the Working for Water programme in 1995 as the first of the Natural Resource Management programmes established primarily for employment creation, but has not managed to get ahead of it.

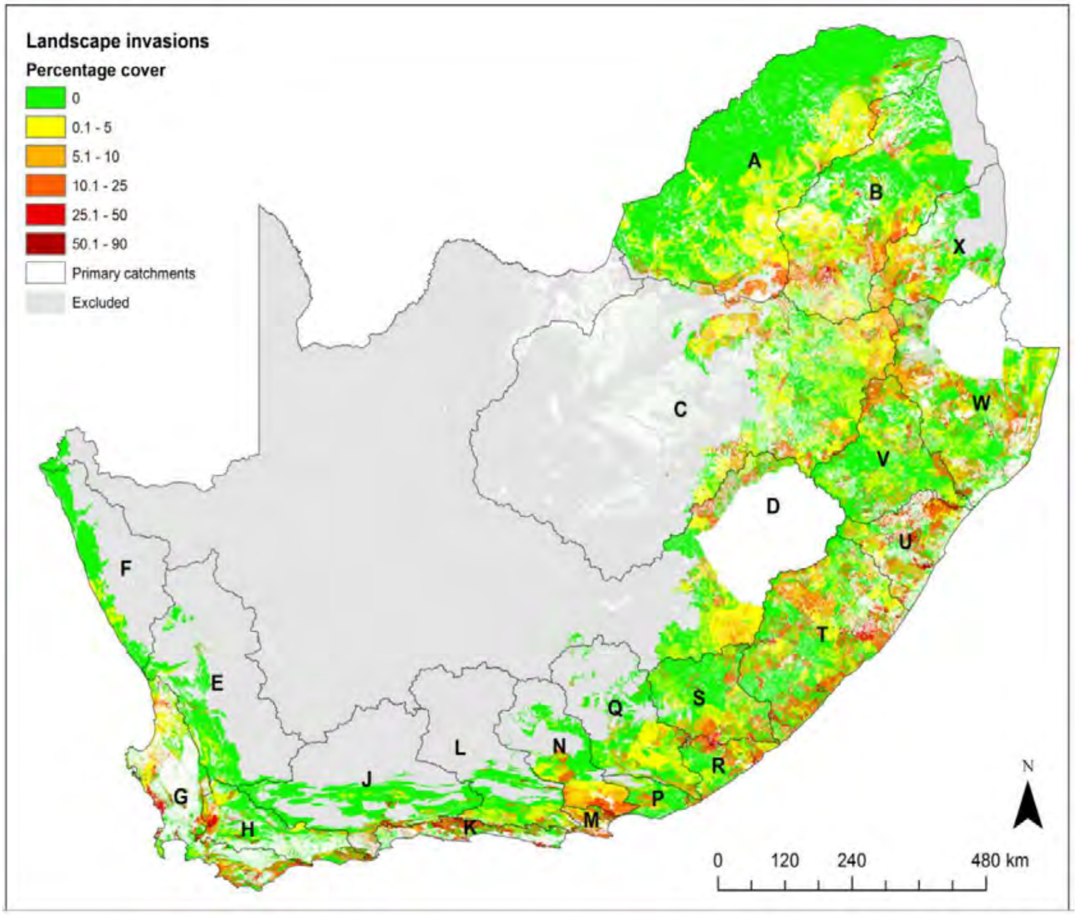

Figure 2.18. Estimated total percentage cover of invasive alien plant species for each homogenous mapping unit included in the landscape invasions as mapped by the NIAPS. Areas denoted by letters are the primary catchments/catchment groupings. In KwaZulu-Natal, W includes the uMfolozi catchment, V = Thukela catchment, U includes the uMgeni catchment and T includes the Mzimkhulu catchment. Source: Le Maitre et al. (2016).

2.7.5 Hydrological alteration

South Africa is a water scarce country and has invested heavily in water supply infrastructure, including a number of inter-basin transfer schemes. Indeed, water from the Thukela basin in KwaZulu-Natal is captured and transferred for use in the country's economic hub of Gauteng. Reservoirs have been built on a large proportion of the country's rivers, and KwaZulu-Natal, in spite of its relatively high rainfall, is no exception. Furthermore, significant quantities of water are abstracted directly from rivers for irrigation agriculture, a trend that has shown a notable increase over the past few decades. While these abstractions are regulated and Environmental Flow Requirements (EFR) are accounted for in policy and legislation[2], the damming and abstraction of water from river systems does affect the health of downstream aquatic ecosystems and the nearshore marine environment. This is especially the case when hydrological alteration is combined with increased sedimentation and pollution.

2.7.6 Poaching and overexploitation of species

Organised wildlife crime and the illegal trade in wildlife products, subsistence poaching and overexploitation pose a threat to many species in KwaZulu-Natal, many of which are nationally and internationally endangered species (Lindsey *et al*. 2015, Ntuli *et al.* 2019). Poaching, defined here as any unsanctioned hunting or capturing of wild animals, can be carried out as a subsistence activity, a small-scale commercial activity or as part of a much larger organised crime operation, with the latter tending to target high-value animals or animal parts for export. While subsistence hunting and harvesting of wild resources has been practiced for millennia, increases in human populations has meant that harvests are often no longer sustainable. Furthermore, these practices have often expanded into commercial enterprises, for example to meet demands for fuel and traditional medicines in urban areas.

Almost 30% of the land area in KwaZulu-Natal is owned by the Ingonyama Trust and largely under communal tenure. In these communal areas where economic opportunities are limited and population densities are high, many people are reliant on wild resources for nutrition, health, energy and raw materials. As a result, subsistence poaching and overexploitation of wild plant and animal species is a growing concern. Moreover, many protected areas in KwaZulu-Natal are now suffering from the dual threat of small scale poaching for bushmeat and organised wildlife crime for non-meat trophies such as ivory and rhino horn. Lucrative payments are made to poachers and trackers, and the private returns are significantly higher than those received through cooperation with community conservation efforts that may exist with the communities surrounding these parks. Since 2007, more than 8500 rhinoceroses have been poached for their horn in South Africa[3]. The Hluhluwe-iMfolozi Park, situated in northern KwaZulu-Natal, is home to the second largest population of rhinoceros in the country which has

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[2] The National Water Act (1998) holds at its core two principles - Basic Human Needs and the Ecological Reserve. The Ecological Reserve is an allocation of water specified as a volume and quality underpinned by flow and duration requirements to sustain the specified river ecosystem.

[3] Statistics taken from https://www.helpingrhinos.org/2019-poaching-stats/ sourced from the Department of Environmental Affairs.

been particularly hard-hit by organised wildlife syndicates. In 2018, KwaZulu-Natal had the second highest number of rhinoceroses poached (142) in the country, representing 18.5% of the total. In 2019, the number had decreased to 133, but represented 22% of the total[4].

Poaching, wildlife crime and overexploitation of species pose a significant threat to the ecology of wildlife areas. These activities cause decreases in abundance, range collapse, and extinction, which can negatively impact on ecosystem functioning. Furthermore, the resulting loss of biodiversity can jeopardize livelihoods by affecting food security and the security of rural economies dependant on wildlife tourism. Note that while we account for subsistence harvesting of wild resources (and overexploitation) in this report, we do not account for high value commercial poaching of endangered species.

2.7.7 Solid waste, air and water pollution

Pollution problems in KwaZulu-Natal tend to be concentrated in aquatic ecosystems and urban areas. The management of solid waste remains a significant environmental challenge not just in KwaZulu-Natal but across South Africa. It is of particular concern in rapidly-developing peri-urban and urban settlement areas where municipalities face exponentially increasing waste generation amidst limited fiscal resources. Much of this solid waste is made up of single-use plastics which block culverts and drains which increases problems of flooding. Solid waste also lands up on beaches and impacts on marine ecosystems (Jambeck *et al.* 2015, Ryan 1990).

Air pollution is a problem in the major industrial centres of Durban, Pietermaritzburg and Richards Bay. The heavily industrialised Durban South Basin is home to the largest concentration of petrochemical industries in the country as well as a number of large paper mills. Transport infrastructure linked to Durban Port is also a major contributor to air pollution. Richards Bay has the largest coal export terminal in the world, as well as the largest aluminium and iron smelters in Africa (Okello *et al.* 2018). In addition, there are several commercial, light and heavy industrial activities such as paper, fertilizer and sugar production located in and around the city, which collectively contribute to most of the air quality concerns in the region (Okello *et al.* 2018). Sugarcane and forestry burning, pesticide usage and dust associated with agricultural processes are common across most of the coastal region of the province.

Water pollution comes from a number of different sources including industrial, residential and agricultural runoff, stormwater outflows, solid waste and effluent return flows from wastewater treatment works. These pollution sources together have a major impact on the health of freshwater, estuarine and marine ecosystems and their biodiversity, particularly in the more populous parts of the province and where informal settlements lack adequate sanitation services.

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[4] As in footnote 4.

3 METHODOLOGICAL FRAMEWORK

3.1 Overview

These accounts have been developed based on the System of Environmental Economic Accounting – Experimental Ecosystem Accounts (SEEA EEA) and associated guidelines (UN 2014a, UN 2014b, UN 2017). In 2012 (formally published in 2014), the System of Environmental-Economic Accounting (SEEA) Central Framework was adopted by the United Nations Statistical Commission as the first international statistical standard for environmental-economic accounting (UN 2014a). The SEEA Central Framework, which builds on previous versions of the SEEA, is a conceptual framework that focuses on understanding the interactions between the economy and environment and for describing stocks and changes in stocks of environmental assets. The Central Framework covers measurement in three main areas (UN 2014a):

1. **Environmental flows**. Flows of natural inputs and products between the environment and the economy, both in physical and monetary terms.

2. **Stocks of environmental assets**. The stocks of individual assets and how these change over an accounting period as a result of economic activity and natural processes, both in physical and monetary terms. Individual assets include water and energy assets.

3. **Economic activity related to the environment**. This relates to monetary flows associated with economic activities that are related to the environment. This includes spending on environmental protection and resource management, as well as the production of ecosystem goods and services.

The SEEA Experimental Ecosystem Accounting (SEEA EEA, UN 2014b) complements, and builds on, the accounting for environmental assets as described in the SEEA Central Framework. However, the SEEA EEA accounting approach recognises that individual resources (e.g. timber, soil and water) function in combination within a broader system, linking ecosystems to economic and other human activities with the intention of integrating environmental sustainability, human wellbeing and economic growth and development into one accounting framework (UN 2014b). Therefore, the SEEA EEA focuses on ecosystems and assesses how individual environmental assets interact as part of natural processes within a given spatial area. Following the ecosystem accounting framework, ecosystem assets are delineated as spatial areas that provide ecosystem services, recognised as contributions and benefits of ecosystems to economic and other human activity (UN 2014b). The SEEA EEA framework uses a system of accounts as follows:

1. **Ecosystem extent account**. This account organises information on the extent of different ecosystem types within a designated spatial area in terms of area.

2. **Ecosystem condition account**. This account measures the overall quality of an ecosystem asset. Using key indicators, the functioning of the ecosystem in relation to its naturalness and ability to supply ecosystem services is captured.

3. **Ecosystem services accounts**. Presented as a set of ecosystem accounts, these measure the supply of ecosystem services as well as their corresponding beneficiaries.

4. **Monetary asset account**. This account records the monetary value of opening and closing stocks of all ecosystem assets within an ecosystem accounting area and any additions or reductions to these stocks.

5. **Thematic accounts**. These are standalone accounts which cover land, water, carbon and biodiversity. They are of direct relevance in the measurement of ecosystems and in assessing policy response.

In October 2017, the SEEA EEA Technical Recommendations report (UN 2017) was published, providing a range of content to support the testing and research on ecosystem accounting. Since the development of the SEEA Conceptual Framework and SEEA EEA, additional issues, interpretation and approaches have arisen and, as a result, advances in thinking on specific ecosystem accounting topics are included in the Technical Recommendations in order to provide up-to-date content in a rapidly developing field (UN 2017). The Technical Recommendations build directly on the ecosystem accounting framework outlined in the SEEA EEA, providing additional explanation and direction for the compilation of ecosystem accounts.

Given the increasing level of interest and ongoing experimentation and testing, the SEEA EEA is currently under revision. The SEEA EEA Revision was officially launched in March 2018 with the focus of advancing four key research issues identified as priority areas for the EEA revision. These are – spatial areas, ecosystem condition, ecosystem services and valuation and accounting treatments. Outputs from these working groups will serve as input into drafting the chapters of the revised SEEA EEA. As such, not all details had been fleshed out or finalised at the time of this study, and this study has therefore involved some experimentation and decisions on methodology, with the aim of informing the finalisation of the ecosystem accounting framework and methods for the EEA revision.

In this analysis, the accounts are developed using spatially explicit estimates of the supply of ecosystem services in physical terms and their benefits in monetary terms. The accounts take the form of tables. For this analysis, the accounts are presented at the scale of the province, disaggregated by biome. The results are also displayed in maps, graphically and in supplementary tables to show patterns as appropriate. The following accounts are presented:

- Ecosystem supply and use accounts in physical terms;
- Ecosystem supply and use accounts in monetary terms; and
- Ecosystem monetary asset accounts.

3.2 Ecosystem services

The concept of ecosystem services emerged in the 1980s and 1990s (Ehrlich and Mooney 1983, Costanza *et al.* 1997; Daily 1997). Since then, a number of conceptual frameworks and classification systems for ecosystem services have been proposed, and the development of a standardised approach to classify and value ecosystem services remains a serious challenge (UN 2014a, Potschin *et al.* 2016, La Notte *et al.* 2017). Accordingly, there is also a range of interpretations of ecosystem services and associated terminology and application, such as the definition and overlap of intermediate and final ecosystem services and the terminology used to describe ecosystem services and the benefits they produce (La Notte *et al.* 2017, UN 2017). Differing interpretations of classification and inconsistency across concepts and terminology has resulted in ambiguity. The SEEA Technical Recommendations (UN 2017) provides some clarification on the issue, but has flagged the "definition and classification of ecosystem services" as a key area for research, stressing the importance of further consultation to introduce a definitive classification system that is appropriate for ecosystem accounting purposes at national scales. It is therefore necessary to provide some clarity on the topic here and to outline the approach and terminology currently adopted by the SEEA EEA (UN 2014b, 2017).

Commonly-used classification systems include the following:

- The **Millennium Ecosystem Assessment** (2005) grouped ecosystem services into four categories - provisioning services, regulating services, cultural services, and supporting services (comprising the underlying processes which maintain conditions for life on Earth). Inclusion of the latter raised concerns about double-counting;

- **The Economics of Ecosystems and Biodiversity** (TEEB) classification (2010) refined the distinction between services and benefits, and replaced "supporting services" with "habitat services" (maintenance of life cycles and genetic diversity; La Notte *et al.* 2017);

- The **Final Ecosystem Goods and Services Classification System** (FEGS-CS) and the **National Ecosystem Services Classification System** (NESCS) were proposed by the US Environmental Protection Agency (Landers & Nahlik 2013, US EPA 2015). These focus on benefits and beneficiaries in order to avoid possible double counting in valuation (La Notte *et al.* 2017). Under the FEGS-CS, processes such as photosynthesis and carbon sequestration are considered intermediate ecosystem services as they are "not directly used by humans" (La Notte *et al.* 2017).

- The **Common International Classification of Ecosystem Services** (CICES; Haines-Young & Potschin 2013, Haines-Young & Potschin 2017)[5] also focuses on "final" ecosystem services (see Appendix 1). For example, the MEA would recognise fodder for livestock production as a service, whereas CICES would identify livestock production as the

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[5] CICES was updated to version 4.3 in 2013, version 5.0 in 2017 and version 5.1 in January 2018

> service, and fodder as an intermediate service. It places greater emphasis on the ecological system than FEGS-CS, which focuses on the socio-economic system (La Notte *et al.* 2017). CICES merges the “habitat services” as described by TEEB with regulating services into a single category called “regulating and maintenance services”. It broadens the concept of ecosystems to include highly modified systems such as croplands and artificial water bodies, and broadens the concept of services to include crop and livestock production (as opposed to the environmental *inputs* to crop and livestock production) and their co-benefits such as draught power. It also includes water, minerals and abiotic energy.

Although initially informed by CICES, the SEEA EEA revision process is currently interrogating a range of ideas and developing its own methods for defining ecosystems and ecosystem services, and for their valuation. Ecosystems are to be very broadly defined to include highly modified systems such as agricultural fields, reservoirs, urban parklands, etc. Indeed, the distinction between natural and modified ecosystems is difficult, since they exist on a continuum, from those with very little or no human inputs, through various degrees of management, to those which are highly modified, and bearing very little resemblance to the natural state. Ecosystem services are defined “from the perspective of contributions that ecosystems make to benefits used in economic and other human activity” (i.e. they are contributions that ecosystems make to human wellbeing, UN 2017). The focus for national-level accounting is on final ecosystem services, all of which have a direct link with economic units (i.e. businesses, households and governments). However, note that the final ecosystem service is often an input (e.g. fodder) along with other human inputs (e.g. labour and fencing) to produce a benefit (e.g. income from livestock production), and it is the contribution to that benefit that must be determined in the valuation of these services.

Ecosystem services to be considered in the SEEA are unlikely to include water, minerals and other abiotic services, since these are not produced by extant ecosystems. These are potentially controversial decisions, as abiotic resources such as water are commonly included in ecosystem service assessments as provisioning services. Indeed, the SEEA EEA Technical Recommendations report recognises that none of the classification systems is necessarily a perfect fit for accounting and further work will be needed to develop an ecosystem service classification system that is fully aligned with the SEEA EEA (UN 2017). It recommends that in the compilation of ecosystem services for ecosystem accounts, CICES, FEGS or NESCS classification frameworks should be used to build an understanding of the gaps in information (e.g. identifying ecosystem services that have not been measured, or identifying ecosystem types where certain ecosystem services have not yet been measured).

For this study, a list of major types of ecosystem services[6] was devised based on the international literature and classification systems as well as our understanding of ecosystem services and the study area (Table 3.1). The list does not include water as a provisioning service, since it is not produced by ecosystems. Rather, we regard ecosystem services pertaining to

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[6] Note that it can be misleading to state or compare the “number” of ecosystem services included in a study, since the types of services discussed are nearly always groupings that could be subdivided in various ways.

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. To regard water as a provisioning service in addition would therefore be double counting. Furthermore, the flows and use of water are usually accounted for separately as a resource account (e.g. see South Africa's National Water Accounts). We also differ from CICES in that within crop and animal production (eco)systems we consider 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 can account for pollination and pest control services as an input from surrounding ecosystems.

Table 3.1. Ecosystem services considered in this study, with brief explanations of the services. Those that are included in this study are highlighted with an asterisk

Broad category	Ecosystem service	Description and physical measure
Provisioning services	Production of **wild biomass***	Wild natural resources harvested from ecosystems for subsistence or small-scale production, in terms of **kg or m^3 per ha per year**
	In situ ecosystem inputs to **reared animal** production*	Numbers of livestock or ranched wildlife supported per ha, standardised in terms of **Large Stock Units per ha**. We do not express this in terms of production, since the wildlife farms have a mix of consumptive and non-consumptive activities.
	In situ ecosystem inputs to **crop** production*	Total output in terms of **kg per ha per year**
	In situ ecosystem inputs to **plantation forestry** production*	Total output in terms of **m^3 per ha per year**
	Genetic resources	Genes and varieties obtained and their influence on pharmaceutical sales and crop and livestock production.
Cultural services	**Experiential value** associated with active or passive use*	Experiential fulfilment associated with active or passive use, through any type of activity ranging from adventure sport to birdwatching to religious activities or cultural ceremonies. Valued in three ways which are considered to be additive: (a) contribution to **property value*** (b) net income generated and consumer surplus generated through **local use** (c) net income (all) and consumer surplus (domestic only) generated through **tourism***
	Existence value	Fulfilment associated with knowledge of **existence** for intrinsic value or for present or future generations. Not considered in SEEA EA and should not be included in ecosystem services accounts.
Regulating services	**Flood attenuation** *	Smoothing of fluvial flows during storm events through interception, infiltration, storage and landscape roughness, reducing the flood peak volume, velocity and flood height in the receiving area, and reduction of coastal flooding by the sea through dampening storm surges and limiting run-up distance by coastal ecosystems such as coral reefs, mangroves and dunes. Estimated in terms of flooding characteristics under different storm return periods or categories.
	Seasonal flow regulation*	Smoothing of flow over the longer duration through infiltration and storage, reducing need for storage to achieve

Broad category	Ecosystem service	Description and physical measure
		a given yield. Measured in terms of higher dry season flows relative to without-service situation.
	Sediment retention*	Reducing soil loss and sediment transportation to downstream environments (including mudslides) through holding soils in situ (by vegetative cover) or through trapping eroded sediments (by slowing down movement of water through the landscape, e.g. in a wetland). Measured in terms of the difference in amount of sediment retained (m^3 per year) at key points between the observed land cover and a situation of bare and degraded landscape (for wetlands this means loss of holding capacity).
	Water quality amelioration*	Reducing nutrients transported to downstream environments as a result of uptake in the environment. Measured in terms of the difference in the nutrient loads (kg per year) delivered at key points between the observed land cover situation and a situation of intensively modified and degraded landscape (for wetlands this means loss of holding capacity).
	Carbon storage and sequestration*	Stocks of carbon in each time period, expressed as tonnes of carbon per ha; annual additions and subtractions are not estimated but net changes are tabulated between two time periods
	Agricultural support services*	Pollination of crops and control of crop pests by animals living in surrounding environments. Measured as difference in output of the serviced areas. Note that this requires attributing some of the ecosystem inputs to crop production to surrounding habitat rather than the land under crops.
	Critical habitat for fisheries and wildlife	Provision of critical habitat for populations that are utilised in other locations, such as fish nursery areas; wildlife breeding areas or migratory staging areas. As for the above service, this requires attributing some of the ecosystem inputs to these activities to the critical habitat areas rather than the areas in which the activities take place.

3.3 Valuation

In order to be compatible with the measures used in the SNA, the SEEA will express the value of ecosystems in terms of “exchange values”, which is the amount that is paid by the users of ecosystem services to the owners of those services, or that would be paid if a market existed (UN 2017). Note that this differs from the welfare measures used in conventional valuation of ecosystem services, e.g. for use in project or policy appraisal methods such as cost-benefit analysis. In the latter, the economic value used is the sum of producer and consumer surplus, where producer surplus is the producer’s net income (turnover minus all costs of production) and consumer surplus is the difference between aggregate willingness to pay and the aggregate expenditure, for a given good or service. The SNA is concerned with income, but not consumer surplus.

The SNA measures the gross output (= turnover or expenditure generated), and the direct value added (= turnover minus intermediate costs) for each sector in the economy. The latter is the

net income generated to all economic actors, and includes net income to the owners of the factors of production (= producer surplus), to employees (= salaries and wages) and to government (= taxes minus subsidies).

In the SNA, environment is not recognised as a sector, and many environmental inputs are not paid for, and thus not accounted for. In some cases, the benefit to which the environmental input contributes is accounted for (e.g. tourism), but in others it is not (e.g. recreation in open access green space areas). The latter production value is said to be outside of the SNA production boundary, as is the hypothetical production of the ecosystem services that form inputs to conventional sectoral outputs. Because it is outside the production boundary, the SNA does not impute values for transactions between ecosystems and their users. This is what the SEEA EA will do, thus providing complementary information that can be interpreted alongside the SNA.

In the SEEA EA monetary ecosystem service accounts, ecosystem services that are used in the generation of benefits are valued as if such a transaction occurred. In some cases, this would be the equivalent of an intermediate expenditure for a sector whose output is already within the SNA production boundary (e.g. inputs to agriculture). In other cases, it would be the equivalent of a final expenditure for a benefit that is outside of the SNA production boundary (e.g. use of public green open space).

It is important to note that for the cases where ecosystem services contribute to outputs that are measured in the SNA, the value assigned to ecosystems is the residual value after all costs are subtracted. A key limitation of this approach is that the proportion of the residual value to the overall gross output of the activity does not necessarily reflect the relative importance of ecosystems services in the generation of that outputs. It is a lower bound value. Indeed, a much larger proportion of the gross output of that sector (possibly all of it) could be lost if the environmental input were lost. These effects can only be determined through an accounting time series.

Not all ecosystem services are valued in this way. Some ecosystem services are consumed purposely, such as provisioning and cultural services, while others are used inadvertently, such as most of the regulating services. The first group are usually consumed through the joint contribution of ecosystem services and some form of man-made capital and labour inputs. For these services, the benefits derived from ecosystem services are valued in terms of the **residual value (or resource rent)** after all human inputs are accounted for, as described above. The second group are generally ecosystem services that could (at least in theory) be replaced by technology or infrastructure, or if lost could result in damages, and are valued in terms of **net costs saved**. Table 3.2 provides a summary of the valuation methods used for each of the services included in the preliminary accounts.

It should also be noted that in the SNA, agricultural output does not include **subsistence production** (production that is consumed by the producer, and therefore not involving any transaction). In South Africa, the value of subsistence consumption may account for an important share of agricultural sector production and makes a significant contribution to livelihoods and household resilience. Thus, in this set of accounts, the gross output from agricultural production was extended to include the value of subsistence consumption as well as sales.

Table 3.2. Summary of the valuation methods used for each ecosystem service

Category	**Ecosystem service type**	**Values and valuation methods used**
Provisioning	Production of wild biomass	Resource rent, based on market prices
	In situ inputs to reared animal production	Resource rent, based on market prices
	In situ inputs to cultivation (including silviculture)	Resource rent of agri/silvicultural commercial and subsistence production, based on market or imputed prices, less contribution of pollination service
Cultural	Experiential value: nature's contribution to tourism and property values*	Resource rent for nature-based tourism, based on market prices. Proportion of the annualised capital value of property attributed to environment, based on market prices using the hedonic pricing method
Regulating	Carbon storage	Annualised avoided damage costs using social cost of carbon
	Crop pollination**	Contribution to agricultural resource rent, based on benefit transfer of a production function
	Seasonal flow regulation	Annualised avoided costs of water supply infrastructure for existing supply systems plus avoided costs of purchasing water from vendors for those people that depend on instream flows for their domestic water supplies.
	Sediment retention	Annualised avoided cost of replacement of lost storage capacity
	Water quality amelioration	Water treatment costs avoided, based on a cost function

*Note these are two out of three elements that should be valued and does not include local recreation

**Note that this study does not include pest control as an input to agriculture due to lack of data.

The benefits derived from ecosystem services were expressed in terms of annual flows of value. The **asset value of ecosystems** was then calculated as the net present value (NPV) of the discounted sum of expected future flows of all ecosystem services that are generated by a particular ecosystem asset over a given period of time. For this analysis, we have used a social discount rate of 3.66% (based on Kotchen *et al.* 2019), and a time period of 25 years due to the high level of uncertainty in projecting beyond this (see review by Badura *et al*. 2017)[7]. This could be extended, but will ultimately need to be consistent. In the case of harvested natural

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[7] The SEEA Tech Recommendations do not make any recommendation as to what the asset life should be and the SEEA Central Framework only discusses the impact of longer asset life and discount rates on values. It does not stipulate what the asset life should be. Some countries (Netherlands, UK, Australia) discount over a period of 100 years, and some authors advocate an infinite time period.

resources, the net present value takes sustainability of use into account. This is described in more detail in the relevant section.

South Africa's national accounts are updated approximately every five years to reflect a new reference year and simultaneously benchmark estimates against new datasets. The most recent benchmark and rebasing[8] was done in November 2014, in which the reference year was updated to 2010. All results, for both 2005 and 2011, are presented in constant 2010 prices.

3.4 Spatial framework

Ideally, ecosystem accounts would track changes in individual ecosystem assets, such as wetlands, forest areas, etc. However, the regional or national scale of accounting would generally preclude this, depending on their classification and the resolution of the spatial data, as there could be tens of thousands of individual ecosystems in an accounting area the size of KwaZulu-Natal. Thus, the accounts summarise the data by biome (the broadest level of ecosystem type, see Figure 2.5) across the ecosystem accounting area. Future accounts should provide summary estimates at a higher level of resolution, such as for each type of wetland, or each type of forest, using an international system of classification to be recommended for the SEEA.

The process of constructing ecosystem accounts involves compiling and organising data on land cover, land use and ecosystem extent into a spatial framework that allows for comparison of several different spatial datasets over the accounting period. This spatial framework is supported through defining a basic spatial unit (BSU) that is internally homogenous in terms of its biophysical properties. The BSU is each cell of a grid of equal-sized cells that covers the entire area of interest for accounting. This BSU grid allows the delineation of ecosystem assets and ecosystem types and allows the integration of different spatial datasets, which often exist at different resolutions. Ecosystem assets can be defined as distinct, contiguous areas covered by a specific ecosystem type (e.g. grassland, wetland, estuary, forest). Ecosystem types, on the other hand, are aggregations of individual ecosystem assets representing a specific type of ecosystem, including non-contiguous areas (e.g. the total area of grassland). The difference between ecosystem assets and types is represented in Figure 3.1. It should be noted that since the international system is still in draft, some of this terminology could change.

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[8] Rebasing is the replacement of the national accounts existing constant prices with new constant prices from a new reference year

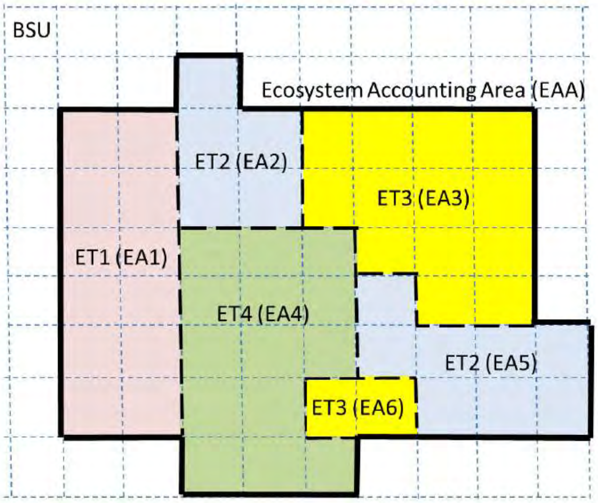

Figure 3.1. Diagram representing the relationship between the basic spatial unit (BSU – underlying grid), ecosystem assets (EAs – contiguous areas, e.g. EA1), ecosystem types (ETs – collection of EAs of similar ecosystem type, e.g. ET3) and the ecosystem accounting area (EEA – area of interest in bold outline). Source: UN (2017)

A 100 x 100 m (1 ha) grid has been constructed by Statistics South Africa (Stats SA) that covers the entire South African land area, including Prince Edward Islands, the exclusive economic zone as well as extending north into the major trans-boundary river catchments. The extent of this grid is over 728 million ha. In order to meet assumptions required for an equal areas projection that extends as far north and south as the grid, a new and unique projection was defined for the BSU grid: Albers Equal Area; Standard parallels -22, -38; Central Meridian 25. The grid was also given a unique naming convention that allows for identification and placement of each individual BSU cell across the extent. Full details of the construction of the BSU grid are given in Anderson & Parry (2018) and Anderson (2019).

In this study, the base raster layers (e.g. land use, biomes, census areas), were first projected and then snapped to the South African BSU grid. This ensured consistency across all the ecosystem services, ensuring no overlaps for any given area per land cover class. To do this, the BSU grid was effectively superimposed on each spatial dataset, and the category assigned to the BSU grid cell was taken as the dominant spatial category from the underlying dataset (known as the “majority rule” in GIS). It should be noted that the BSU layer is at a coarser resolution than most of the raster layers used (i.e. the grid cells are larger).

3.5 Accounting tables

The supply and use tables ideally only account for ecosystem services which are used. 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. These deviations are explained in more detail under the relevant sections of Chapter 4.

The supply of each type of ecosystem service is summarised for each broad ecosystem type (biome), and the use is summarised for different economic actors. As required in accounting tables, the sum of supply must equal the sum of use. The **supply tables denote origin of the utilised services** and should not be confused with ecosystem capacity to supply a particular service (which may be different from the utilised amount). For wild biomass, the amount used would also include illegal use and amounts exceeding sustainable yield. The supply and use tables also have the ability to account for intermediate ecosystem services (i.e. ecosystem service flows from one ecosystem type to another that help support the functioning of that ecosystem type), but these flows are not developed in this report.

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. The asset value is calculated as the net present value (NPV) of the benefits of ecosystem services over a finite time period (in this case 100 years). The asset valuation takes the effect of unsustainable use into account, but in this study is kept simple in that all other factors (population, economic output, climate, other ecological or socio-economic factors) are assumed to be constant. This is explained further below.

4 ECOSYSTEM SERVICES AND BENEFITS

4.1 Wild resources

4.1.1 Overview of the service

Millions of South Africans harvest wild plant and animal resources for nutrition, health, energy and raw materials, particularly where there are limited economic opportunities. The capacity of the landscape to supply different types of wild resources is related to vegetation type and condition, availability of water and other factors. However, a number of other factors determine their use and value, and these vary in space and time. The accessibility of wild resources is determined by regulations such as land tenure and harvesting rights, by social norms and informal agreements, by geographic features such as topography and rivers, and man-made features such as roads. The demand for wild resources is influenced by the socio-economic circumstances of households and the prices of alternatives. Due to data constraints, few, if any, studies have modelled these factors comprehensively. In this study we have devised relatively simple estimates of capacity, accessibility and demand. This study does not include estimates of legal commercial harvesting of wild resources outside of game ranches (which is limited), or illegal commercial-scale poaching of high value, endangered species (which was modest in 2005 of these accounts but has escalated significantly since then).

4.1.2 Data and methods

Data sources

Data were collated on the demand for different resources by households, the stocks and yields of these resources in the different habitat types of the study area, and the spatial distribution and characteristics of households in the study area.

Very little of the harvesting of wild natural resources is monitored in South Africa. Therefore, this estimation was based on ecological and socio-economic studies that have taken place in KwaZulu-Natal and in other areas with similar characteristics. The harvesting of natural resources has been studied to varying degrees in the province, particularly in the rural communal land areas (tribal authority land). Available information on system yields, quantities harvested, harvesting costs and market prices for different resource types were obtained from the literature, using information from the study area as far as possible (see Table 4.1). Where data for KwaZulu-Natal were limited, then information from comparable socio-ecological systems in South Africa or southern Africa was used. The quality of each study was also taken into consideration in deciding whether findings should be taken into account in devising our assumptions.

Table 4.1. Summary of information sources consulted in estimating the availability and use of natural resources in KwaZulu-Natal

Wild biomass	Reference	Data
Fuelwood, poles, timber	Glenday (2007)	Canopy heights, basal areas and woody volumes (m^3/ha/y) for different land cover classes in KwaZulu-Natal
	Barnes *et al.* (2005)	Tree volumes, % use suited and production yields for fuelwood, poles and timber.
	Bembridge & Tarlton 1990, Borchers *et al.* 1990, Ward 1994, Mander & Quinn 1995, Banks *et al.* 1996, Solomon 2000, Dovie *et al.* 2002, Shackleton 1993, Shackleton *et al.* 2002a, Shackleton *et al.* 2002b, Cocks and Wiersum 2003, Twine *et al.* 2003, Shackleton & Shackleton 2004, Turpie *et al.* 2007, Shackleton *et al.* 2007, Turpie *et al.* 2010a.	Household participation, average household harvesting rates (kg/hh/y), prices for fuelwood, poles and withies, timber and wood for craft production.
	Turpie *et al.* 2014	Prices and household woody resource harvesting rates at the ward level for three municipalities in the St Lucia area of KwaZulu-Natal.
Grass, reeds, sedges and palm leaves	Shackleton 1990, Turpie *et al.* 1999, McKean 2001, McKean 2003, Tarr *et al.* 2006, Turpie *et al.* 2007	Annual production rates (kg/ha) and sustainable yields for thatching grass, reeds and sedges and palm leaves
	Dovie *et al.* 2002, Shackleton *et al.* 2002.b, Twine *et al.* 2003, Shackleton *et al.* 2007, Turpie *et al.* 2010a, Mmopelwa & Blignaut 2009	Household participation, average household harvesting rates (kg/hh/y) and prices for various rural villages.
	Shackleton 1990, McKean 2003, Otsub 2004, Adekola *et al.* 2008, Mmopelwa & Blignaut 2009, Turpie *et al.* 2014	Grass, reed and palm leaf bundle size and weights
	Turpie *et al.* 2014	Prices and household non-woody resource harvesting rates at the ward level for three municipalities in the St Lucia area of KwaZulu-Natal.
Wild plant foods and medicines	Mander (1998)	Comprehensive study of medicinal plant harvesting in KwaZulu-Natal providing supply and demand data.
	Turpie *et al.* (2007)	Production and sustainable harvesting rates for medicinal plants in the Drakensberg.
	Bahuchet *et al.* 1991, Campbell *et al.* 1991, Campbell *et al.* 1997, Sato 2001, Ngorima 2006, Assefa & Abebe 2010a	Production yields, harvesting rates for wild foods in different habitats across southern Africa.
	Dovie *et al.* 2002, Dold & Cocks 2002, Cocks and Wiersum 2003, Shackleton *et al.* 2002a,b, Twine *et al.* 2003, Shackleton & Shackleton 2004, Dovie *et al.* 2007, Shackleton *et al.* 2008, Turpie *et al.* 2010a, Turpie *et al.* 2014	Household participation, average household consumption, harvesting rates and prices.
Wild animal resources	Rowe-Rowe & Scotcher 1985, Prins & Reitsma 1989, Wirminghaus & Perrin 1993, Caro 1999, Mizutani 1999, Monadjem 1997, Monadjem & Perrin 2003, Cumming & Cumming 2003, Georgiadis *et al.* 2007, Kaschula and Shackleton 2009	Wild bird and animal biomass densities (production yields) for wooded grassland, grassland, thicket, forest, woodland, wetland, and savanna habitats.
	Parry *et al.* 2009 and Fa *et al.* 2002, 2003. Based on Robinson & Redford 1991	Sustainable yields
	McCafferty *et al.* 2012, Welcomme 1985 and DWS 2014	Fish production (kg/ha) for inland water bodies
	Lamberth & Turpie 2003	Prices and fish production for estuaries
	Merron *et al.* 1993, Shackleton *et al.* 2002a, b, Twine *et al.* 2003, Turpie & Egoh 2003, Shackleton *et al.* 2007, Kaschula & Shackleton 2009, Turpie *et al.* 2010a	Household participation, bushmeat and fish household harvesting rates and prices
	Turpie *et al.* 2014	Fish harvesting rates for St Lucia and Mfolozi estuaries.

The Census data (South African Census 2001 and 2011) contains detailed household information at the provincial, municipal, ward, main place and sub-place level. The information can be disaggregated at any of these levels but do not align spatially with the magisterial districts, for example. For this analysis, the data were analysed at the sub-place level (similar to a suburb).

Grouping of wild resources used

People in KwaZulu-Natal use hundreds of species of plants and animals for food, medicine, energy and raw materials. For the purposes of this study and based on the nature of the data, the resources were grouped as follows (Table 4.2).

Table 4.2. Wild biomass groupings based on the CICES framework

	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

Estimation of stocks

Spatial variation in resource stocks and yields per unit area were estimated based on information from the literature for ecosystem types corresponding to the different natural land cover classes of the KwaZulu-Natal Land Cover series, in conjunction with information on vegetation types (from SANBI's 2018 digital update of the South African Vegetation Map of Mucina & Rutherford 2006) or species distributions, where appropriate (see Appendix 3 for more detail). The land cover provides the most suitable primary data for the assessment, since it is based on satellite imagery of vegetation structure at the time of the account, whereas the vegetation map is a static description of the distribution of floral communities before the influence of man and in some areas bears little relationship to the vegetation present at the time period under study. It should be noted that the "forest" and "grassland" land cover classes match up almost exactly with the forest and grassland biomes in the vegetation map, whereas there is much more variation in land cover classes within the savanna biome. Table 4.3 provides a list of land cover classes in KwaZulu-Natal that were used in the estimation of natural resource stocks and yields per unit area.

Estimation of demand

The quantities of resources harvested by subsistence and small-scale users from terrestrial, freshwater and estuarine habitats was estimated based on the estimated household demand and available stocks in the landscape. Quantities demanded were estimated at the census sub-place (~village) level based on household survey data and census data on numbers of households and types of dwelling. In KwaZulu-Natal there were 4196 sub-places within 51 municipalities and 11 district municipalities in 2011. Relevant census data available at the sub-place level included: population, number of households, average household size, number of traditional dwellings, number of informal dwellings, households using wood, number of households collecting water from rivers and streams, and number of households using wood for heating and cooking.

Table 4.3. 2011 KwaZulu-Natal natural land cover classes. Source: Ezemvelo KZN Wildlife

Land cover class	Description
Water (natural)	All areas of natural open water, excluding estuarine, and coastal waters.
Water (estuarine)	All areas of natural open water, associated with the estuarine reaches of a river.
Wetland	All permanent, near permanent or daily freshwater, brackish or saline wetland areas.
Mangrove wetland	Mangrove wetlands
Grassland	Open grassland areas.
Degraded grassland	Areas of Grassland that show a significant loss of grass canopy cover, when compared to surrounding areas of grassland. If tree loss is significant, “degraded woodland and wooded grassland” areas will be included in this class.
Bush clumps/grassland	Grassland dominated areas with scattered bush and thicket clumps.
Woodland & wooded grassland	Tree based communities with an open grass layer, with tree canopy closure between 10-70%.
Medium bush	Medium / tall shrub dominated communities with 40-70% canopy closure.
Dense thicket and bush	Dense, medium/tall, tree and shrub dominated communities with > 70 % canopy closure
Degraded bushland (all types)	Areas of Bushland (all types, dense thicket & bush, medium bush, bush clumps & grassland) that show a significant loss of tree and/or shrub canopy cover, when compared to surrounding areas of natural Bushland. If tree loss is not significant, “degraded woodland and wooded grassland” areas will be included in this class.
Forest (indigenous)	Dense, tall tree dominated forest communities with > 70% canopy closure.
Degraded forest	Areas of Forest that show a significant loss of tree and shrub canopy cover, when compared to surrounding areas of natural Forest.
Forest glade	Naturally occurring open grassy regions, enclosed within closed canopy indigenous forests.
Alpine grass-heath	Communities of low shrubland and grassland typically associated with the high-altitude Drakensberg Escarpment Plateau regions.

Household demand in 2011 was based on the 2011 Census data. In order to estimate the demand in 2005, a linear interpolation was made between the Census 2001 and 2011 data at the district municipality scale (Table 4.4). This generated a set of adjustment factors that were applied to estimate household numbers and characteristics in 2005 at the sub-place level. While the population and number of households increased from 2005 to 2011, the number of people residing in traditional dwellings and informal dwellings decreased.

Table 4.4. Adjustment factors applied to the Census 2011 data to generate estimates for 2005. Based on interpolations between Census 2001 and 2011 data.

District Municipality	Population	Households	Traditional dwelling	Informal dwelling
Amajuba	0.96	0.92	1.42	2.04
eThekwini	0.94	0.90	1.30	1.21
iLembe	0.95	0.86	1.13	1.49
Harry Gwala	0.79	0.79	0.78	1.34
Ugu	0.98	0.91	1.10	1.06
uMgungundlovu	0.95	0.88	0.96	1.48
uMkhanyakude	0.95	0.88	1.33	2.92
uMzinyathi	0.94	0.88	1.05	1.03
uThukela	0.99	0.95	1.14	3.02
King Cetshwayo	0.99	0.91	1.19	2.70
Zululand	1.00	0.95	1.39	3.51

The potential aggregate household demand for all natural resources was estimated using models developed by Turpie *et al.* (2010a) that relate average use to household characteristics, or average values from a range of socio-economic studies that have been carried out in the communal areas of KwaZulu-Natal and elsewhere in South Africa where data was lacking (Table 4.5, see Appendix 2 for more detail). In this way, the total demand (e.g. kg/y, m^3/y) for each resource was estimated for each sub-place.

Table 4.5. Criteria and assumptions used for each resource group to calculate total demand per sub-place. Table indicates whether models from Turpie et al. (2010a) were used or if data from the literature was used in conjunction with Census 2011 data.

Resource group	Method/assumptions	Number of studies used	Other information
Fuelwood	hh using fuelwood; 3000 kg/hh/year	18	Converted kg/y into m^3/y using avg. wood density of 0.855 g/cm^3 (FAO)
Poles & withies	66% hh, 200 kg/hh/year	12	
Timber & wood	4% hh; 900 kg/hh/year	3	
Grass	33% hh; 76 bundles/hh/year	7	Grass bundle = 4.9 kg
Reeds & sedges	Turpie *et al.* (2010a) model	2	Reed bundle = 7 kg
Palm leaves	1.2% trad. hh; 660 leaves/hh/year	2	Each leaf provides 0.31 kg of weaving material
Wild fruits	Turpie *et al.* (2010a) model	1	
Wild vegetables	75% hh; 20 kg/hh/year	9	
Medicines	26% hh; 32 kg/hh/year	4	
Wild animals	Turpie *et al.* (2010a) model	1	
Wild birds	Turpie *et al.* (2010a) model	1	Avg. bird weight of 0.9kg
Fish	Turpie *et al.* (2010a) model	1	

For the resources where the average percentage households harvesting was used to calculate demand, we applied this to traditional households within each sub-place and not to all households. Therefore, this is a likely conservative estimate of demand for some resource groups, such as wild foods and medicines, where user households may not be restricted only to traditional houses. A nation-wide, comprehensive household survey of wild resource use is needed for standardisation purposes. Where more detailed information was available for specific areas in KwaZulu-Natal, such as for 25 sub-places in the St Lucia area of northern KwaZulu-Natal (see Turpie *et al.* 2014), specific data collected on household demand during household surveys of this particular area were used instead. The total demand in each sub-place was then mapped to the location of settlements within that sub-place. The same approach and assumptions and criteria used to estimate total demand per sub-place for each resource in 2011 were used to estimate household demand in 2005.

Available stocks

All of the harvestable resources were considered fully available and accessible within areas under communal land tenure. In reality, this could be limited by local traditional leaders as has been found to be the case in other parts of the continent, but there is little information on this, and such limitations are unlikely in the study area. The assumed availability was reduced to 10% of standing stocks in protected areas and for natural land under private ownership, such as commercial rangelands or wildlife ranches. The retention of some availability in these areas was to allow for illegal or limited sanctioned harvesting.

The assumption of 10% was arbitrary and may be modified in future on the basis of further research. While the protected areas have historically had a no-take policy for resources, most have experienced some level of unsanctioned resource extraction. Over time, various protected areas have introduced arrangements to allow controlled access to certain resources, particularly where parks are adjacent to poor rural communities (Vermeulen *et al.* 2019). More recently, resource harvesting agreements have also been introduced or formalised under land claim settlements, which have come about as restitution for the forced removal of people when the parks were established. Some parks do maintain data on legal and illegal resource harvesting, and these efforts will need to be extended, collated and analysed in a systematic way for use in the accounts.

Wild resources harvested

The amount of wild resources harvested for subsistence use was estimated based on the minimum of the estimated demand and the estimated available stocks of resources within a specified distance of the demand source. This is a slightly different approach to that used by Turpie *et al.* (2017a) in which *sustainable* use was estimated at national scale by comparing demand with sustainable yields at the municipality level. In this study, we estimate total wild resources harvested, and use a more refined method of estimation of the spatial location of harvesting that does not compartmentalise harvesting within administrative boundary lines and which is more suitable for a provincial-scale analysis. This method does have limitations which are discussed further below, which can be resolved through further data collection and more complex spatial modelling.

We based the dimensions of our analysis on an estimated average travelling distance to harvest natural resources of about 6 km. The literature from South Africa and other African countries reports a large range in such distances, and often focuses on the time spent harvesting rather than distance travelled. It is also worth noting that total distance travelled is also not necessarily in a straight line away from household, so total distance travelled is likely to be more than twice the potential radius of the area searched. This decision of 6 km was based on reviewing the following studies:

- Matsika *et al.* 2013 – 180-240 mins/trip
- Banks *et al.* 1996 – up to 3 km
- Wessels *et al.* 2013 – not beyond 1000 m
- Madubansi & Shackleton 2007 – 207-277 mins (1991) & 220-239 mins (2002)
- Agea *et al.* 2010 – 8-12 km round trip
- Amoah *et al.* 2015 – 3-4 km
- (referenced in Amoah *et al.* 2015) - Tanzania 3 km
- (referenced in Amoah *et al.* 2015) - Zambia 7.7 km
- Turpie & Egoh 2003 – 1-12km depending on resource, 120-180 min/trip

In order to estimate and map harvesting at higher resolution than Turpie *et al.* (2017a), we used a running mean method (see Figure 4.1). The method was selected after experimentation with several possible spatial approaches, including use of the Focal Statistics tool within ArcGIS. The running-mean method entailed estimation of the value for each grid cell based on multiple spatial computations, based on the spatial relationships between the units of demand (households) and the availability of the relevant resources in the surrounding landscape.

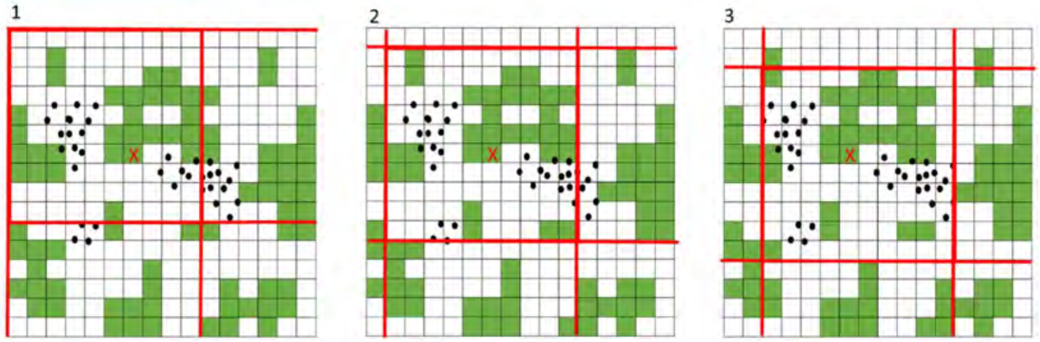

Figure 4.1. Graphic illustration of three steps in a 10-step process to calculate the running mean estimate of resource use value in the square marked X. Green areas are areas with stocks of a resource, and the dots are households demanding the resource at a certain rate. Source: this study.

The dimensions of the square (10 x 10 km) relate to the assumption of the expected maximum distance travelled from households to collect resources, since the average distance from centre to the perimeter is about 6 km. The running mean was generated by recalculating the values using a total of ten 10 x 10 km grids, each of which offset from the previous grid by 1 km to the east and south. In each iteration the relative demand and availability differ. The running-mean method leads to resource value estimates being higher in the supply zones closer to the centres of demand and attenuating from there, which provides a relatively realistic pattern of harvesting under some simplifying assumptions, and does away with the need for modelling a complex distance-decay function in GIS. However, it is still limited in that it does not take factors such as topography, other physical barriers or use of road transport into account. In situations where the local demand is higher than can be sustained within usual walking distance, it is to be expected that entrepreneurs with access to transport will bring resources from more distant areas. For this reason, harvesting is unlikely to be capped at levels of availability within the local area, but the total size of the source area used to meet demand will be determined by economics as well as accessibility. ***Future accounting efforts should seek to incorporate these factors***.

Valuation of harvested resources

As per EEA guidelines, the estimated total amount of resources extracted was valued, irrespective of whether the estimated level of harvesting was sustainable or permitted. The resource rent method was used for valuing the quantities harvested, where value is the total revenue minus intermediate costs, labour costs and depreciation and return on fixed capital.

Total revenue was taken to be the market value of the resources harvested, irrespective of whether they were consumed or sold, using average prices obtained from the literature (Table 4.6). The costs of harvesting natural resources includes the opportunity cost of labour and input costs, including annualised costs of equipment. Previous studies have taken the approach of using the shadow price of wage labour which represents the rate at which people would be willing to work for, i.e. adjusted for employment conditions. In the more remote, rural areas of KwaZulu-Natal where natural resources are harvested for subsistence purposes, the rate of unemployment is high and there are few alternative income opportunities. Employment in the formal sector (e.g. in the tourism and sugar industries) is very limited. In 2011, outside of the urban municipalities, the employment rate was as low as 20% (Census 2011). Therefore, those individuals that are spending their time harvesting resources are not doing so at the cost of alternative income. In this study it was assumed that all input costs were negligible.

Table 4.6. Values used for natural resources harvested

Resource	unit	Value per unit, 2010 ZAR
Fuelwood	m^3	864
Poles	m^3	722
Timber	m^3	1360
Wild medicines	kg	27
Wild plant foods	kg	12
Thatching grass	kg	24
Reeds and sedges	kg	25
Palm leaves	kg	44
Bushmeat	kg	15
Fish	kg	11

Contribution of wild resources to ecosystem asset value

Asset value is calculated based on projected flows of benefits over time, holding external factors such as change in climate, population, income levels and preferences constant for the sake of simplicity and comparability. However, in the case of wild resources provisioning, the contribution of this service to asset value needs to take sustainability of harvesting into account. To account for this, harvesting was compared to the corresponding sustainable yield at the level of the BSU. Where harvesting exceeded the estimated sustainable use, the stocks were eroded at the corresponding rate, affecting future use and values.

It was assumed that the maximum sustainable yield (MSY) corresponds to the intrinsic rate of production r at 50% of the stock x at carrying capacity X, that utilised, non-degraded vegetation types (or healthy populations) were at $0.5X$ on average and that resources could be harvested at their maximum rate of production r, so that $S = r = MSY$. In degraded natural land cover classes, the sustainable yield S was lowered in proportion to the estimated reduction in stocks, based on the literature. The net present value of wild resource provisioning services NPV_w was calculated for each BSU as

$$NPV_w = \sum_{i=0}^{i} \left(\sum_{t=0}^{100} \frac{\min(h_t, [x_{t-1} - \Delta_{t-1}])}{(1+\delta^t)} . P_i \middle| [\Delta_{t-1} = S_{t-1} - h_{t-1}] \in [0, S_{t-1}] \right),$$

Where x is the stock of the ith resource, Δ is the depletion in stock due to overharvesting, or zero in the absence of overharvesting, P_i is the unit value of the ith resource, and δ is the discount rate.

The sustainable yields for each resource were based on information collated from the literature and are shown in Table 4.7. The quantity of fuelwood, poles and timber that can be harvested from the environment on a sustainable basis is known as the wood supply. The calculation of the annual wood supply was based upon an annual wood production rate of 3% of the standing wood biomass (Rutherford 1979, Shackleton 1993, 1994, Banks *et al.* 1996, Glenday 2007). The sustainable yield of thatching grass, reeds and sedges was 30% of standing biomass based on a study by McKean (2001) on the sustainable use of *Phragmites* in northern KwaZulu-Natal. It was assumed that thatching grass had the same sustainable yield as that of reeds and sedges. McKean (2003) estimated the sustainable yield of palm leaves in northern KwaZulu-Natal to be 34% of standing biomass. The sustainable yield of wild animal resources was estimated to be 20% of the production biomass (from Parry *et al.* 2009; based on Robinson & Redford 1991).

Table 4.7. Sustainable yields (as a percentage of stocks) used for each resource

Resource	Sustainable yield
Fuelwood, poles & withies, timber	3% of standing biomass
Thatching grass, reeds and sedges	30% of standing biomass
Palm leaves	34% of standing biomass
Wild animal resources	20% of total population/biomass

The sustainability adjustment was applied for woody and non-woody raw materials. For wild foods and medicines and animal resources, in the absence of adequate data on stocks and/or productivity, use was estimated to be sustainable. ***More research is needed to refine these estimates in future studies.***

4.1.3 Results and discussion

Maps of the estimated informal harvest of different types of wild resources in 2011 are shown in the figures below (Figure 4.2 to Figure 4.6). Only the maps for 2011 are shown, as differences in the maps for 2005 are not perceptible at provincial scale. The estimated harvests of fuelwood, bushmeat and thatching grass were high across most of the communal areas of the province, while those of palm leaves, reeds and sedges were more localised because of limited ranges and habitats in which they are found. The estimated harvests are summarised at the biome level (broad vegetation type groupings) in the supply tables for 2005 (Table 4.8) and 2011 (Table 4.9). Note that in accounting terminology, supply means the amount that was harvested, not the amount available for harvesting.

Provisioning of wild resources was estimated to be worth some **R3.7 billion** in 2005 and **R3.1 billion** in 2011 (in 2010 prices). The reduction in value of R535 million over the 6-year period suggests an annual rate of decline of 2.4% per year. These values compare well with the national ecosystem services study (Turpie *et al.* 2017) in which KwaZulu-Natal was estimated to contribute R3.4 billion to the total national value of R7.5 billion. While similar approaches were used for both studies, this analysis was based on total harvests as opposed to sustainable harvests and used a more refined methodology for estimating the spatial location of harvesting. The lower value in this study may be related to the more restrictive assumption used on the harvesting distance based on walking distance. This is also a limitation of the model, which needs to be extended to consider road access to more distant sources that might be used for supplying resources to denser settlements.

Unsurprisingly, fuelwood was estimated to be the most valuable resource harvested across the province followed by thatching grass and wild foods and medicines. Fuelwood is used for heating and cooking; grasses are used in construction and for making crafts; and wild fruits and medicines are important for maintaining livelihoods and reducing household poverty. However, the value of all of these groups of wild resources decreased over the six-year period. The most significant loss in value was from the grassland and savanna biomes. On the supply side (in the sense of the amount available for harvesting), this is likely due to loss of vegetation cover and bush encroachment due to overgrazing, the spread of invasive alien plants and the expansion of low-density settlements into natural areas. On the demand side, the reductions in harvests could also be caused by urbanisation, alternative sources of income and increased availability of alternatives in construction, reducing reliance on natural resources such as grasses, reeds and poles for construction in traditional homesteads. However, for certain resources, the reduction in value could be in response to changes in the availability of the resource in the wild. For example, overharvesting of medicinal plants has resulted in many species becoming locally extinct.

In this study, the estimated sustainability of harvesting was taken into account in the calculation of net present value, by assuming that overutilization leads to a depletion of the resource base.

Areas of overharvesting were identified by mapping the relationship between estimated natural resource stocks, harvests and sustainable yields. This was done for each resource, and maps of estimated overharvesting are shown for the two most severely-overharvested resources – thatching grass and fuelwood – in Figure 4.7. The ratio between actual harvests and sustainable yield was highest for fuelwood in the communal areas of northern KwaZulu-Natal and the interior region between Pietermaritzburg and Ladysmith. Thatching grass appears to be severely overharvested across the province, particularly in the communal areas of the interior.

Based on the above assessments, the contribution of this service to the asset value of ecosystems in KwaZulu-Natal was estimated to be worth **R32.1 billion** in 2005 and **R28.4 billion** in 2011 (Table 4.12). There was a 11% reduction in this value over the six-year period. It is important to note that, while the asset value in each time period is considerably lower than it would be were the resources being harvested sustainably, the change in asset value is in large part due to an estimated change in demand. Thus, changes in asset value must be interpreted very carefully, as it may not necessarily indicate a change in capacity to deliver ecosystem services.

Nevertheless, the results suggest that there is cause for concern about the way in which natural resource stocks are being managed. While there is a trend towards the reduction in dependence of households on natural resources, this could easily be reversed as populations grow and as climate change and other pressures are brought to bear on these vulnerable communities, since natural resources tend to be the fall-back option for households suffering from economic shocks. It is important that measures are put in place to protect the stocks and reduce consumption to sustainable levels. Furthermore, encouraging sustainable land management in communal areas and implementing restoration programmes is also important to prevent further degradation of the grassland and savanna biomes.

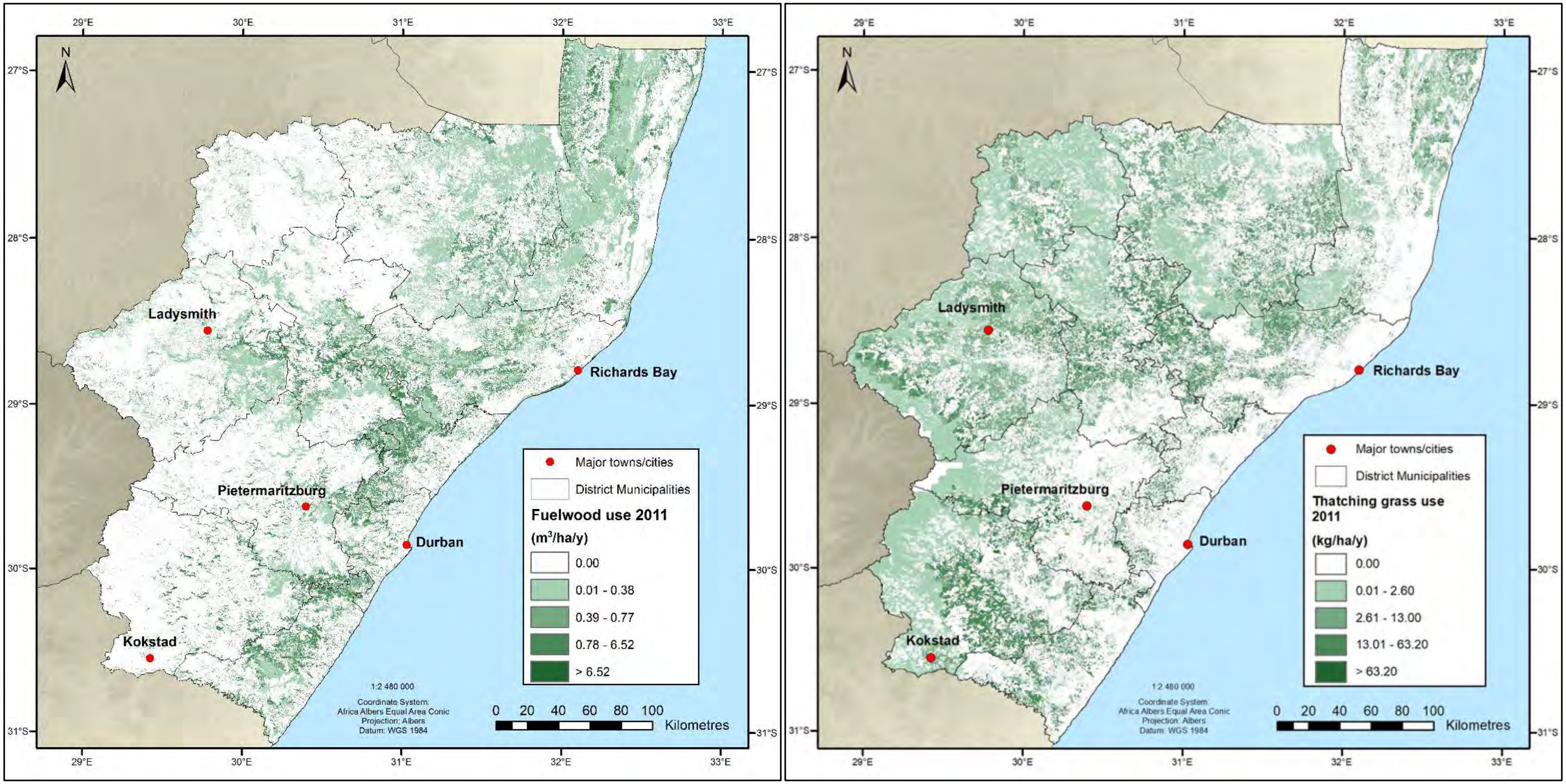

Figure 4.2. Estimated spatial variation in the informal harvesting of (a) fuelwood and (b) thatching grass across KwaZulu-Natal.

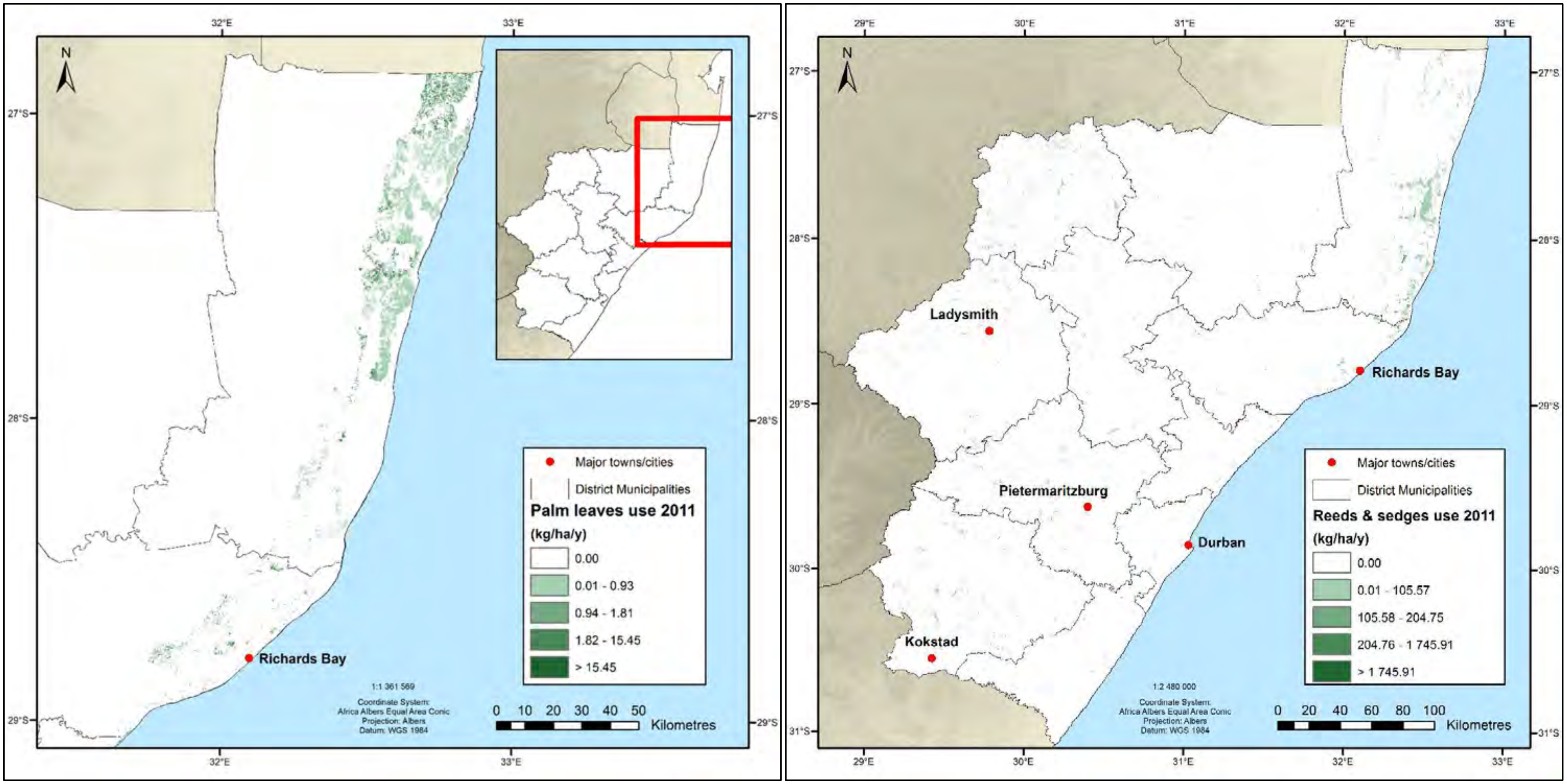

Figure 4.3. Estimated spatial variation in the informal harvsting of (a) palm leaves and (b) reeds and sedges across KwaZulu-Natal.

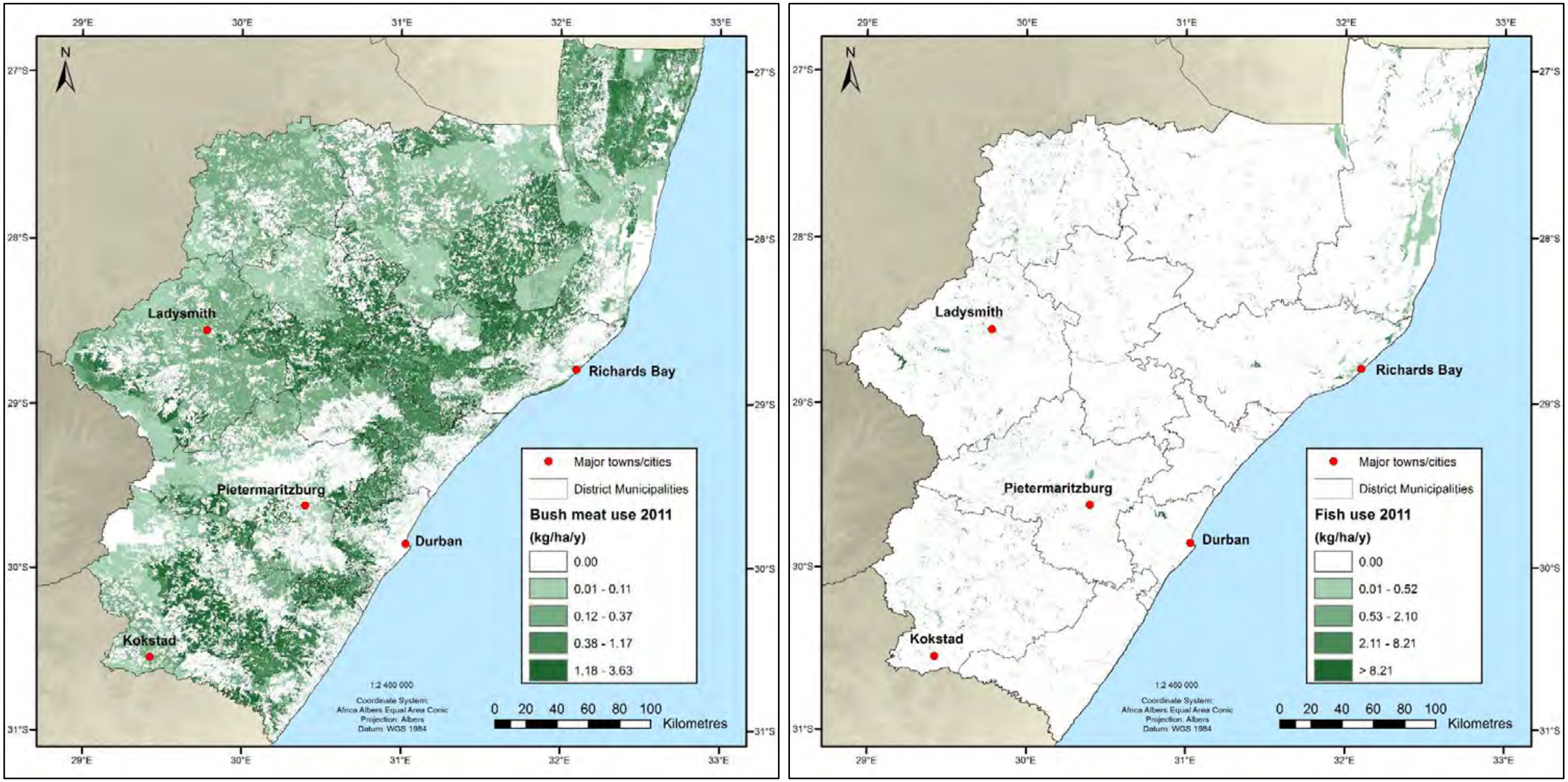

Figure 4.4. Estimated spatial variation in the informal harvesting of (a) bushmeat and (b) fish across KwaZulu-Natal.

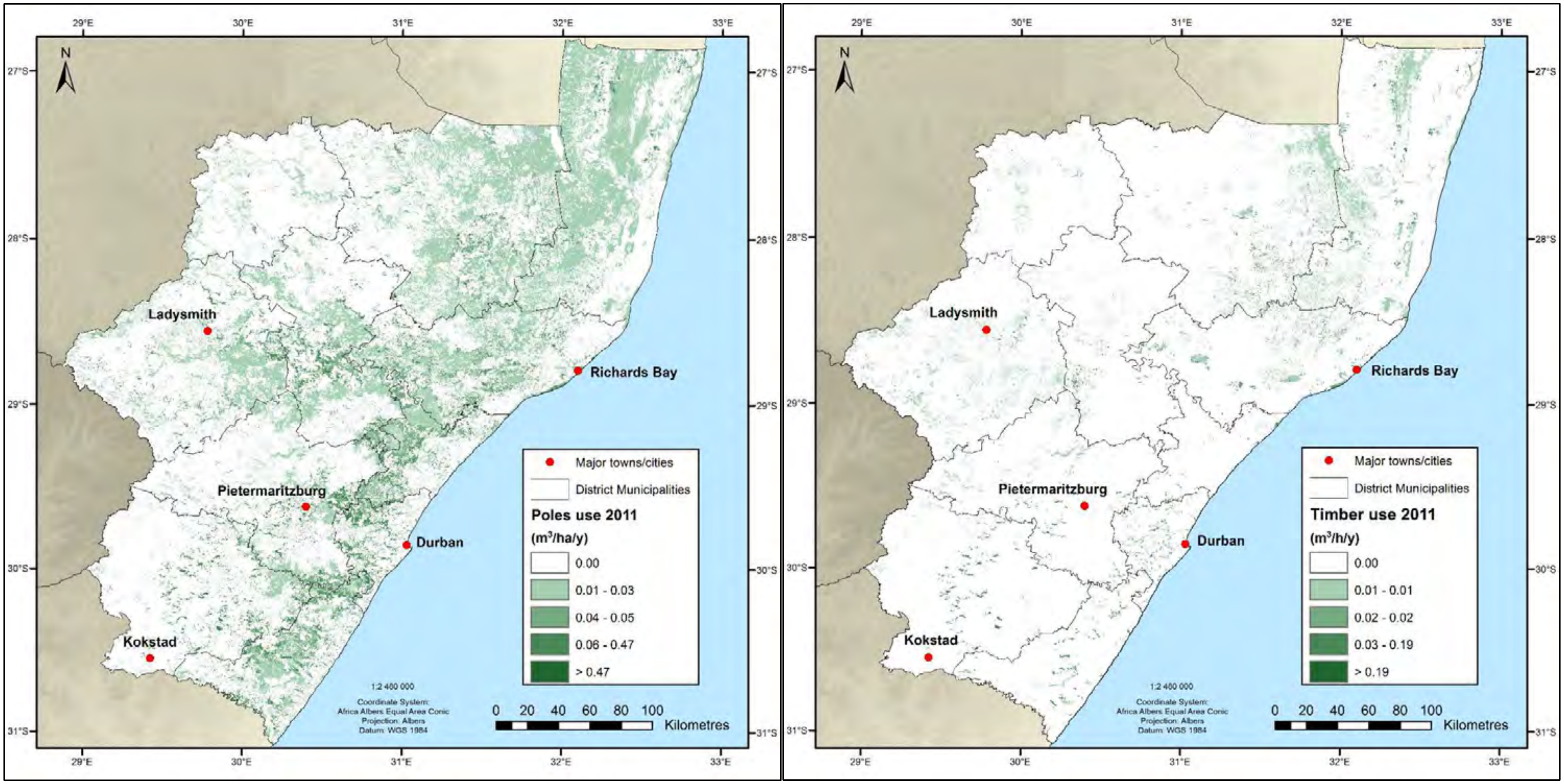

Figure 4.5. Estimated spatial variation in the informal harvesting of (a) poles and (b) indigenous timber across KwaZulu-Natal.

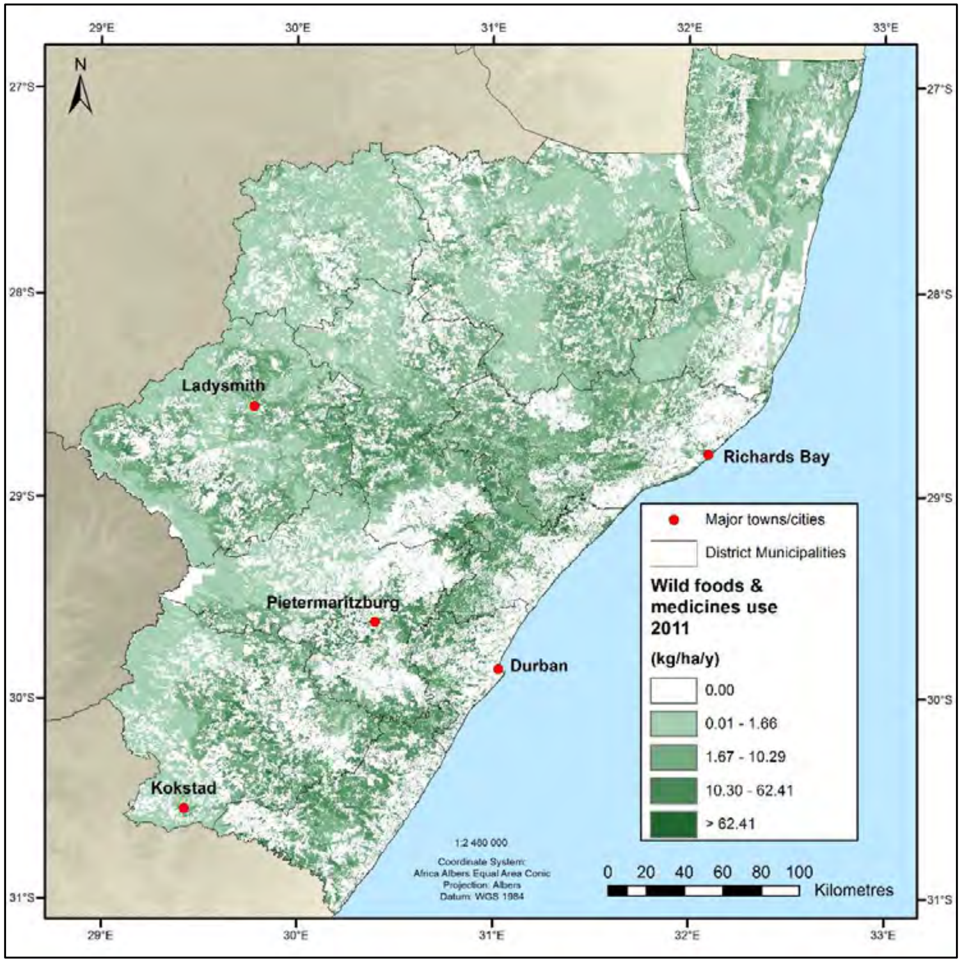

Figure 4.6. Estimated spatial variation in the informal harvesting of wild plant foods and medicines across KwaZulu-Natal.

*Table 4.8. Physical supply table for wild resources by broad ecosystem type (biome) for 2005. *Note that fish assigned to terrestrial biomes are from rivers and reservoirs in those biomes.*

Biome **Resource**	**Freshwater ecosystems**	**Grassland**	**Indian Ocean Coastal Belt**	**Savanna**	**Forests**	**Estuaries**	**TOTAL**
Fuelwood (m^3)	3 341	663 349	223 178	755 244	247 315	158	**1 892 584**
Poles (m^3)	163	29 645	10 948	28 560	11 165	8	**80 489**
Timber (m^3)	20	2 643	999	3 491	8 567	3	**15 723**
Thatching grass (tonnes)	33	25 973	4 935	17 383	59	3	**48 384**
Reeds & sedges (tonnes)	752	3 801	1 508	2 371	324	22	**8 779**
Palm leaves (tonnes)	-	-	292	-	-	-	**292**
Wild foods/med (tonnes)	121	14 483	4 951	13 113	2 327	6	**35 001**
Bushmeat (tonnes)	6	1 542	338	1 934	179	0	**3 998**
Fish (tonnes)*	42	315	75	298	22	8	**759**

*Table 4.9. Physical supply table for wild resources by broad ecosystem type (biome) for 2011. *Note that fish assigned to terrestrial biomes are from rivers and man-made reservoirs in those biomes.*

Biome **Resource**	**Freshwater ecosystems**	**Grassland**	**Indian Ocean Coastal Belt**	**Savanna**	**Forests**	**Estuaries**	**TOTAL**
Fuelwood (m^3)	3 623	577 156	199 665	684 019	228 188	181	**1 692 832**
Poles (m^3)	162	27 922	9 231	25 318	10 504	7	**73 144**
Timber (m^3)	16	1 359	415	2 516	8 410	2	**12 719**
Thatching grass (tonnes)	19	20 465	3 000	12 552	34	2	**36 072**
Reeds & sedges (tonnes)	598	3 796	1 176	2 578	192	14	**8 355**
Palm leaves (tonnes)	-	-	235	-	-	-	**235**
Wild foods/med (tonnes)	145	14 311	3 984	11 265	2 681	7	**32 393**
Bushmeat (tonnes)	4	1 161	220	1 404	138	0	**2 926**
Fish (tonnes)*	29	389	65	271	14	6	**774**

Table 4.10. Monetary supply table for wild resources by broad ecosystem type (biome) for 2005; values in 2010 R millions

Resource \ Biome	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	TOTAL
Fuelwood	2.89	573.13	192.83	652.53	213.68	0.14	1 635.19
Poles	0.12	21.40	7.90	20.62	8.06	0.01	58.11
Timber	0.03	3.59	1.36	4.75	11.65	0.00	21.38
Thatching grass	0.80	623.34	118.43	417.19	1.41	0.06	1 161.23
Reeds & Sedges	18.81	95.03	37.71	59.28	8.09	0.56	219.49
Palm leaves	0.00	0.00	12.86	0.00	0.00	0.00	12.86
Wild foods & Medicines	1.91	228.10	77.98	206.54	36.64	0.10	551.27
Bushmeat	0.08	23.12	5.07	29.01	2.68	0.00	59.97
Fish	0.46	3.46	0.82	3.28	0.24	0.09	**8.35**
Total	**25.09**	**1 571.19**	**454.96**	**1 393.19**	**282.46**	**0.96**	**3 727.86**

Table 4.11. Monetary supply table for wild resources by broad ecosystem type (biome) for 2011; values in 2010 R millions

Resource \ Biome	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	TOTAL
Fuelwood	3.13	498.66	172.51	590.99	197.15	0.16	1 462.61
Poles	0.12	20.16	6.66	18.28	7.58	0.01	52.81
Timber	0.02	1.85	0.56	3.42	11.44	0.00	17.30
Thatching grass	0.47	491.15	72.01	301.24	0.82	0.04	865.73
Reeds & Sedges	14.95	94.90	29.40	64.46	4.81	0.35	208.88
Palm leaves	0.00	0.00	10.34	0.00	0.00	0.00	10.34
Wild foods & Medicines	2.29	225.39	62.75	177.42	42.23	0.10	510.19
Bushmeat	0.06	17.41	3.30	21.06	2.06	0.00	43.90
Fish	0.32	4.28	0.72	2.98	0.15	0.07	8.51
Total	**21.36**	**1 353.81**	**358.26**	**1 179.86**	**266.25**	**0.72**	**3 180.25**

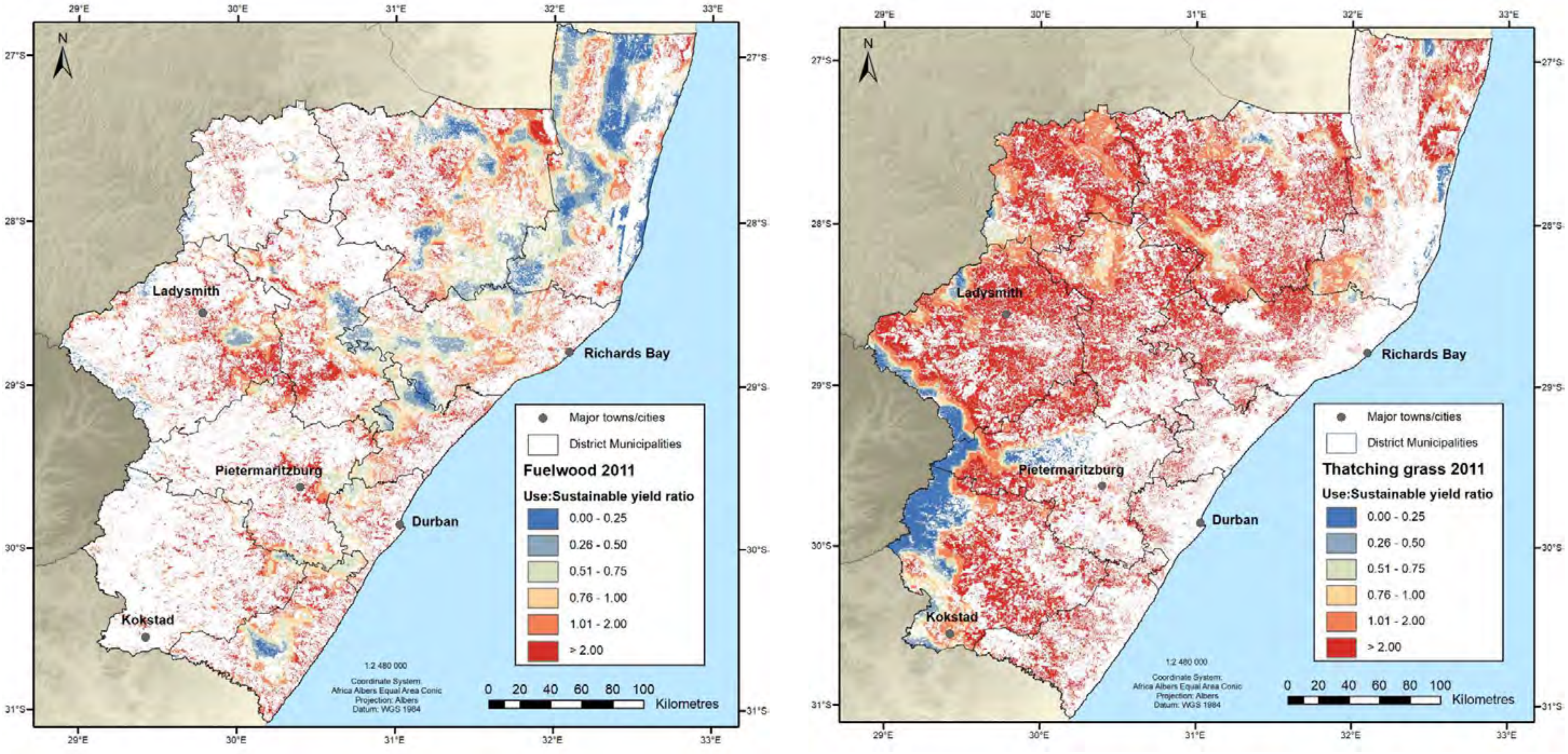

Figure 4.7. Maps showing overharvesting of (a) fuelwood and (b) thatching grass across KwaZulu-Natal based on estimates of natural resource stocks, actual use and sustainable yields.

Table 4.12. Ecosystem monetary asset account 2005-2011 for wild resources. Unsustainable harvesting of wild resources was incorporated into the calculation of asset values where the stocks were eroded over time if harvesting was identified as being unsustainable. Values are net present value in R millions.

	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	Total
Opening stock (2005)	352.36	10 788.68	4 006.58	13 868.85	3 002.79	12.97	32 032.23
Additions	0.00	0.00	0.00	0.00	0.00	0.14	0.14
Reductions	-59.19	-930.77	-793.00	-1 667.10	-138.25	-3.57	-3 591.89
Net change	-59.19	-930.77	-793.00	-1 667.10	-138.25	-3.43	-3 591.75
Closing stock (2011)	293.18	9 857.91	3 213.57	12 201.74	2 864.54	9.54	28 440.48
Net change %	-16.8%	-8.6%	-19.8%	-12.0%	-4.6%	-26.5%	-11.2%

4.2 *In situ* inputs to reared animal production

4.2.1 Overview of the service

This service is the contribution of the land to reared animal production. This includes natural fodder production. In this study, reared animal production that relies directly on ecosystem inputs included extensive livestock and game production. In future iterations, inputs to aquaculture could also be considered in this grouping, the main such production within KwaZulu-Natal being the raising of exotic fish species such as trout and bass in both purpose-built and existing reservoirs.

Extensively grazed livestock in KwaZulu-Natal include cattle, sheep, goats, horses, donkeys, and wildlife, mainly through fodder production. This aligns with the approach used in the Netherlands and UK ecosystem accounts, where fodder production is viewed as the service, and the farmed animals are considered as produced rather than natural assets (UK ONS 2019, Horlings *et al.* 2020). This differs from the CICES approach which sees the output of reared animals as the service. Nevertheless, the valuation outcome is similar, and in this study, the service is quantified in physical terms as the amount of production (in terms of large stock units) supported. This excludes non-consumptive wildlife enterprises, which are valued in terms of tourism value.

A large proportion of KwaZulu-Natal is under rangeland with the mesic conditions favouring the production of cattle, in particular. About 20% of all cattle in the country are located within KwaZulu-Natal. Certain areas of the province also favour the commercial production of sheep and goats, and large tracts have been developed for wildlife ranching. In the communal rangelands, cattle and goats dominate and sheep are far less abundant. Nevertheless, it should be noted that the rangeland animal production is supported to various degrees by supplementary feeding, and significantly so in KwaZulu-Natal, particularly for dairy farming. While these inputs can easily be accounted for in monetary terms, it is more difficult to ascertain what proportion of reared animal stocks would be supported by the land in the absence of these inputs. This is of particular significance, since the ecosystem service is the contribution of the natural system to rangeland production, and should be determined in physical as well as monetary terms.

In the communal rangelands, farming systems tend to be ‘low-input, low-output’ systems, which is more straightforward from an ecosystem services perspective, but the values of livestock production are complex, and include a range of indirect monetary values and non-monetary values.

Rangeland production is also linked to rangeland condition, about which there is limited information. Once long time series are in place and data are available at a higher spatial resolution, a cross sectional analysis will make it easier to determine the effect of changes in rangeland condition on the value of reared animal production, or better understand what is limiting output to the sector. This study provides an estimate of the value of the land contribution to reared animal production. The tourism values associate with reared animals (particularly wildlife) are accounted for elsewhere.

4.2.2 Data and methods

Data sources

Data relating to the commercial livestock and wildlife sectors have been collected through Agricultural Censuses in 2002 and 2007. The data from both of these censuses were summarised at the Magisterial District level (i.e. this was the lowest resolution). However, the data from 2007 were patchy. The 2007 data contained information on the numbers of cattle and sheep but data on goats were not available. Furthermore, data on livestock products (milk, wool etc.) were irregular and the financial data were not very comprehensive. Numbers of wildlife sold and hunted and the gross income from this production were only available at the provincial level. The census 2002 data provided estimates of cattle, sheep and goat numbers and disaggregated cattle into dairy and beef. Detailed information on livestock products was also available, as were the financial data at Magisterial District level. As a result, the 2002 Census Data were used for cattle, sheep and goats and adjusted for 2005 and 2011 using data collated from Meissner *et al.* (2013) and DAFF quarterly statistics. The 2007 Census Data was used for wildlife and adjusted for 2005 and 2011 using data collated from Taylor *et al.* (2015) and Ezemvelo KZN Wildlife. The data sourced are summarised in Table 4.13. Further information is provided in Appendix 4.

Table 4.13. Data used in the valuation of commercial livestock production.

Source	Data
Stats SA 2002 Census of Commercial Agriculture	Numbers of cattle (dairy & beef), goats and sheep on commercial farms Numbers of cattle (dairy and beef), goats, sheep Amount of livestock and game products (milk, cream, wool) produced Gross income from sale of livestock and livestock products Average prices Farm expenditure
Stats SA 2007 Census of Commercial Agriculture - Financial and production statistics	Numbers of wildlife sold through live sales and hunting Gross income from the sale of wildlife Average prices
DAFF quarterly livestock statistics	Numbers of cattle, sheep and goats per province for each quarter from 1996-current.
Meissner *et al.* (2013)	Total number of cattle, goats and sheep per province for commercial and communal sectors in 2010. Applied to DAFF statistics and used to determine the percentage split between communal and commercial livestock numbers in KwaZulu-Natal.
Taylor *et al.* (2015)	Number of wildlife ranches in KwaZulu-Natal in 2000, 2014 Average size of wildlife ranches in KwaZulu-Natal in 2014 Mean number of animals sold per ha in 2014 Mean number of animals hunted per ha in 2014
Ezemvelo KZN Wildlife	List of the commercial wildlife ranches in KwaZulu-Natal in 2019 and their size

Information related to communal livestock production is limited. The 2002 and 2007 national agricultural censuses focused only on commercial agriculture. However, agricultural households, including those in communal areas, were surveyed during the 2011 census as part of the Agricultural Households Survey. This dataset was the most comprehensive and was used in conjunction with the DAFF quarterly statistics and household survey data collated from the literature to estimate communal livestock production (Table 4.14).

Table 4.14. Data used in the valuation of communal livestock production.

Source	Data
Stats SA 2011 Census, Agricultural Households Survey	Number of households in communal areas keeping cattle, goats and sheep Number of livestock per household summarised into three categories: 1-10, 11-100, 100+
DAFF quarterly livestock statistics	Numbers of cattle, sheep and goats per province for each quarter from 1996-current.
Household survey data (Five studies carried out in communal areas of KwaZulu-Natal)	Percentage households keeping cattle, sheep and goats Average number of cattle, sheep and goats per livestock keeping household Average annual production rate and percentage offtake of cattle, sheep and goats per livestock keeping households Average price per head of cattle, sheep and goats

Estimation and mapping of reared animals and production – commercial land

In this study, we used the amount of livestock production supported as a proxy for land inputs for describing the service in physical terms. For cattle, sheep and goats the Agricultural Census 2002 data were summarised at the magisterial district level. The dataset contained information on the numbers of cattle (dairy and beef), sheep and goats as well as information on the numbers of livestock sold and the amount of livestock products (e.g. milk, cream and wool) produced within the commercial sector in 2002. These data were used to get an estimate of the spatial distribution of livestock across the province. The DAFF quarterly statistics provided estimates of the total numbers of commercial cattle, sheep and goat within KwaZulu-Natal in 2005 and 2011. These livestock numbers were spread across the magisterial districts based on the 2002 spatial distribution. The number of livestock sold in 2002 were converted into average percentage offtake and applied to the 2005 and 2011 data to get estimates of production for the two time periods. The amount of livestock products (milk, cream and wool) produced were estimated for 2005 and 2011 by multiplying the numbers of cattle, sheep or goats by the average milk/cream/wool produced per animal based on estimates from 2002. This provided a total amount (in litres or kg) of livestock product per magisterial district specific to each year. For wildlife, the Agricultural Census 2007 data provided estimates of wildlife production at the provincial level. Data on the total number of wildlife across KwaZulu-Natal does not exist. Data on the average number of wildlife sold and hunted per ha were used to get estimates of production (live sales and hunting offtake) in 2005 and 2011. It should be noted that wildlife production only includes live sales and hunting offtake from private wildlife ranches and does not include the sale of live animals from protected areas.

Estimation and mapping of reared animals and production – communal land

The number of households keeping different types of livestock (cattle, sheep and goats) communal areas were extracted from the Stats SA Census 2011 Agricultural Households database. This was summarised at the ward level which was the lowest possible resolution for these data. Data from a total of 828 wards in 51 municipalities and 11 district municipalities were included in the analysis.

The percentage of households owning cattle/sheep/goats per category is shown below. The majority of households that own livestock tend to keep fewer than 10 animals. A small percentage of households own more than 100 animals. Three approaches were used to estimate the total number of cattle, goat and sheep per municipal ward. The first approach used the number of households keeping 1-10, 11-100 and 100+ cattle/sheep/goats and assumed averages for each category and each type of livestock based on information from the literature. The averages used per category are shown in Table 4.15. These average per category were multiplied by the number of livestock keeping households to get total number of livestock per ward. The second approach involved multiplying the total number of livestock keeping households by an overall average number of livestock per household (i.e. not per category) based on an average per livestock type taken from household survey literature. For cattle the average was 9 per cattle keeping households, for goats it was 8 per goat keeping households and for sheep it was 5 per sheep keeping households. The third approach calculated the median number of cattle expected per ward based on the number of households keeping livestock in each category (1-10, 11-100, 100+), multiplied by the total number of households keeping livestock.

Table 4.15. The percentage of livestock keeping households per category and per livestock type and the average number of livestock per household per category and per livestock type. Source: Census 2011, household surveys.

	% of livestock keeping households		
	1-10 stock per household	**11-100 stock per household**	**100+ stock per household**
Cattle	83.3%	16.5%	0.2%
Goats	78.9%	20.8%	0.2%
Sheep	75.6%	22.9%	1.5%
	Average number of livestock per household per group		
Cattle	8	13	100
Goats	3	13	100
Sheep	2	12	100

The DAFF quarterly livestock statistics for 2011 provide an estimate of the total number of communal cattle, goats and sheep in KwaZulu-Natal. These were used to compare the total numbers of livestock using each of three approaches described above. The first approach of using an average per stock category proved to be slightly more accurate than the other two approaches, with total stock estimates being closest to those recorded by the DAFF quarterly assessments. Therefore, we applied the first approach and used these totals to estimate production.

Data collated from household surveys conducted in KwaZulu-Natal were used to estimate an average annual percentage offtake. Four studies from with KwaZulu-Natal and one study from the Eastern Cape were used for this. The percentage offtake was based on average numbers of stock kept per livestock keeping household and the average number of livestock consumed and sold per year. The average annual percentage offtake was estimated to be 24% for cattle, 29% for goats and 30% for sheep. These offtake rates were applied to the total number of cattle, goats and sheep within each municipal ward to get an estimate of annual production.

Data on the numbers of livestock households in 2005 do not exist (that we are aware of). Therefore, in order to estimate the value of livestock production in 2005 a set of adjustment factors were used. These were based on a linear interpolation between the Census data from 2001 and 2011. However, in 2001 no agricultural data were collected at the household level and a proxy for livestock households had to be used. Given that households owning livestock in communal traditional/tribal areas generally reside in traditional houses, this was used as the proxy. The DAFF quarterly livestock statistics show that communal livestock numbers have decreased since 1996. From 2001 to 2011 in KwaZulu-Natal there was a 4% decline in communal cattle numbers, a 15% decline in goat numbers and a 6% decline in sheep numbers. The declining livestock numbers could be attributed to livestock households keeping fewer animals or the more likely assumption being that the number of livestock households has decreased over time. Given that the number of traditional households in KwaZulu-Natal have decreased over the same time period it made sense to use this as a proxy for determining the change in livestock numbers from 2011 to 2005.

The Census 2011 and 2001 data were comparable only at the district municipality level. The percentage change in traditional dwellings per district municipality from 2001 to 2011 was used to adjust the 2011 estimates of livestock households within each municipality. This was done by assuming a linear relationship in the rate of change from 2001 to 2011. The number of livestock households in 2011 was multiplied by the % change in traditional dwellings from 2001 to 2011 to get the number of livestock households in 2001. This was then adjusted to 2005 using the linear relationship between 2001 and 2011 estimates. The number of livestock households in 2005 was then divided by the number of livestock households in 2011 to get an adjustment factor for that municipality. The adjustment factor was then applied to the 2011 municipal ward data to get estimates of livestock numbers at the ward level for 2005. The total livestock numbers were then compared to the DAFF livestock statistics for 2005.

An example of the calculations for just two of the district municipalities is shown below (Table 4.16). Column A is based on the change in traditional dwellings from 2001 to 2011 extracted from the Census data. The livestock households in 2011 in column B was extracted from the 2011 Census Agricultural Households Database. Livestock households in 2001 (column C) was calculated by multiplying B by A. The % change in livestock households to 2005 was based on the linear interpolation between 2001 and 2011. The number of livestock households in 2005 were calculated by multiplying C by D. The adjustment factor was calculated by dividing E by B. This factor was then applied to the 2011 municipal ward data.

Table 4.16. Example of adjustment factor calculations for estimating livestock numbers in 2005. This was based on a linear interpolation from Census 2011 to Census 2001 data. Source: Census 2011 and 2001

	A	B	C	D	E	F
District Municipality	**% change in traditional dwellings 2001-2011**	**Livestock hh in 2011**	**Livestock hh in 2001**	**% change to 2005**	**Livestock hh in 2005**	**Adjustment factor**
iLembe	-18%	15 790	18 632	-6%	17 495	1.108
Ugu	-14%	21 084	24 035	-5%	22 855	1.084

The same approach used above in Step 1 and Step 2 in calculating the 2011 production values was used for calculating 2005 production. It was assumed that production and offtake rates remained the same as in 2011.

Valuation

The annual production was valued in terms of resource rent. The resource rent is the economic rent that accrues in relation to environmental assets, including natural resources and ecosystems (UN 2017). The idea being that the value of the contribution of an ecosystem service to production is included in the price and that this value can be calculated by subtracting all other inputs, leaving a residual that represents the value of the service (UN 2017). Labour costs, user costs of fixed capital and intermediate inputs are deducted from the market value of the outputs (benefits). The ratio of intermediate expenditure, labour costs and capital expenditure to gross income was taken from the 2007 Agricultural Census. The annual capital expenditure was taken as a proxy for cost of capital. For commercial production, gross output was estimated at the magisterial district level using average selling prices of livestock, wildlife and associated products reported in the Agricultural Censuses (2002 and 2007), converted to 2010 Rands using the Consumer Price Index (CPI).

For communal area production, prices were obtained from household survey data (Turpie *et al.* 2010, 2014) and adjusted to 2010 values using the CPI. The average household costs of production for cattle and goat keeping households were obtained from Shackleton *et al.* (2005). These include annual cost estimates for hiring herders, vet care, dipping, and supplementary feed, and the capital and maintenance costs associated with equipment and kraals, calculated as a percentage of gross income. These factors were then applied to gross income to generate the resource rent of communal livestock production in 2005 and 2011.

For each time period, the values were mapped to the private and communal rangeland areas in each magisterial district based on land cover as well as land tenure, and the contribution of reared animal outputs to asset values was calculated at the scale of the BSU.

4.2.3 Results and discussion

Maps of livestock and wildlife production in 2011 are shown in the figures below (Figure 4.8). The maps for 2005 are not shown as they are visually indistinguishable at this scale. Production per biome (commercial and communal livestock units – LSU) is summarised in the physical supply tables for 2005 (Table 4.17) and 2011 (Table 4.18).

The resource rent value of commercial livestock production in KwaZulu-Natal was **R846 million** in 2005 and **R810 million** in 2011 (2010 prices). Values were highest in the central inland districts of Dundee and Vryheid and in Mount Currie district in southern KwaZulu-Natal. The value for each district was mapped to the identified commercial rangeland areas outside of protected and private game farming areas using the KwaZulu-Natal land cover maps. The Ezemvelo KZN Wildlife private game ranch layer was used to isolate the private wildlife ranches as opposed to private livestock ranches.

The resource rent value of communal livestock production was estimated to be **R824 million** in 2005 and **R658 million** in 2011 (2010 prices). The values per municipal ward were mapped to the identified communal (traditional/tribal) areas outside of protected and private areas using the KwaZulu-Natal land cover map 2005, 2011.

Over the six-year study period there was a loss in production of R35 million in the commercial sector and R166 million in the communal sector. This loss in production is likely due to the loss in carrying capacity of rangelands on private and communal land due to poor grazing and fire management which is further exacerbated by changing climatic conditions (i.e. drought). Overgrazing causes significant degradation which encourages bush encroachment. High intensity fires are needed to properly control woody encroachment. However, overgrazing prevents the build-up of the grass layer that is required for high intensity burns. This is particularly evident in communal areas where there is open access grazing and rangelands are not rested. There is lower production on private wildlife ranches as some ranches focus on tourism (the value of which is captured elsewhere).

Commercial wildlife numbers in KwaZulu-Natal increased by 15% between 2005 and 2011. This is unsurprising given the rapid growth in the private wildlife sector in South Africa over the last two decades. Numerous livestock farmers saw the opportunity in switching to farming wildlife and started to realise increasing financial returns from rangeland areas. Wildlife areas provide the opportunity for ecotourism activities as well as hunting and breeding activities. The values presented here relate only to the consumptive use of wildlife. Non-consumptive wildlife enterprises are valued in terms of tourism value.

Based on the above assessments, the contribution of this service to the asset value of ecosystems in KwaZulu-Natal was estimated to be **R27.1 billion** in 2005 and **R23.9 billion** in 2011 (Table 4.21). The contribution to asset value decreased by R3.2 billion, with the most significant negative net change seen in the savanna biome which lost 26% of its value from 2005 to 2011, amounting to over R2.2 billion (Table 4.21).

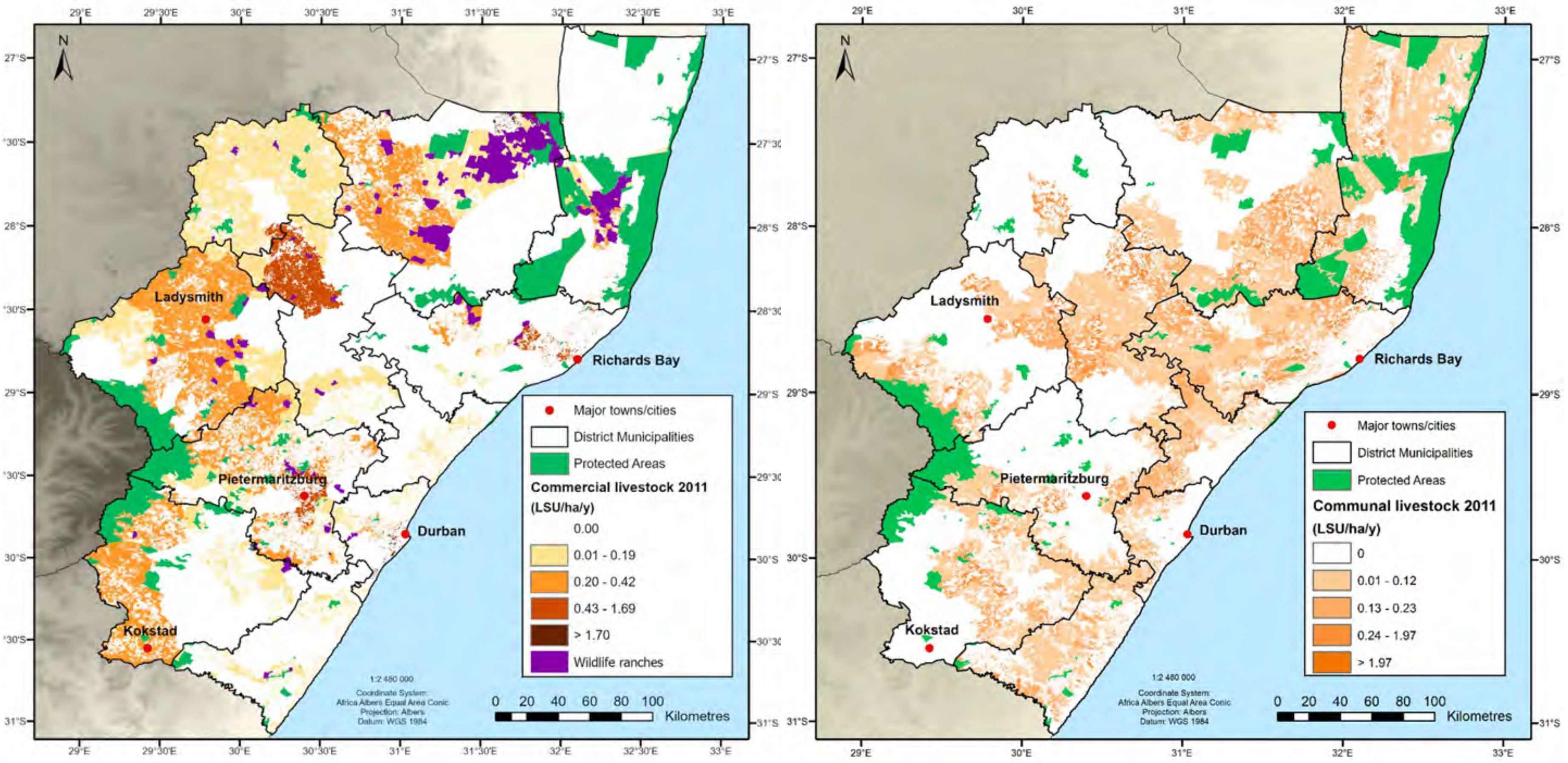

Figure 4.8. Maps showing variation in the annual production value of (a) commercial livestock and (b) communal land livestock across KwaZulu-Natal, as well as the location of wildlife ranches (in purple) and protected areas (in green).

Table 4.17. Physical supply table for reared animal production supported by broad ecosystem type (biome) for 2005 in terms of large stock unit (LSU) sales per year

Biome / **Service**	**Freshwater ecosystems**	**Grassland**	**Indian Ocean Coastal Belt**	**Savanna**	**Forests**	**Estuaries***	**TOTAL**
2005							
Community Livestock (LSU/y)	611	152 142	32 585	174 852	958	17	**361 166**
Commercial Livestock (LSU/y)	1 095	530 663	19 535	108 815	1 014	323	**661 445**
Commercial Wildlife (LSU/y)	10	1 893	42	5 996	38	-	**7 978**
Total	**1 716**	**684 698**	**52 162**	**289 663**	**2 010**	**340**	**1 030 589**

* Livestock grazing within estuary floodplain areas

Table 4.18. Physical supply table for reared animal production (livestock unit, LSU/y) by broad ecosystem type (biome) for 2011

Biome / **Service**	**Freshwater ecosystems**	**Grassland**	**Indian Ocean Coastal Belt**	**Savanna**	**Forests**	**Estuaries***	**TOTAL**
2011							
Community Livestock (LSU/y)	673	143 656	28 378	114 827	1 426	18	**288 977**
Commercial Livestock (LSU/y)	1 246	503 517	18 103	106 960	1 160	266	**631 252**
Commercial Wildlife (LSU/y)	12	2 168	48	6 867	43	-	**9 137**
Total	**1 931**	**649 341**	**46 529**	**228 654**	**2 629**	**284**	**929 366**

* Livestock grazing within estuary floodplain areas

Table 4.19. Monetary supply table for reared animal production by broad ecosystem type (biome) for 2005; values in 2010 R millions

Service \ Biome	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries*	TOTAL
Community Livestock	1.4	347.0	74.3	398.7	2.2	0.0	**823.6**
Commercial Livestock	1.2	690.4	32.4	119.3	1.6	0.6	**845.5**
Commercial Wildlife	0.0	0.9	0.0	2.9	0.0	-	**3.9**
Total	**2.6**	**1 038.3**	**106.7**	**521.0**	**3.8**	**0.6**	**1 673.0**

* Livestock grazing within estuary floodplain areas

Table 4.20. Monetary supply table for reared animal production by broad ecosystem type (biome) for 2011; values in 2010 R millions

Service \ Biome	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries*	TOTAL
Community Livestock	1.5	326.8	64.6	261.2	3.2	0.0	**657.4**
Commercial Livestock	1.5	656.7	30.5	118.6	1.7	0.5	**809.5**
Commercial Wildlife	0.0	1.4	0.0	4.5	0.0	-	**5.9**
Total	**3.0**	**985.0**	**95.1**	**384.3**	**5.0**	**0.5**	**1 472.9**

* Livestock grazing within estuary floodplain areas

Table 4.21. Ecosystem monetary asset account 2005-2011 for in situ inputs to reared animal production. NPV calculated using an asset lifespan of 25 years and a discount rate of 3.66%. Values are net present value in R millions.

	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	Total
Opening stock (2005)	**42.13**	**16 818.83**	**1 728.97**	**8 439.63**	**60.76**	**10.36**	**27 100.67**
Additions	6.31	0.00	0.00	0.00	20.38	0.00	26.70
Reductions	0.00	-863.63	-188.63	-2 214.38	0.00	-1.69	-3 268.33
Net change	6.31	-863.63	-188.63	-2 214.38	20.38	-1.69	-3 241.63
Closing stock (2011)	**48.44**	**15 955.19**	**1 540.34**	**6 225.25**	**81.14**	**8.66**	**23 859.03**
Net change %	15.0%	-5.1%	-10.9%	-26.2%	33.5%	-16.3%	-12.0%

4.3 *In situ* inputs to crop production

4.3.1 Overview of the service

Croplands, orchards and forestry plantations, in spite of the fact that they replace natural ecosystems, are also considered to be types of ecosystems in the broad definition used in ecosystem service accounting. In 2011, roughly a quarter of the province's land cover comprised cultivated land types.

Different ecosystem service classifications view cultivated resources differently. In the original sense of ecosystem services, the service provided by the area under cultivation was taken to be the production capacity of the land, net of the man-made capital and labour inputs, and technically also net of inputs from surrounding ecosystems, such as wild pollination. Other frameworks such as CICES prefer to consider total production in the same way that agricultural production is accounted for in the existing SNA. The former approach is saddled with the problem of trying to attribute value to the land, and this value is generally best revealed in data-rich, complex statistical models but can be estimated using simple assumptions. The latter approach is more closely aligned to the classification of agricultural land types as ecosystems. If they are to be considered as ecosystems, then the full production value should be taken. In this study we have taken the service to be the final production. The production in tons per hectare and monetary value of each crop were mapped using the cultivation land cover classes and the most appropriate data available for the classes.

4.3.2 Data and methods

Data sources

Values for production per hectare were obtained from the 2002 and 2007 Agricultural Census. These data are summarised for all crops by province in the national report, and for selected crops by Magisterial District in the provincial reports (Stats SA 2006, 2011). These were the most comprehensive agricultural statistics available for the study area. The Agricultural Census provided estimates of planted area, production and value for a wide range of crops, both individually and summarised in 16 broader groupings (see Table 4.22 for 2007 values). The provincial report provided details at the Magisterial district level for maize, wheat, soya, cane, potatoes, cabbage, pineapples, bananas and oranges. However, data were not available for every district. For those districts where land cover data indicated presence of the particular crop but data were missing from the Agricultural Census, we used production figures from one or more neighbouring districts, as appropriate.

Table 4.22. Planted area, production and value of different types of commercial crops in KwaZulu-Natal in 2007. Values in 2007 Rands. Source: Stats SA (2011) Census of commercial agriculture 2007

	Dryland		**Irrigated**		
KwaZulu-Natal	**Planted ha**	**Production metric tons**	**Planted ha**	**Production metric tons**	**Income R'000**
Summer cereals	59 167	244 969	19 218	135 082	441 685
Winter cereals	4 380	9 727	4 795	23 063	53 106
Oil seeds	12 767	25 905	3 103	9 029	66 734
Legumes	735	922	568	1 410	8 975
Fodder crops	31 921	171 314	7 936	70 420	54 603
Other field crops	1 837	10 496	1 845	3 831	22 117
Vegetables			8 484	236 504	404 143
Sugar cane	209 270	11 726 164	34 673	2 451 123	2 345 360
Pineapples	1 638	50 947			131 591
Citrus fruit	3 258	93 628			109 036
Bananas	2 453	51 090			113 679
Other subtropical fruit	821	24 607			34 145
Deciduous & grapes	157	2257			10346
Nuts	3239	4263			24 375
Flowers	170	numbers only			36 392
Other horticulture	671	14403			53 191
Total					**3 909 478**

Aligning land cover classes and information on crop production

The KwaZulu-Natal landcover 2005 and 2011 raster layers were reclassified to isolate the cultivated classes, and then grouped to align with available data on production and value from the census data (Table 4.23). Values were applied at the highest level of resolution available, i.e. at the Magisterial District level where possible, otherwise a provincial average production and output value per ha was applied. Since the census data (2002, 2007) were not aligned with the land cover data (2005, 2011), we used average production per ha and average value per unit of production across the two census periods. While most of the land cover classes had corresponding crop information in the Census data, there were no data for cashew nuts, for which land cover data recorded 1 011 ha in 2011 (almost all in one magisterial district). Different land cover categories for sugarcane area had to be combined, since the census data did not distinguish the same sub-types.

For plantation forestry, production was considered to span the areas categorised as having trees as well as the clear-felled areas, since these areas collectively represent the total area under timber rotation. Values for m^3/ha and R/ha were attained from the total of pulpwood, sawlog and other roundwood volumes harvested in 2011 in KwaZulu-Natal, according to Forestry South Africa (2017).

For home gardens, the mean estimated income earned from fruit and vegetable production (R430 per household per year, 2010 prices) was taken from Ogundiran *et al.* (2014) who estimated the role of home gardens in household food security in the Eastern Cape. The estimation results from the panel regression model for predicting crop revenues from Tibesigwa *et al.* (2019) was used to calculate the percentage change in production revenues from 2005 to

2011. Based on these outputs, production revenues from home gardens were estimated to be 7% lower in 2011 compared to 2005. This was used to adjust the annual production value for home gardens in 2011 (R401, 2010 prices). This value was then multiplied by the estimated number of household gardens within low-density rural settlement areas of KwaZulu-Natal. The value of production was net of the contribution of pollination services from natural habitats to home garden revenues (see section 4.6). The production output from home gardens was not estimated in physical terms.

Table 4.23. Grouping of cultivation land cover classes.

KZN LC dataset	Land cover classes	Production data
2 3	Plantation Plantation – clear-felled	Annual provincial production data from Forestry South Africa (2017)
6	Orchards - permanent, irrigated, banana's and citrus	Census data on production and income values for bananas and oranges
7	Orchards - permanent, dryland, cashew nuts	Other data (mainly in one district)
8	Orchards - permanent, dryland, pineapples	Census data on production and income values for pineapples (mainly in one district)
9 10	Sugarcane, commercial, irrigated & dryland Sugarcane, semi-commercial, emerging farmer, irrigated & dryland	Census data on sugarcane production (no distinction into commercial and emerging), and the data on irrigated and dryland had to be combined.
16	Cultivation, commercial, annual crops, dryland	Census data. Combined values for dryland maize, wheat and soya crops
17	Cultivation, commercial, annual crops, irrigated	Census data. Combined values for irrigated maize, wheat and soya crops as well as potato and cabbage crops
15	Cultivation, subsistence, dryland	Average value of subsistence agriculture production for northern KwaZulu-Natal (Turpie *et al.* 2014)

Valuation

Horlings *et al.* (2020) who developed the experimental monetary accounts for the Netherlands used three different valuation approaches for calculating crop production. These were the resource rent method, user cost method and rental price method.

From their analysis, they found the resource rent approach produced relatively low values that fluctuated significantly over years due to sensitivity to price changes. The analysis found that the user cost of agricultural land (as calculated from market land values) and rental prices offered a better approximation for the ecosystem services contributing to crop production and livestock farming in the Netherlands and that these methods produced estimates within the same order of magnitude. However, the user cost and rental price method rely on access to detailed rental price data and value of agricultural land. Such data are often not available, especially at the scale needed for ecosystem accounting. This same study tested two valuation methods for timber production – resource rent and stumpage prices. Similarly, to the crop production analysis, the resource rent approach produced lower estimates than the stumpage price method (Horlings *et al.* 2020). The authors concluded that the stumpage price method directly reflects the value of the ecosystem services and that the resource rent method is subject to uncertainties on labour and equipment costs (Horlings *et al.* 2020).

In this analysis, the resource rent approach was used for valuing crop production and silviculture as stumpage prices were not available. The resource rent is the economic rent that accrues in relation to environmental assets, including natural resources and ecosystems (UN 2017). The general idea is that the value of the contribution of an ecosystem service to production is included in the price or rent and that this value can be calculated by subtracting all other inputs, leaving a residual or rent that represents the value of the ecosystem service. Costs of labour, user costs of fixed capital and intermediate inputs are deducted from the market value of the outputs (benefits). The ratio of intermediate expenditure, labour costs and cost of capital to gross income was taken from the 2007 Agricultural Census. It was assumed that the annual capital expenditure was a good enough proxy for cost of capital. Although the income per unit production reported in the census varied across magisterial districts, we used the overall average unit value for the province for each crop type. Monetary values were converted to the base year of 2010 Rands using the Consumer Price Index (CPI).

4.3.3 Results and discussion

A map of crop production in 2011 is shown in Figure 4.9. The map for 2005 is not shown as they are visually indistinguishable at this scale. Production is not summarised per biome, since agricultural land replaces the former vegetation types but is summarised per crop type (Table 4.24). The production data are summarised in Table 4.25. The resource rent value of crop production in KwaZulu-Natal was **R6.5 billion** in 2005 and **R7.5 billion** in 2011 (2010 prices). Values were highest along the coastal areas north and south of Durban and in areas in the northern uMkhanyakude District. Important timber production areas are located along the north coast near Richards Bay and the inland farming areas around Pietermaritzburg and Kokstad. In Richards Bay there is intense competition with other land uses such as aluminium mining.

The most noticeable change over the six-year period saw sugarcane production in KwaZulu-Natal decrease by some 3.5 million tonnes, while subsistence production increased by 2.5 million tonnes. High input prices, drought and weak protection against imports has not only deterred small-scale farmers from farming sugar but has had a significant negative affect on production of existing sugarcane farms. Production from irrigated crops declined while production from dryland crops increased. There was growth in the production of banana and citrus as well as in pineapples. A number of the larger sugarcane growers started to diversify their income base by planting nut orchards as well as citrus on their farms. This follows the findings of Driver *et al*. (2015) who found that the biggest regression in percentage terms in the KwaZulu-Natal land accounts was in sugarcane, which decreased by nearly 25% (approximately 117 000 ha), mostly in the period 2005 to 2008.

The contribution of this service to the asset value of cultivated land in KwaZulu-Natal was estimated to be **R105 billion** in 2005 and **R122 billion** in 2011. Values increased by some R17 billion from 2005 to 2011, an overall increase of 17%.

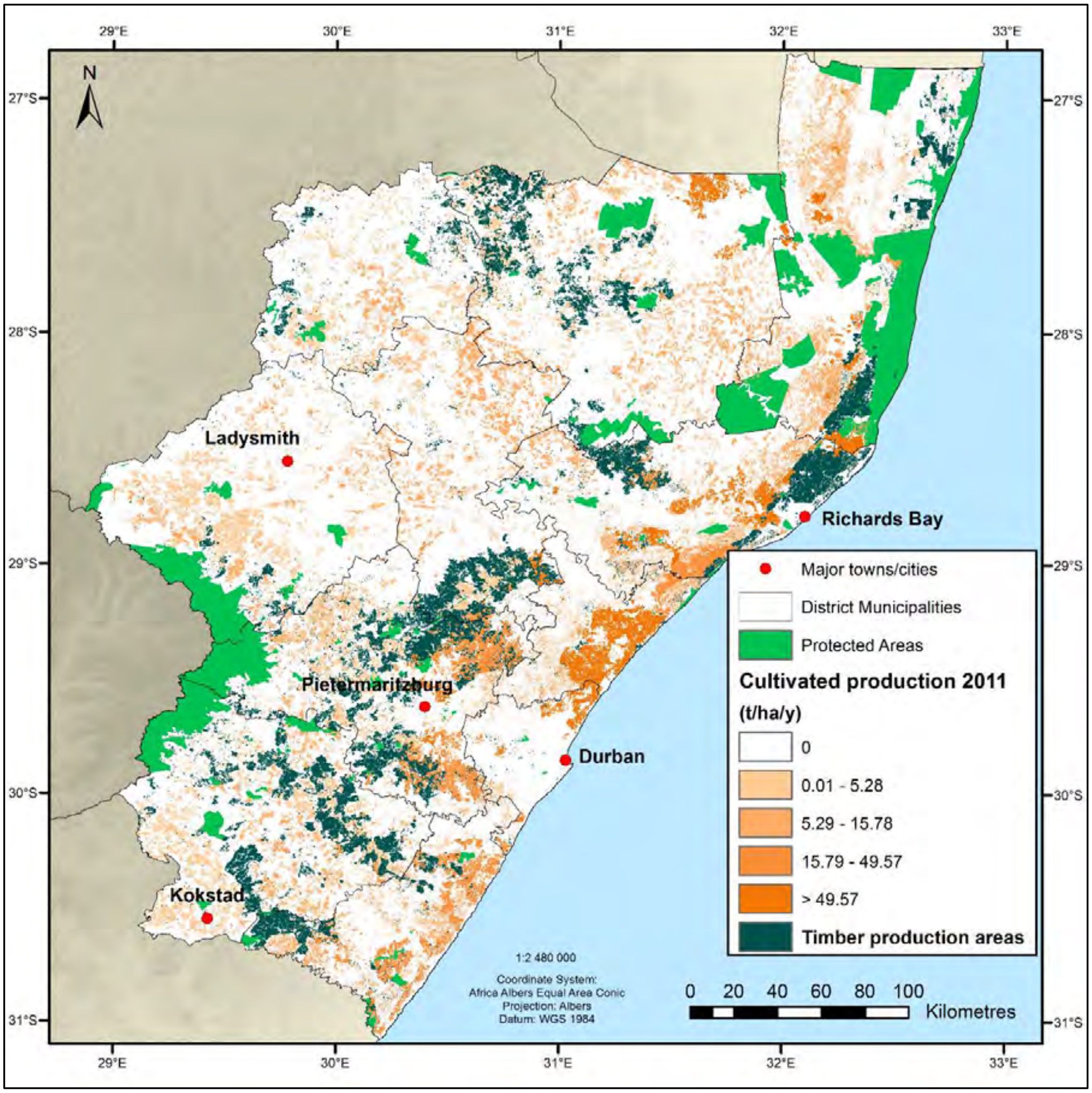

Figure 4.9. Map showing variation in agricultural production across commercial and small-scale/subsistence cultivated areas of KwaZulu-Natal, and the location of plantation forestry production.

Table 4.24. Physical supply table for cultivated crop and tree production for all cultivated land by crop type for 2005 and 2011

Crop type Service	Plantations	Orchards (banana, citrus)	Orchards (cashew)	Pineapple crop	Sugarcane	Irrigated crops	Dryland crops	Subsistence	TOTAL
2005 **Cultivated Crops & Orchards (tonnes)**	-	167 189	1 587	102 917	25 808 674	425 622	933 413	1 446 552	**28 885 956**
Plantations (m^3)	14 419 825								**14 419 825**
2011 **Cultivated Crops & Orchards (tonnes)**	-	330 360	1 340	147 754	22 279 333	383 013	1 301 364	4 002 740	**28 445 903**
Plantations (m^3)	15 165 751								**15 165 751**

*Table 4.25. Monetary supply table for cultivated crop and tree production for all cultivated land, for 2005 and 2011; values in 2010 R millions. *Home gardens are associated with households within low density rural settlement areas.*

Crop type Service	Plantations	Orchards (banana, citrus)	Orchards (cashew)	Pineapple crop	Sugarcane	Irrigated crops	Dryland crops	Subsistence	Home gardens*	TOTAL
2005 **All cultivated products**	2 389.8	108.5	4.1	118.6	2 439.3	222.5	573.1	556.4	44.3	**6 456.7**
2011 **All cultivated products**	2 513.5	234.7	3.5	171.6	2 029.2	212.3	790.0	1 539.5	41.2	**7 535.4**

4.4 Experiential value (Recreational and related use)

The aesthetic, recreational, spiritual, scientific and educational values derived from ecosystem attributes manifest as tangible values in several ways, including property value, tourism value, reduced healthcare costs, and avoided loss of productivity. They also manifest in less tangible ways, but these welfare contributions are not yet recognised within the accounting framework. This pilot study focuses on nature-based tourism values and amenity value to property owners as a component of cultural service values.

4.4.1 Ecosystem contribution to tourism

Nature-based tourism is an important ecosystem service in KwaZulu-Natal. The province is a popular holiday destination offering numerous leisure activities. Nature-based tourism is also an important component of the overall tourism sector in the province. This account specifies the contribution of nature-based tourism to the overall tourism sector in KwaZulu-Natal and highlights the areas that contribute most to this value. Nature-based tourism encompasses all tourist activities related to nature, both on land, along the coast and on inland waters. Activities include visits to nature areas and game reserves, outdoor activities such as hiking, cycling or boating, and beach holidays. The most popular nature-based tourism destinations in KwaZulu-Natal include the iSimangaliso Wetland Park and uKhahlamba Drakensberg Park, both of which are UNESCO World Heritage Sites, the blue-flag beaches along the KwaZulu-Natal coast and the numerous state- and privately-owned game reserves such as the Hluhluwe-iMfolozi Park and Phinda Private Game Reserve.

Following the work done in the eThekwini Municipality (Durban and surrounds; Turpie *et al.* 2017b) and at national scale Turpie *et al.* (2017a), this study uses a combination of tourism data, patterns of geotagged photographs uploaded to the internet, and spatial data on land cover and land ownership in order to estimate ecosystem contribution to nature-based tourism value in 2005 and 2011 in KwaZulu-Natal.

In 2005, 1.6 million foreign tourists and 13.8 million domestic tourists spent a total of R8.3 billion and R5.3 billion in KwaZulu-Natal, respectively. In 2011 these numbers had decreased with just under 1 million foreign tourists and 7.1 million domestic tourists visiting KwaZulu-Natal, spending a total of R7.1 billion and R5.2 billion, respectively. 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 based on information collated from the SA Tourism annual performance reports and from data collected in regional tourist offices (Table 4.26). 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 and so these contributions are not insignificant. Using the percentage spend for each group of tourists and the percentage spent on attractions (Table 4.26), we estimate that in 2005 approximately 38% (R2 billion) and 20% (R1.7 billion) of total domestic and foreign tourism spend was spent on visiting attractions. In 2011 these figures were approximately 57% (R3 billion) and 57% (R4 billion) of total tourism spend, respectively. The higher spend on attractions in 2011 is attributed to the fact that the proportional percentage spend of holiday/leisure tourists (both foreign and domestic) had increased significantly since 2005 with the proportional percentage spend of VFR tourists decreasing over the same period.

The ecosystem contribution to tourism was valued as resource rent generated by nature-based tourism, which is the residual of the total output after all costs for capital and labour have been subtracted. Calculating the resource rent was done in two steps. The gross operating surplus was first calculated based on conversion factors for 2005 and 2011 extracted from the South African Tourism Satellite Accounts (Stats SA 2010, 2015). Gross operating surplus (GOS) is estimated as follows:

$$GOS = total\ output - (intermediate\ consumption + labour\ costs \\ + taxes\ less\ subsidies\ on\ production)$$

Resource rent was then derived from the gross operating surplus by subtracting user costs of fixed capital, as follows:

$$Resource\ rent = gross\ operating\ surplus - user\ cost\ of\ fixed\ capital$$

Information pertaining to costs of capital were not available for the South African tourism industry and so a factor of 6% of total output was used based on the results of Remme *et al*. (2015) for Limburg Province in the Netherlands for which the estimates of labour costs and intermediate costs for nature-based tourism were proportionally similar those for KwaZulu-Natal. The values were then converted into 2010 prices. Based on these calculations, the resource rent of tourism spend on attractions in KwaZulu-Natal was **R727 million** in 2005 and **R1.2 billion** in 2011 (in 2010 prices).

Table 4.26. Typology of domestic and foreign tourists, the % of spend for each type of tourist, and % of group spending on tourist attractions in 2005 and 2011. VFR=Visiting friends and relatives. Source: KZN Tourism (2012), SA Tourism (2005, 2006, 2011).

			Domestic tourists		Foreign tourists	
Main purpose	**Domestic tourists (%)**	**Foreign tourists (%)**	**% spend**	**% of group spending on attractions**	**% spend**	**% of group spending on attractions**
2005						
Holiday	12	63	34	100	19	100
Business	7	8	11	24	18	4
VFR	69	25	44	3	63	2
Other	12	4	12	0	1	15
2011						
Holiday	36	58	52	100	54	100
Business	8	19	17	24	29	4
VFR	52	19	29	3	11	2
Other	4	5	3	0	5	15

The spatial distribution of tourism value was mapped using the InVEST Recreation Model 3.5.0 (www.naturalcapitalproject.org). This model uses geotagged photographs uploaded on the website *flickr.com* in order to estimate the relative value of tourism across an area. Densities of geotagged photographs uploaded to platforms such as *flickr.com* provide a means of mapping value to tourism attractions, rather than to the places where tourists spend their money (e.g. at their accommodations), so is more accurate in assigning the tourism value to the actual attractions that caused the expenditure. Wood *et al*. (2013) used the location of geotagged photographs in *Flickr* to estimate visitation rates at over 800 recreational sites around the world and compared these estimates to empirical data at each site. The study found that using geotagged photographs can indeed serve as a reliable proxy for empirical visitation rates and can provide opportunities for understanding which elements of nature attract people to locations and whether changes in ecosystems will alter visitation rates (Wood *et al.* 2013). Lee & Tsou (2018) studied geotagged *Flickr* photos collected from the Grand Canyon area over a 12-month period and found that the frequency of uploaded monthly photos was similar to total tourist numbers counted at the site. The study also used spatiotemporal movement patterns of tourists in conjunction with the uploaded photos to show how this approach can be used for the improvement of national park facility management and regional tourism planning (Lee & Tsou 2018). Barros *et al.* (2019) explored the potential of geotagged data to analyse visitors' behaviour in a national park in Spain. Using geotagged photo data from *Flickr* and GPS tracks from a web platform called Wikiloc the study determined the spatial distribution of visitors, the points of interest with the most visits, itinerary network, temporal distribution and visitors' country of origin, which was used to improve national park facilities and management.

The model calculates the average annual photo-user-days (PUDs) for each grid cell (1km x 1 km) across the period 2005-2011. The model used the latitude/longitude data from photographs as well as the photographer's user-name and photo date to calculate PUDs. One PUD is one unique photographer who took at least one photo in a specific location on a single day. This minimises the duplicated counts due to one photographer taking multiple photos at any given site. Across KwaZulu-Natal an annual average of 1434 PUDs were recorded.

Photographers upload their photos to a specific location. However, the photographer could be taking a photo of an attraction in the distance, not specific to the exact location where the photo was uploaded. This can create gaps within the data. To deal with this, a smoothed contour map reflecting the distribution of photos across KwaZulu-Natal was created using the 2005-2011 PUD data. This was done by sampling the number of PUDs to a higher resolution (5 000 m), creating a raster of this layer and then creating a contour map of this raster layer. This approach generated a smoothed version of PUD distribution, removing gaps or "holes" from the 2005-2011 data. To test that the smoothed results gave the same proportional break down of PUDs across the 11 district municipalities, the number of photos predicted by the smoothed layer was extracted per district municipality and compared to the actual number of photos for all time periods (Figure 4.10).

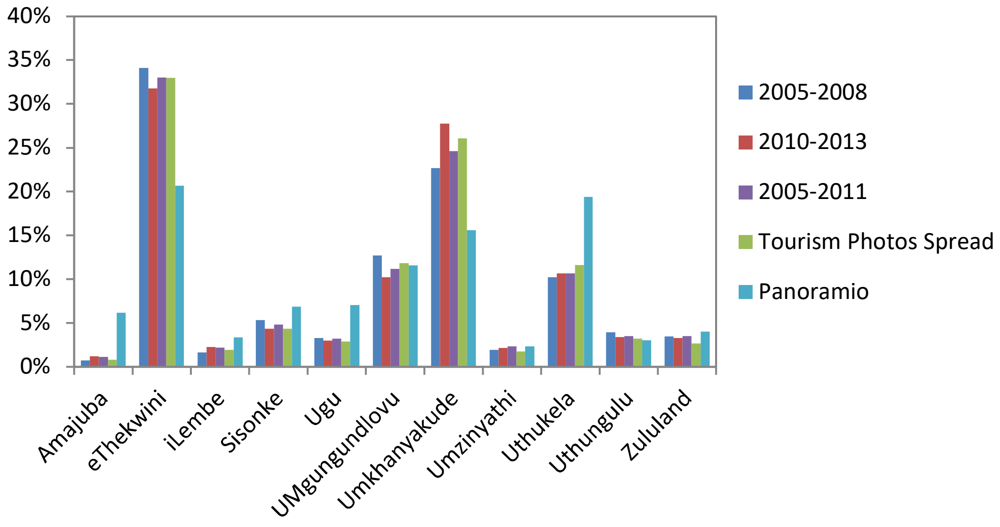

Figure 4.10. Percentage PUDs per district municipality for the three time periods, the smoothed photo layer and Panoramio layer (Turpie et al. 2017a). Note: Sisonke now known as Harry Gwala and uThungulu now known as King Cetshwayo.

A second comparison was also made with the number of photos according to the Panoramio grid layer compiled by Turpie *et al.* (2017a). There was no significant difference in the number of photos across the time periods and the smoothed layer. In some municipalities there were observed differences between Flickr and Panoramio.

The tourism value was spatially allocated in proportion to photo density. These values were then apportioned based on land cover data using KwaZulu-Natal Land Cover 2005, 2011. However, it became apparent that photos uploaded to coastal grid cells were being incorrectly assigned to terrestrial land cover classes rather than being assigned to the coast or marine environment. As a result of this, a study by Turpie *et al.* (2017b) which valued and mapped the nature-based tourism value of eThekwini Municipality was used to calibrate the proportion of photos assigned to different land cover categories. Turpie *et al.* (2017b) analysed the content of the photographs uploaded, assigning them to one of five categories; natural areas, built environment, natural man-made open space, agriculture/rural and coastal/marine. For this study we isolated the coastal grid cells for the eThekwini Municipality and looked at the percentage of coastal/seaside/marine photos uploaded per cell. Using this information, we reassigned photos uploaded to terrestrial land classes within a 1km buffer from the coast along the entire KwaZulu-Natal coastline. A proportion of the photos that had been assigned to the built environment, natural areas, rural/agriculture and man-made open space were instead assigned to the coastal environment (Figure 4.11). This provided a more realistic assessment as a significant portion of the photos taken within a 1 km buffer of the coast are in fact of the marine environment. The value assigned to the coastal strip was then deducted from the total value as the marine environment is not included in the accounts.

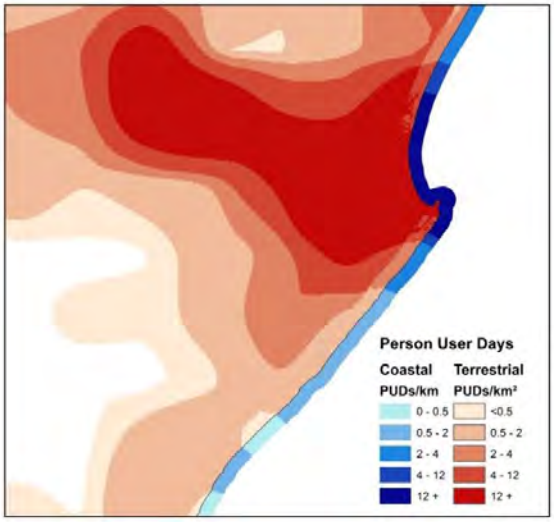

Figure 4.11. Close up of a section of KwaZulu-Natal coastline showing the deduction of PUDs from coastal land cover types and allocation to the coastal environment.

The total attraction-based tourism value for KwaZulu-Natal excluding the marine component was R727 million in 2005 and R1.2 billion in 2011. The marine component represented 3% of the total attraction-based tourism value in KwaZulu-Natal. The value of natural areas was estimated to be **R448 million** in 2005 and **R637 million** in 2011. This represented 64% and 57% of the total terrestrial tourism value, respectively. The tourism value of the agricultural/rural land in KwaZulu-Natal was estimated to be R85 million in 2005 and R162 million in 2011, representing 12% and 14% of the total value, respectively.

It is difficult to identify exactly what may have caused the nature-based tourism value to increase by R189 million between 2005 and 2011. However, it is possible to make some inferences based on available data and the tourism market over this time. Between 2005 and 2011 the proportion of domestic tourists holidaying in KwaZulu-Natal increased significantly from 12% to 36%. This was likely due to the economic recession during this time which forced South African residents to holiday locally as opposed to regionally and internationally. This increase in domestic holiday makers would have had a significant impact on tourism expenditure. Furthermore, nature-based tourism is one of the fastest growing sectors of the global tourism industry and has become a very popular leisure activity over the past decade. In southern Africa, especially, nature-based tourism generates significant revenue. Indeed, Balmford *et al.* (2009) used information on visitor numbers to 280 protected areas in 20 countries between 1992 and 2006. The study found that population-adjusted visitor numbers had been increasing in 15 of the 20 countries, of which South Africa was one. Reasons for an increasing trend in nature-based tourism include health and wellbeing with people increasingly seeking out nature-based activities for relaxation and exercise; urbanisation which has increased peoples need for green open space; social media which has broadened travel itineraries; and economic growth in developing countries which has facilitated the expansion of tourism in previously unvisited areas.

Most of the nature-based tourism comes from the Savanna and Grassland Biomes (Table 4.27) and is overwhelmingly in areas outside of former homelands (Table 4.28). Savanna and grassland biomes are the dominant biomes within the main protected areas, such as the uKhahlamba Drakensberg Park and Hluhluwe-iMfolozi Park.

Table 4.27. Distribution of nature-based tourism value across the Biomes within KwaZulu-Natal for 2005 and 2011, values in 2010 R millions.

Biome	Nature-based Tourism Value (2010 R millions)		% of Nature-based Tourism Value	
	2005	2011	2005	2011
Grassland	147.68	216.90	33%	34%
Indian Ocean Coastal Belt	84.84	99.88	19%	16%
Savanna	152.60	223.24	34%	35%
Forests	34.02	52.22	8%	8%
Freshwater ecosystems	9.04	14.10	2%	2%
Estuaries	19.87	30.59	4%	5%
Total	**448.04**	**636.92**		

Table 4.28. Distribution of nature-based tourism value across broad tenure types within KwaZulu-Natal for 2005 and 2011, values in 2010 R millions.

Tenure Type	Nature-based Tourism Value (2010 R millions)		% of Nature-based Tourism Value	
	2005	2011	2005	2011
Former homeland	70.21	95.09	16%	15%
Non-former homeland	377.83	541.83	84%	85%

The spread of nature-based tourism value is not evenly distributed across the different district municipalities and this has also changed between 2005 and 2011 (Table 4.29 & Figure 4.12). Almost two thirds of the nature-based tourism value within the province is within the uMkhanyakude, uThukela District Municipalities and eThekwini. Two of the most visited parks in KwaZulu-Natal, the Hluhluwe-iMfolozi Park and the iSimangaliso Wetland Park are situated in the uMkhanyakude district municipality and the uKhahlamba Drakensberg Park is located in the uThukela district municipality.

Based on the above assessments, the tourism contribution to the asset value of ecosystems in KwaZulu-Natal was estimated to be **R8.6 billion** in 2005 and **R12.9 billion** in 2011 (Table 4.30). There were no reductions in values over this time, with a positive net change of 50% or just over R4.3 billion over the six-year period.

Table 4.29. Distribution of nature-based tourism value across the District Municipalities within KwaZulu-Natal for 2005 and 2011, values in 2010 R millions.

District Municipality	**Nature-based Tourism Value (2010 R millions)**		**% of Nature-based Tourism Value**	
	2005	**2011**	**2005**	**2011**
DC21: Ugu	8.17	11.85	2%	2%
DC22: uMgungundlovu	42.86	58.41	10%	9%
DC23: uThukela	73.44	112.69	16%	18%
DC24: uMzinyathi	7.60	10.87	2%	2%
DC25: Amajuba	3.57	5.35	1%	1%
DC26: Zululand	16.48	23.96	4%	4%
DC27: uMkhanyakude	167.46	255.87	37%	40%
DC28: King Cetshwayo*	13.19	18.51	3%	3%
DC29: iLembe	3.30	4.84	1%	1%
DC43: Harry Gwala^	24.56	36.66	5%	6%
ETH: eThekwini	87.40	97.92	20%	15%

*Formerly known as uThungulu, ^Formerly known as Sisonke

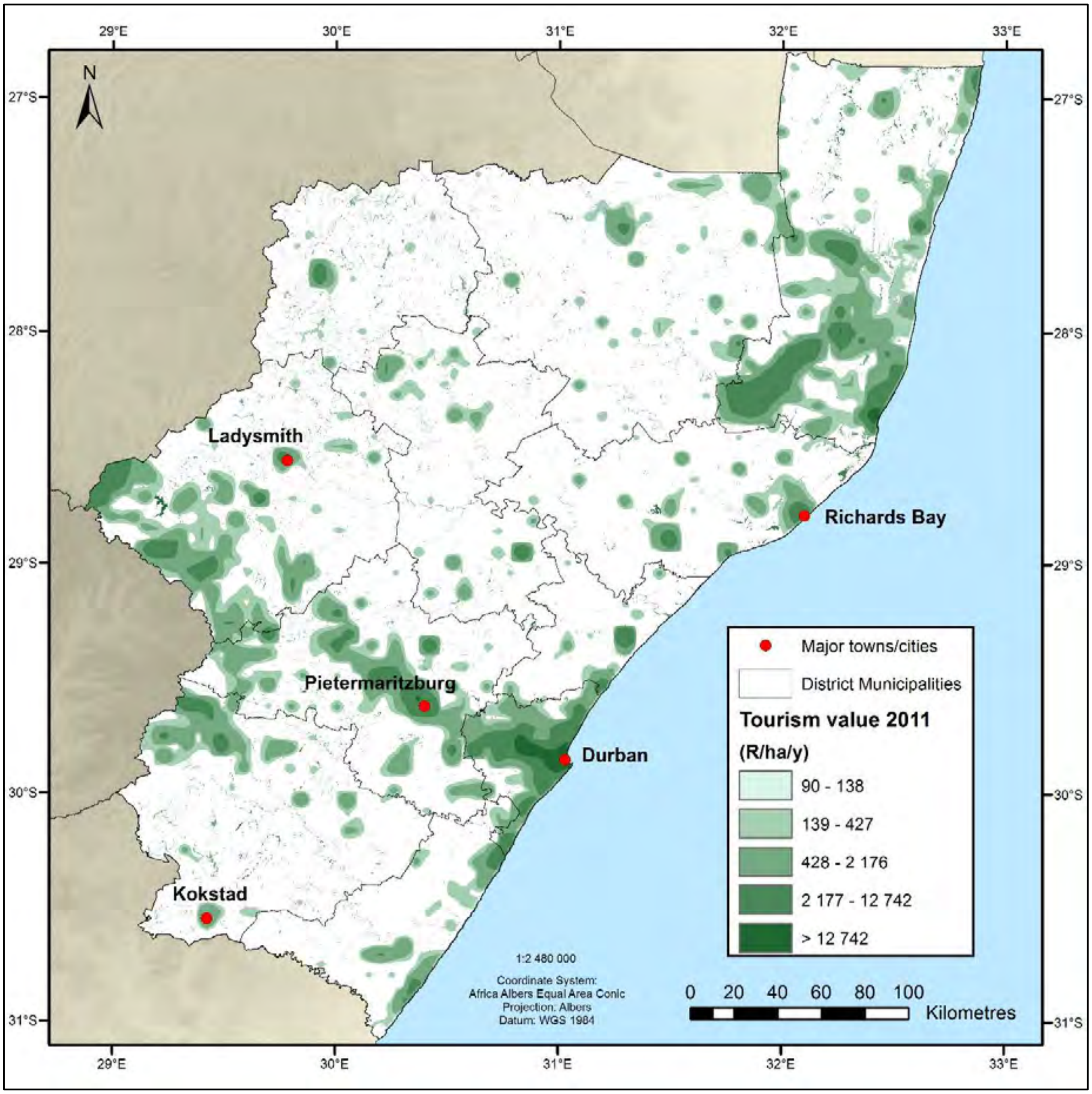

Figure 4.12. Nature-based tourism value for the year 2011 across KwaZulu-Natal based on the distribution of geo-references photos uploaded to Flickr

Table 4.30. Ecosystem monetary asset account 2005-2011 for nature-based tourism. NPV calculated using an asset lifespan of 25 years and a discount rate of 3.66%. Values are net present value in R millions.

	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	Cultivated	Total
Opening stock (2005)	**146.45**	**2 392.19**	**1 374.27**	**2 471.94**	**551.04**	**321.87**	**1 373.55**	**8 631.31**
Additions	81.92	1 121.28	243.68	1 144.27	294.93	173.66	1 249.17	4 308.90
Reductions	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net change	81.92	1 121.28	243.68	1 144.27	294.93	173.66	1 249.17	4 308.90
Closing stock (2011)	**228.37**	**3 513.48**	**1 617.95**	**3 616.21**	**845.97**	**495.53**	**2 622.72**	**12 940.22**
Net change %	55.9%	46.9%	17.7%	46.3%	53.5%	54.0%	0.0%	49.9%

4.4.2 Ecosystem contribution to property value

Green open space areas in cities provide several benefits, such as opportunities for recreation and tourism, attractive views, habitat for wildlife, improved air quality and biodiversity conservation. Green open space may also be valued based on an absence of unpleasant qualities associated with development in cities, such as noise, traffic congestion and pollution. The value that residents place on open space is reflected, to an extent, in private property and real estate markets. When prospective homebuyers purchase a home, they reveal their preferences for different characteristics through the amount that they are willing to pay for it. Homes that have a higher number of desirable characteristics fetch a higher price. Such characteristics may include physical attributes of the property such as size of the living area, number of bathrooms, security, and condition of the property, neighbourhood characteristics such as schools and crime levels, and environmental characteristics such as views and proximity of natural features or parks. If residents do value the latter, then it would be expected that this should be revealed in higher property prices.

The property value of urban green open space areas was estimated based on data used in the hedonic pricing study of eThekwini Municipality (Durban and surrounds; Turpie *et al.* 2017b). In Durban, the average property price premium associated with urban green open space was related to average income per residential census sub-place (similar to a suburb, n=389). The model from this detailed study was used in conjunction with census data to produce an estimate of the likely magnitude of premiums paid for green open space in other urban areas of KwaZulu-Natal.

The CSIR Functional Town Typology (van Huyssteen *et al.* 2018) provides a fine grained, but nationally comparable overview of regional scale settlement patterns and trends. This layer was used to identify the main urban centres classified as either city regions, cities, very large regional centres, large regional centres or regional centres (see Table 4.31).

Table 4.31. CSIR Functional Town Typology used to isolate the ten main urban areas in KwaZulu-Natal. Source: van Huyssteen et al. (2018)

Typology	Description
City Region	Large urban functional regions with a diverse economic output > R40 816 million/y (2013) and a population > 1 million people.
Cities and Very Large Regional Centres	Dense urban areas with interconnected settlements. Economy is service related with economic output > R7 900 million/y (cities) and > R4 000 million/y (very large towns). Population > 500 000 people (cities) and > 300 000 (very large towns).
Large Regional Centres	A regional node consisting of interconnected settlements and a significant social and economic service role in the region. Economic output > R1 400 million/y and population 100 000 – 300 000 people.
Regional Centres	A regional node consisting of interconnected settlements and a significant social and economic service role in sparsely populated region. Economic output > R1 100 million/y with a population < 100 000 people.

A total of ten urban centres in KwaZulu-Natal were identified using this classification system. Within these ten urban centres the urban residential area (from the 2014 national land cover) was mapped. The property model was then applied to the census sub-places located within these residential areas within the ten main urban centres (see Figure 4.13).

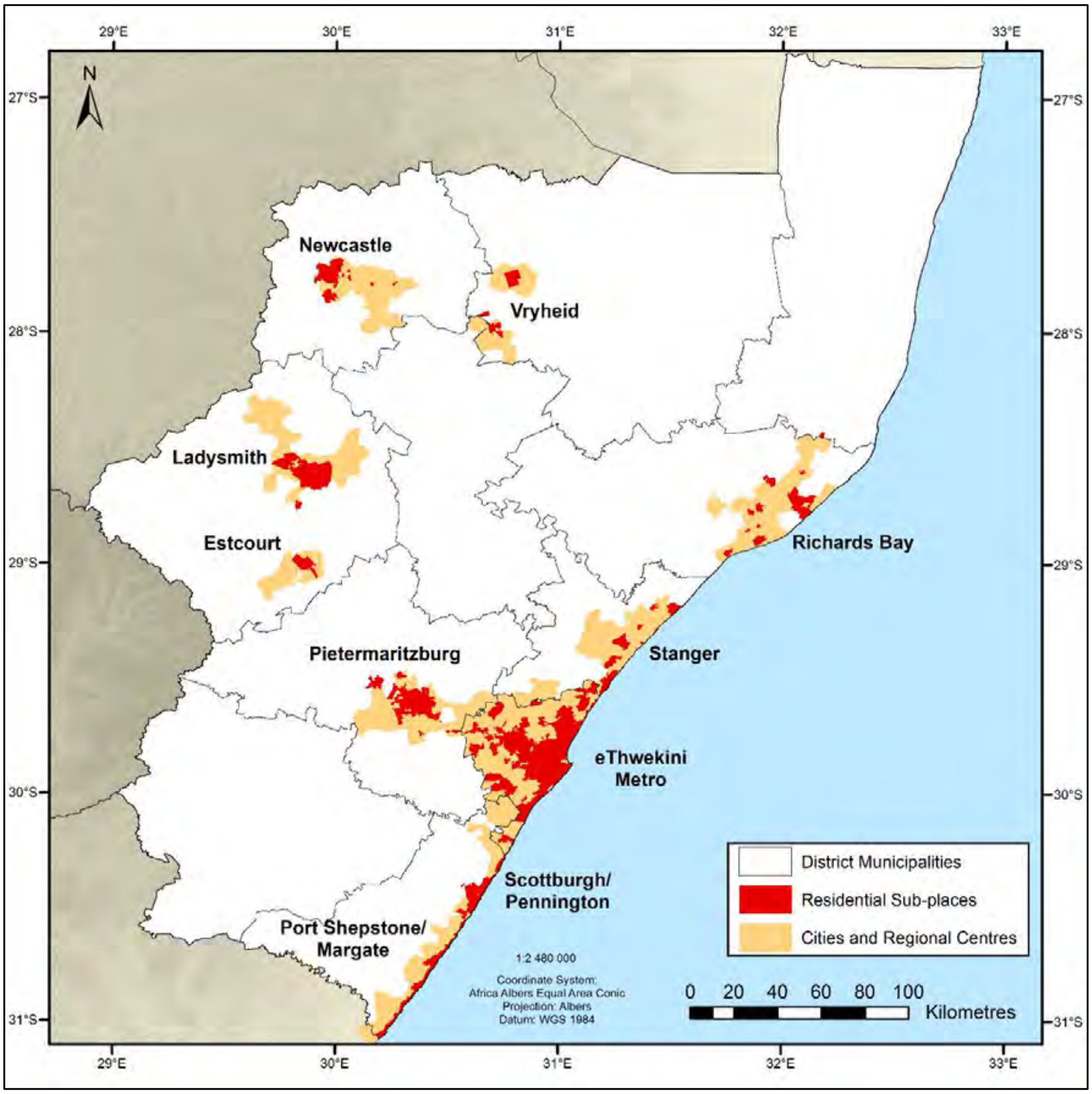

Figure 4.13. Map of KwaZulu-Natal showing the ten main urban centres as classified using the CSIR Functional Town Typology (orange areas) and the urban residential areas within these urban centres. Source: van Huyssteen et al. (2018)

In the eThekwini Municipality, the property value associated with environmental assets was estimated using the Hedonic Pricing Method (HPM), a form of multiple regression analysis. The HPM assumes that the final price of a good is a function of the values of the individual attributes (Rosen 1974). It relates the market price of a property to structural, locational and environmental attributes, with each property owner choosing their property based on utility maximization given by the price function (Taylor 2003, Anderson & West 2006). Assuming that nature is implicit in property prices, HPM can be used to estimate values for environmental goods or services from market-based transactions by including measures of access to natural and other open space areas in the regression model (UK ONS 2018). The HPM returns market-based transaction values which are consistent with the exchange value concept of national accounting.

The hedonic pricing study from the eThekwini Municipality was based on 16 149 property sales over a two-year period. Each property sale transaction in the dataset was geo-coded which allowed for matching each sale with a property boundary in the eThekwini municipal GIS cadastral layer. GIS was used to quantify the environmental surrounds of each property. Spatial data on green open space areas were taken from the Durban Metropolitan Open Space System (D'MOSS) map produced by the eThekwini Environmental Planning and Climate Protection Department (EPCPD), while spatial information on urban typologies (residential, industrial and commercial areas and roads) was taken from a land use land cover (LULC) map produced by the eThekwini GIS Department. The areas of green and urban typologies surrounding each property were calculated within three radiuses ("buffers") – 300 m, 1500 m and 5000 m. The amount of open space within the smaller 300 m buffer was not included in the larger 1500 m buffer and so on, so that the values remained independent of one another. Table 4.32 provides a list and definitions of variables included in the eThekwini hedonic model.

Table 4.32. Definitions of variables used in the eThekwini hedonic model. Source: Turpie et al. (2017b)

Variable name	Definition
Structural variables:	
Sales Price	Property transaction price (Rands)
Date	Year of sale
Total Living Area	Total area of main living space (m^2)
Garage	Presence/absence of a garage
Pool	Presence/absence of a swimming pool
Security	Level of security: Med-high or None-low.
View	View from property
Condition	Condition of property: Good, Average, Poor
Neighbourhood variables:	
Population density	Number of persons per km^2 in census sub-place
CBD	Distance to Central Business District (km)
School	Distance to nearest independent school (m)
Income	Modal household income per census sub-place (Rands)
Industry	Amount of industrial land within property radius (ha)
Commercial/Retail	Amount of commercial/retail land within property radius (ha)
Road	Amount of major roadway within property radius (ha)
Coastline	Distance to nearest coastline point (km)
Tree cover	Percentage neighbourhood tree cover per census sub-place (%)
Open space amenities:	
Golf course	Amount of golf course within property radius (ha)
Park	Amount of park land within property radius (ha)
Sugarcane farmland	Amount of sugarcane farmland within property radius (ha)
Natural vegetation	Amount of natural vegetated open space in a good (1), intermediate (2) or degraded (3) condition within property radius (ha)
Rivers	Length of river in a good (1), intermediate (2) or degraded (3) condition within property radius (m)

Each property was assigned to a census level sub-place (roughly equivalent to a suburb) and the effect of open space (natural and parks) on property values was obtained from the estimated hedonic model coefficients, which provide the percentage change in property value given a unit change in the value of the open space variable under consideration. The aggregate effect of open space, or the monetary stock value, in the study area was then estimated by applying the regression results to the entire stock of residential houses within each sub-place of the municipality.

Using the hedonic model from the eThekwini Municipality, a simple property model was developed in order to estimate the property premiums associated with urban green open space in the ten main urban centres of KwaZulu-Natal in 2011. The model related the average property premium associated with urban green open space (natural open space areas and parks) to average household income ($R^2 = 0.42$, $P < 0.001$). The model was applied to census data (2011) for each urban residential sub-place within the ten urban centres to generate a total property premium value for that urban centre. The total premium value was converted into 2010 Rands and then annualised.

The total property premium associated with urban green open space in KwaZulu-Natal in 2011 was estimated to be in the order of **R1 328 million per year** (Table 4.33). eThekwini Municipality accounts for some 68% of this value. The value associated with eThekwini is based on detailed property sales data and was calculated with a high degree of confidence. The results for the other nine urban centres are not based on actual property sales data specific to each area and therefore reflect only the ***likely magnitude*** of property premiums associated with urban green open space in these areas.

Table 4.33. Total annualised property premium associated with urban green open space in the ten main urban centres in KwaZulu-Natal in 2011. Values in 2010 R millions.

Urban Centre	CSIR Functional Town Typology	Total annualised property premium (2010 R million)
Estcourt	Regional Service Centre	8.9
eThekwini	City Region	897.0
Ladysmith	Large Regional Service Centre	39.7
Newcastle	Very Large Regional Service Centre	42.6
Pietermaritzburg	City	146.8
Port Shepstone/Margate	Regional Service Centre	42.7
Richards Bay	City	83.3
Scottburgh/Pennington	Regional Service Centre	13.6
KwaDukuza	Regional Service Centre	34.0
Vryheid	Regional Service Centre	19.2
Total		**1 327.8**

In the absence of property data for 2005, we used the South African real (inflation adjusted) property growth rate between 2005 and 2011 in order to estimate the property premium in 2005. This was taken from the FNB Property Barometer report which contained the monthly house price index (%y/y) from 2001-2019. Based on this, the annualised property premium associated with urban green open space in the ten main urban centres in KwaZulu-Natal in 2005 was estimated to as **R1 165 million per year**.

These values could not be mapped. The KwaZulu-Natal land cover map does not provide sufficient detail within urban areas to be able to accurately apportion the value to individual green open space. Turpie *et al.* (2017b) were able to map the values in their study as the Durban Metropolitan Open Space System (D'MOSS) map produced by the eThekwini Environmental Planning and Climate Protection Department (EPCPD) provided such detail. **Going forward, the accounts should use a land cover which includes a detailed typology of urban land classes**.

The property value contribution of ecosystems was estimated to be **R18.9 billion** in 2005 and **R21.5 billion** in 2011 to ecosystem asset value. This amounts to an increase of just over R2.6 billion between 2005 and 2011, or a net change of 14%.

Based on the results for Durban, 76% of the ecosystem value was attributed to public parks, and 24% to natural open space occurring within the residential subplaces of the ten urban areas in the analysis. Since the area of public parks was not known for all ten urban areas, the per ha value is expressed in terms of the total built area. **Both of these aspects need to be refined in future accounts, and will require obtaining detailed property sales and open space data from municipalities.**

4.5 Carbon storage and sequestration

4.5.1 Overview of the service

Natural systems (and to an extent cultivated systems) are understood to make a significant contribution to global climate regulation through the sequestration and storage of carbon. 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. 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 conservation and restoration of natural systems thus helps to reduce the rate at which greenhouse gases accumulate in the atmosphere and the consequent impacts of climate change. This is a global benefit, but it is possible to estimate the benefit from a national perspective. It would not be necessary or appropriate to further disaggregate the benefit to a regional scale for a regional account.

4.5.2 Data and methods

As part of the SEEA, the carbon accounts will keep track of carbon stored in ecosystems (= carbon stocks) and the changes over time as a result of sequestration of carbon from the atmosphere by plants and releases of carbon back into the atmosphere that occur as a result of ecosystem disturbance (= carbon flows). Carbon itself is an abiotic element, however it is included in the ecosystem accounts because it is actively sequestered and stored by plants, and even its storage in soil is linked to biological processes and ecosystem health. Both sequestration and storage are ecosystem services, and ecosystem disturbance changes both of these parameters, more often than not resulting in a net reduction of stored carbon. Carbon stocks are easier to determine than carbon flows, and the net flows can be determined as the difference in carbon stocks. Since it is the net change in carbon stored in ecosystems versus the atmosphere that matters most, this should be the focus of the ecosystem accounts, rather than trying to account for one part of the flows - carbon sequestration – that is typically known as the ecosystem service. This is the approach taken in this study. Ideally, however, both types of flows should be accounted for and should sum to the change in stocks. Carbon sequestration rates in specific ecosystem types can be derived from literature and from IPCC guidelines on stock inventory estimates for the LULUCF and used to produce look up tables. The estimation is the product of an area in hectares and a coefficient. Horlings *et al.* (2019), in their compilation of experimental monetary accounts for the Netherlands, focused on carbon sequestration as the service, valued as the actual capture of CO_2 from the atmosphere into biomass. The UK Office for National Statistics also followed this approach, valuing the removal of carbon dioxide equivalent (CO_2e) from the atmosphere by habitats in the UK (UK ONS 2019).

Using the South African National Carbon Sink Assessment (DEA 2015), total ecosystem carbon in KwaZulu-Natal was estimated for 2005 and 2011. The physical mean carbon value (g C/m^2) for each natural and cultivated (i.e. vegetated) land cover class was extracted from the National Carbon Sink Assessment Total Ecosystem Organic Carbon map and multiplied by the area of each land cover class within KwaZulu-Natal in 2005 and 2011 to get a total ecosystem carbon value for each land cover class in each year. In 2005, total ecosystem carbon was estimated as 1237 Tg C, which equates to approximately 4540 Tg CO_2 (using molecular weight of CO_2/molecular weight of carbon, i.e. 44/12; EPA, 2016). In 2011 total ecosystem carbon was estimated as 1197 Tg C and 4393 Tg CO_2. The highest ecosystem carbon values were from the grassland land cover class.

The benefit of both sequestration of carbon from the atmosphere and limiting the release of stored carbon through ecosystem degradation is the reduced impact of climate change as a result of reduced concentrations of carbon dioxide in the atmosphere. Termed the social cost of carbon (SCC), the damages that would be incurred under climate change are typically estimated in terms of changes in GDP, which is therefore a directly compatible measure for ecosystem accounting. An alternative way to value the service is using its value in markets that have developed as a result of government and private efforts to “neutralise” carbon emissions. Some studies do both. For example, Horlings *et al.* (2020) estimated the value of carbon sequestration using both the SCC and the carbon price of policy targets. The latter approach was used by the UK Office for National Statistics (UK ONS 2019). In this study, the SCC was used as there has been very little trade in biomass carbon credits.

The SCC is usually defined as the net present value of the cumulative impact of one additional ton of carbon dioxide emitted into the atmosphere today over its residence time in the atmosphere (Watkiss *et al*. 2005), with the latter typically being taken to be 100 years. Estimates of the global social cost of carbon vary greatly, depending on the climate change scenario, the design of the integrated assessment model (IAM) and the choice of discount rate. The most well-known of the IAMs is the Dynamic Integrated model of Climate and the Economy (DICE, Newbold 2010).

By 2008, there were at least 232 published estimates of SCC, the average of which was about US\$33/tCO$_2$ (Tol 2008). In an effort to refine these estimates, the more recent literature has also tended to broaden the types of damage costs considered, increasing the estimates of SCC. Thus, estimates now range from US\$10 to US\$1000/tCO$_2$ (Ricke *et al*. 2018). In their critical review of the literature, Van den Bergh & Botzen (2014) suggested a lower bound value of US\$125/tCO$_2$. A recent expert meeting of scientists and economists found a mean SCC of US\$150-200/tCO$_2$.

More recent studies have also attempted to disaggregate these global SCC estimates to regional or country level. For example, Nordhaus (2017) provided an updated estimate of global SCC as US\$31/tCO$_2$ and estimated that 3% of this would be borne in Africa. Turpie *et al*. (2017a,b) further disaggregated that estimate to country level based on relative GDP and climate change vulnerability of African countries, and estimated that South Africa is likely to bear only 0.35% of the global SCC (~\$0.11/tCO$_2$). Ricke *et al.* (2018) produced a far higher estimate of global SCC (US\$417/ tCO$_2$) and disaggregated this to country-level, with the estimated cost to south Africa being US\$3.31, which is 0.8% of their global SCC estimate. These values are shown in 2010 Rands in Table 4.34. The global SCC net of the South African portion can be considered as an exported service in the form of cost savings to the rest of the world.

In this study, for comparison purposes, we applied both the SCC values of Ricke *et al.* (2018) and Nordhaus (2017) to estimate the total value of carbon storage in KwaZulu-Natal from both a South African perspective and a global perspective (Table 4.34). It is important to note that the value of SCC is expected to increase over time as populations and per capita incomes grow, and thus it is strictly correct to see the estimate being specified in terms of the year of emission. For example, using the DICE model, Nordhaus (2017) provided updated estimates of the SCC for a ton of CO$_2$ emitted in 2015 (US\$31.25/tCO$_2$ in 2010 US\$) and also for CO$_2$ emissions in a range of future years. These values increased at a real growth rate of 3% per year. The SCC estimate should therefore ideally correspond to the year of the account. Carbon retained in the environment will increase in real value over time. Thus, we adjusted the Ricke *et al.* (2018) and Nordhaus (2017) SCC estimates for at a rate of 3% per year to derive different estimates for 2005 and 2011 (Table 4.34).

Table 4.34. The estimates of the Global and South African SCC values per tCO$_2$ used in this study based on values from Nordhaus (2017) and Ricke et al. (2018), all in 2010 South African Rands.

	Nordhaus 2017	**Ricke *et al.* 2018**
Global SCC per tCO$_2$ 2005	175.33	1 775.95
Global SCC per tCO$_2$ 2011	209.35	2 120.58
South Africa SCC per tCO$_2$ 2005	1.39	14.03
South Africa SCC per tCO$_2$ 2011	1.65	16.75

The SCC is a net present value of avoided costs, typically over 100 years. However, for accounting purposes, values must be determined for the year in question. Thus, the annualised social cost of carbon (ASCC) was then estimated as:

$$ASCC = \frac{(\delta * SCC)}{(1 - (1 + \delta)^{-t}}$$

where δ is the discount rate, and t is the time period of the SCC calculation in years. For this study, we assumed t = 100 years, and we used a social rate of discount of 3.66%.

4.5.3 Results and discussion

KwaZulu-Natal had an estimated 1 237 Tg of carbon in 2005 and 1 197 Tg of carbon in 2011 (Table 4.35). Between 2011 and 2005, there was an overall loss of 40.1 Tg of ecosystem carbon in KwaZulu-Natal, which suggests that carbon is being lost at a rate of 0.54% per annum. The majority of these losses are attributed to the degradation and loss of grassland, bushland and forest areas. Note that these losses are net of any gains made by bush encroachment and the spread of invasive alien plants, as well as the gains made by the planting of higher biomass crops such as trees.

Using the more conservative estimate of SCC from Nordhaus (2017), in 2005, the retained carbon stocks had an annualised global value of some **R29.9 billion per year** of which national benefits amount to **R236 million per year**. In 2011, these values were **R34.6 billion per year** and **R273 million per year**, respectively (Table 4.35). The 2011 values were higher than the 2005 values in spite of a reduction in carbon, because of the increasing value of retaining carbon over time.

Using Nordhaus's (2017) estimate, the values are 10% and 12% of Ricke *et al*. (2018) estimates, respectively. To put these values into perspective, the KZN economy was worth R366 bn and R450 bn in 2005 and 2011, respectively. The estimated **annualised** global benefits based on Nordaus's (2017) value are approximately 8% of the value of the region's economy, whereas the estimates based on Ricke *et al.* (2018) are about 80% of the value of the region's economy.

Based on the Nordhaus (2017) estimate of SCC, the contribution of this service to the asset value of ecosystems in KwaZulu-Natal was estimated to be **R485 billion** in 2005 and **R560 billion** in 2011 (Table 4.35). The avoided costs to South Africa were R3.8 bn and R4.4 bn of this, respectively. The carbon already lost from the study area from 2005 to 2011 will incur global costs of at least R17 billion over 25 years in net present value terms. The carbon remaining in the landscape is becoming increasingly important.

Table 4.35. Total estimated ecosystem carbon (Tg C) in 2005 and 2011 and the estimated avoided global cost and social cost to South Africa. Values in 2010 R millions.

	Land cover class	**Total ecosystem carbon (Tg C)**		**Diff (Tg C)**	**SA SCC (2010 R million) Nordhaus (2017)**		**Global SCC (2010 R millions) Nordhaus (2017)**		**Global SCC (2010 R millions) Ricke *et al.* (2018)**	
		2005	**2011**		**2005**	**2011**	**2005**	**2011**	**2005**	**2011**
Natural/Semi-natural	Wetlands	13.3	15.5	2.2	68	94	8 550	11 898	86 607	120 520
	Mangroves	0.1	0.2	0.1	1	1	64	154	651	1 555
	Forest	34.3	30.6	-3.7	174	186	22 050	23 489	223 356	237 929
	Dense bush	140.5	155.6	15.1	714	944	90 323	119 441	914 912	1 209 863
	Bushland	132.9	100.8	-32.1	675	611	85 437	77 376	865 422	783 767
	Woodland	45.1	38.8	-6.2	229	235	28 993	29 783	293 684	301 688
	Grassland/bush clumps	52.1	54.5	2.3	265	330	33 493	41 835	339 266	423 763
	Grassland	477.1	397.5	-79.6	2 423	2 411	306 711	305 127	3 106 795	3 090 748
	Alpine grass - heath	2.7	2.7	0	14	16	1 736	2 073	17 582	20 994
	Forest glade	0.1	0.1	0	1	1	64	77	651	778
	Degraded forest	0.1	0.9	0.8	1	5	64	691	651	6 998
	Degraded bushland	12.3	17.6	5.3	62	107	7 907	13 510	80 096	136 848
	Degraded grassland	47.5	41.6	-5.9	241	252	30 536	31 933	309 312	323 459
	Total	**958.1**	**856.4**	**-101.7**	**4 866**	**5 193**	**615 930**	**657 386**	**6 238 985**	**6 658 910**
Cultivated	Plantation	118.4	120.9	2.5	601	733	76 115	92 805	771 001	940 054
	Plantation: clear-felled	15.9	20.5	4.6	81	124	10 222	15 736	103 538	159 397
	Orchards (banana, citrus)	1.2	2.5	1.3	6	15	771	1 919	7 814	19 439
	Orchards (cashew)	0.2	0.2	0	1	1	129	154	1 302	1 555
	Pineapples dryland	0.4	0.6	0.2	2	4	257	461	2 605	4 665
	Sugarcane: commercial	47.3	47.3	0	240	287	30 408	36 308	308 010	367 780
	Sugarcane: emerging	11.9	3.9	-8.1	60	24	7 650	2 994	77 491	30 324
	Subsistence (rural)	27.1	75.1	48	138	455	17 422	57 648	176 471	583 938
	Commercial crops: dryland	33.5	46.5	13.1	170	282	21 536	35 694	218 146	361 559
	Commercial crops: irrigated	15.4	16.1	0.7	78	98	9 900	12 359	100 282	125 185
	Old, cultivated fields & smallholdings	7.4	7	-0.5	38	42	4 757	5 373	48 188	54 428
	Total	**278.7**	**340.6**	**61.8**	**1 415**	**2 065**	**179 167**	**261 450**	**1 814 847**	**2 648 324**
	Grand Total	**1 237**	**1 197**	**-40.1**	**6 281**	**7 259**	**795 097**	**918 836**	**8 053 833**	**9 307 234**
	Annualised value (R millions)				**236**	**273**	**29 923**	**34 579**	**303 097**	**350 267**

Table 4.36. Ecosystem monetary asset account 2005-2011 for carbon. NPV calculated using an asset lifespan of 25 years and a discount rate of 3.66%. Values are net present value in R millions.

	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	Cultivated	Total
Opening stock (2005)	**1 963**	**200 482**	**23 873**	**136 199**	**12 916**	**80**	**109 232**	**484 745**
Change due to C stocks	-170	-22 559	-5 027	-15 313	-637	-22	26 615	-17 113
Change due to C price	366	36 909	4 188	25 075	2 450	14	23 551	92 552
Closing stock (2011)	**2 159**	**214 832**	**23 034**	**145 962**	**14 729**	**71**	**159 398**	**560 185**
Net change	**196**	**14 350**	**-839**	**9 763**	**1 813**	**-8**	**50 165**	**75 440**
Net change %	10%	7%	-4%	7%	14%	-11%	0%	16%

4.6 Crop pollination

Agricultural support services include pollination of crops and control of agricultural pests by animals living in surrounding environments. These services are measured as the difference in output of the serviced areas. Our analysis only includes pollination to crops and is restricted to pollination inputs to "home gardens" in the low-density settlements of communal areas of KwaZulu-Natal. While the pollination of low input crop systems is likely to be the most important aspect of this group of services in KwaZulu-Natal, future versions of the accounts will also need to consider pest control and support services to commercial crops, and control of livestock pests.

4.6.1 Overview of the service

Pollination services are widely recognized as critical for human wellbeing and survival given their vital role in ensuring food security. However, the value of wild pollinators remains unclear. This is concerning for sub-Saharan Africa, a region highly dependent on subsistence agriculture as a main source of livelihood (Tibesigwa *et al.* 2019). The presence of wild pollinators is directly linked to natural vegetation (Kremen *et al*. 2004) which plays a critical role in certain life cycle stages of pollinator species, such as through the provision of nesting sites or forage at certain times of year. Insects are responsible for 80-85% of all pollinated commercial crops which represents about one-third of global food production (Williams 1996, Allen-Wardell *et al*. 1998, Klein *et al.* 2007). Commercial agriculture in the province of KwaZulu-Natal is dominated by the production of sugarcane, maize, soy beans, wheat, potatoes, cabbage, pineapples, bananas, and oranges. Except for cabbage, and to a limited extent, oranges, these crops do not require insect pollination. However, there is a diversity of other food crops produced in the study area. Where pollination is required for these species, commercial farmers hire commercial hives for this purpose. Commercial hives are typically moved around the country, fulfilling pollination needs as required and are therefore not directly affected, or constrained, by changes in land cover. However, this is not the case for subsistence producers in the province who are almost completely reliant on wild pollinators for the successful pollination of their crops. These subsistence producers make up a large proportion of the population in the study area and tend to be among some of the poorest in the country.

Whilst subsistence farmers in KwaZulu-Natal focus predominantly on wind-pollinated maize crops, many have fruit and vegetable gardens around their homesteads which are critical to household food security, and these are almost exclusively pollinated by wild pollinators, mostly bees. There is a clear need to understand the potential implications of land cover change within KwaZulu-Natal on pollination services and the potential economic value of these. Detailed work carried out in Tanzania (Tibesigwa *et al.* 2019) has provided insights into the mechanisms, impacts and value of pollination services within a rural African context. This study will be drawn on to estimate the value of pollination services for subsistence farmers in KwaZulu-Natal.

The crop pollination service is defined as the increase in crop production in pollinator-dependent crops that are supplied by the natural ecosystem assets surrounding cropland to the economic user of the land (i.e. the farmer, Horlings *et al.* 2020). The economic benefit is therefore increased crop production. The wild pollination service is primarily provided by surrounding natural habitat rather than the land under crops. Therefore, we account for pollination as an input from surrounding ecosystems.

4.6.2 Data and methods

There are several estimates of the value of pollination services in South Africa (e.g. Turpie & Heydenrych 2000, Turpie *et al.* 2003, Allsopp *et al.* 2008, Mouton 2011, de Lange *et al.* 2013, Turpie *et al.* 2017a), though none of these are based on empirical analysis. There are, however, several empirical studies investigating the relationships between wild pollinators and agricultural production at very localised scales (e.g. Allsopp *et al.* 2008, Mouton 2011, de Lange *et al*. 2013). Most of the valuation studies have used replacement cost methods, where the value of the service was estimated in terms of the additional input costs that would be incurred if pollinators were no longer present (i.e. the service was lost) and hand pollination would be required to replace the service provided by bees, or beehives would need to be hired. This approach uses cost estimates of hand pollination, labour and pollen, or the cost associated with hiring beehives.

Tibesigwa *et al*. (2019) provides the first empirical valuation study of wild pollination services in Africa. Their study estimated the contribution of wild pollinators to crop revenues for smallholder crop farms in Tanzania, based on detailed plot-level panel data on production and surrounding land cover. A production function was created with the following inputs: plot-level agricultural data (Tanzania National Panel Survey); plot revenue from crop farming; wild pollination services (i.e. % share of natural habitat - NASA Servir Land Cover Data); production inputs; plot and household characteristics; and weather characteristics. To capture the relationship between crop productivity, foraging distance and frequency of pollination, buffers of 100 m, 250 m, 500 m, 1000 m, 2000 m and 3000 m distance, were placed around each of the farm plots and the percentage share of natural habitat (forest) within each of the buffers was determined. The results showed that natural habitats of wild pollinators make a significant contribution to plot-level crop revenue, with the areas in close proximity contributing much more than those farther away. Furthermore, changes in natural habitat from 2008 to 2013 reduced crop revenue by as much as 29% (mean) and 4% (median), highlighting the importance of natural habitats in boosting crop yields of smallholder farms (Tibesigwa *et al*. 2019).

For estimating the value of wild pollination services in KwaZulu-Natal and in in determining the impacts of a loss of natural vegetation immediately surrounding homesteads, we adopted a benefit transfer approach, drawing on the work of Tibesigwa *et al.* (2019). The production areas in the Tibesigwa *et al.* (2019) study comprised a variety of food crops that included known wild insect dependent pollinated crops, non-insect dependent crops and unknown crops. For the purposes of this study, we assumed that production in our study area contained similar food crop species mixes, and similar pollinator ratios. Tibesigwa *et al.* (2019) estimated three regression models to predict crop revenue from (1) pollinator-dependent crops, (2) all crops and (3) pollinator-independent crops. Given that household home gardens are mainly pollinated we used the first panel model that precited crop revenue from pollinator-dependent crops.

Our analysis was restricted to pollination inputs to "home gardens" in the low-density settlements of communal areas (Ingonyama Trust land) within KwaZulu-Natal, using information on land cover within these "low density settlements" for 2005 and 2011. Based on the Statistics South Africa Community Survey (Stats SA 2016 there were 6 401 307 people and 1 416 877 households in the low-density settlement areas of rural KwaZulu-Natal in 2011 (Stats SA 2016). Approximately 19% of these households were engaged in some form of agriculture, and of these, 84% had home gardens (Stats SA 2016). This equates to 221 919 households with home gardens used to grow fruit and vegetables. The average size of a home garden was estimated to be 229 m^2, based on studies in KwaZulu-Natal (mean size = 224 m^2, n = 53; Shisanya & Hendriks 2011) and the Eastern Cape (mean size = 234 m^2, n = 90; Ogundiran *et al.* 2014). There were no data available on the proportion of households with home gardens in 2005. Therefore, for this analysis it was assumed that the number of households with home gardens was the same in 2005 as in 2011. However, given that the area of low-density settlements increased from 2005 to 2011 within the communally-managed traditional areas of KwaZulu-Natal we acknowledge that this is not a strong assumption and that the extent of home gardens in 2005 could have been lower than in 2011.

The surrounding land cover was estimated using a 1000 m buffer around each of the settlement areas. The choice of buffer distances was based on the findings of Tibesigwa *et al.* (2019), which showed an overall decline in crop production with increasing distance from natural vegetation, and that the modelled effect of natural vegetation on production value increased with increasing buffer distance up to 1000 m, after which a slight decline was observed for the 2000 m and 3000 m buffers (Tibesigwa *et al.* 2019). A 1000 m buffer therefore captures the critical value contribution natural areas can provide in enhancing pollination services, and decreasing marginal returns are evident at distances beyond this.

We then applied the panel regression model from Tibesigwa *et al.* (2019) to predict crop revenue from pollinator-dependent crops, using the percentage share of natural habitat in each sub-place for 2005 and 2011, and keeping all else constant. Tanzanian values (Tsh per acre) were converted to Rands per ha (2010 prices). To estimate the value of the service, we compared the result with a hypothetical scenario in which the natural vegetation surrounding the home gardens had been lost. The difference provided the contribution of natural habitats to the value of home garden production.

Notes: (i) *Our assessment is conservative in that it is restricted to pollinator-dependent crop production in household gardens only. Many small-scale (low input) farmers do also farm pollinator-dependent crops on larger fields for income. In addition, commercial farmers, while they do tend to use managed hives and other methods for pollination, are also likely to benefit from the existence of wild pollinators. Future studies should aim to include these additional benefits*. (ii) *Our study is also based on an empirical analysis from Tanzania, which involved the type of data that are not available in South Africa, collected repeatedly over several years. Similar efforts need to be made in South Africa to inform estimates of this as well as other services.*

4.6.3 Results and discussion

In 2005 the percentage share of natural vegetation (forest, woodland, wooded grassland, dense bush and bushland) within 1000 m surrounding home gardens was 35.9% and in 2011 this had decreased to 33.4%, a difference of 2.6%. This is a loss of just over 50 000 hectares of natural vegetation from within the buffer zones. Bushland and woodland were the most severely affected, with decreases in area of 2.7 and 0.9 percentage points, respectively. These losses are similar to those reported by Tibesigwa *et al.* (2019), who found a 2.38 percentage points loss in forest cover in the 1000 m buffer from 2008 to 2013. This loss in natural vegetation is likely due to expansion of settlement areas and the impacts of overgrazing in traditional areas.

The distribution and value of the pollination service to home gardens in 2011 is shown in Figure 4.14. The value of wild pollination services (contribution to production from pollinator-dependent crops in household gardens) per biome for 2005 and 2011 is summarised in the supply table below (Table 4.37). Based on the percentage share of natural vegetation with a 1000 m buffer distance of home gardens and the total annual plot revenue per 0.06 acre from pollinator-dependent crops (~R230), we estimate the value of wild pollination services to nature dependent subsistence home gardens in KwaZulu-Natal to be **R51.3 million** in 2005 and **R47.7 million** in 2011. This gives a per hectare value of R48 for the natural vegetation within the 1000 m buffer. Savanna ecosystems contribute the most to these values.

Ogundiran *et al.* (2014) investigated the role of home gardens to household food security in the Eastern Cape and found that the average income earned from vegetable production per year from home gardens, with an average size of 0.06 acres (242 m^2), was R430 (2010 Rands). The main vegetables sold were cabbage, spinach, carrot, butternut, onions, lettuce, green peppers and potatoes. This value aligns with our results in that the revenue generated per 0.06 acre plot (R230) relates only to pollinator-dependent crops, suggesting that just over half of the revenue generated is from fruit and vegetable crops that rely on wild pollinators.

Based on the above assessments, the contribution of this service to the asset value of ecosystems in KwaZulu-Natal was estimated to be **R830 million** in 2005 and **R773 million** in 2011 (Table 4.38). Reductions over this time amounted to almost R58 million (7%).

Table 4.37. Monetary supply table for wild pollination services, for 2005 and 2011; values in 2010 R millions

Biome / Service	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	TOTAL
2005 **Pollination service to subsistence household "home garden" production**	0.07	11.87	6.07	31.35	1.88	0.00	**51.26**
2011 **Pollination service to subsistence household "home garden" production**	0.06	11.09	5.03	29.73	1.77	0.00	**47.69**

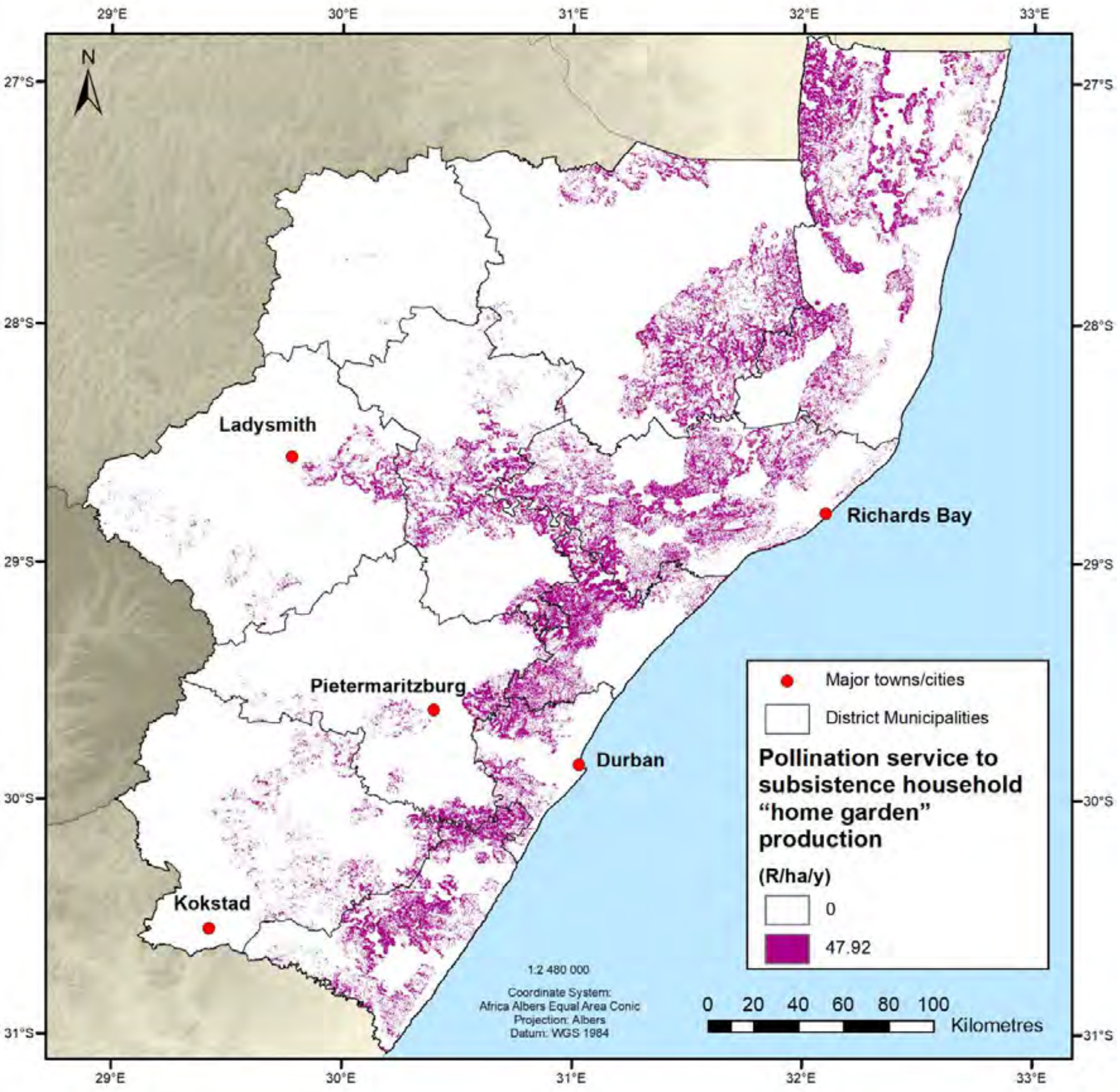

Figure 4.14. Contribution of pollination services from natural habitats to home garden revenues (R/ha/y), 2010 Rands.

Table 4.38. Ecosystem monetary asset account 2005-2011 for agricultural support services. NPV calculated using an asset lifespan of 25 years and a discount rate of 3.66%. Values in R millions.

	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	Total
Opening stock (2005)	1.17	192.34	98.40	507.83	30.51	0.07	**830.33**
Additions	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reductions	-0.14	-12.69	-16.88	-26.31	-1.79	-0.02	-57.83
Net change	-0.14	-12.69	-16.88	-26.31	-1.79	-0.02	-57.83
Closing stock (2011)	1.03	179.65	81.52	481.52	28.72	0.05	**772.50**
Net change %	-11.9%	-6.6%	-17.2%	-5.2%	-5.9%	-28.1%	-7.0%

4.7 Flow regulation (maintenance of base flows)

4.7.1 Overview of the service

Ecosystems can reduce variation in downstream river flows over the longer duration through infiltration and temporary storage in the catchment areas, reducing the need for built storage to achieve a given yield through the year. This service is therefore likely to be more important where there is high seasonality in rainfall patterns, and especially where demand is strongly seasonal, such as for irrigation during the dry season.

There can be substantial natural intra- and interannual variation in river flows, depending on the climatic zone. Where such variability is high, the amount of water available for use in the low flow period can be increased by building reservoirs that capture water during high flow periods (Figure 4.15).

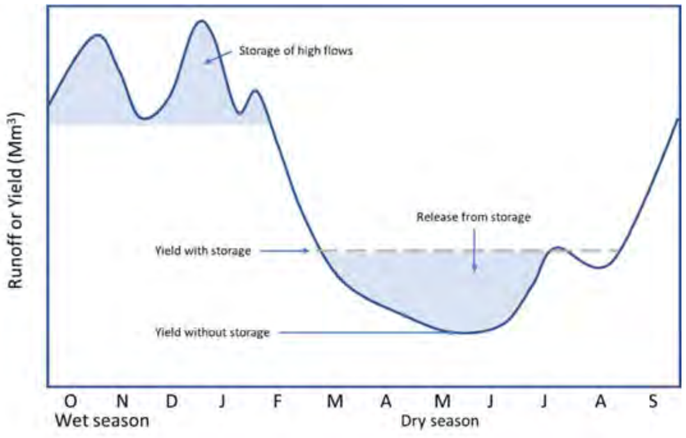

Figure 4.15. Schematic representation of stream flow and storage of a year

The more storage capacity there is in a basin, the more water there is available for dry season use, and the greater the yield as a proportion of total runoff. For a given streamflow, there is a relationship between reservoir capacity, the yield obtained from the reservoir and the reliability of this yield (assurance of supply, usually expressed as return period or percentage of years in which the yield is not obtained; Vogel *et al.* 1999, Vogel *et al.* 2007, McMahon *et al.* 2007). Reservoir managers usually have to work to defined levels of reliability, such as 98% for an irrigation scheme, and allocate water licences on this basis. For a given level of reliability, yield as a proportion of runoff is determined by the combination of storage capacity and the extent of variation in water inflows (Figure 4.16). For a given level of inflow variation, increasing storage will increase yields at a decreasing rate, up to an asymptotic maximum (i.e. with a decreasing return on investment).

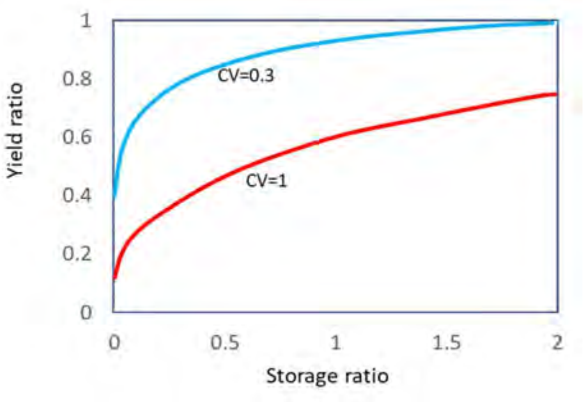

Figure 4.16. The relationship between the storage ratio S/μ and both the yield ratio Y/μ for coefficient of variations (CV) of annual streamflows CV= 1.0 and CV = 0.3, where S = storage capacity, Y = yield and μ = annual inflows. Based on Vogel et al. 2007.

Most pertinently in terms of ecosystem services, a greater variation in runoff requires more storage capacity to obtain the same yield. Furthermore, where storage capacity is a relatively small proportion of annual runoff, the coefficient of variation (CV) in water inflows has a more pronounced effect. In other words, larger reservoirs are better able to deal with variations in flows than smaller ones. Major water supply reservoirs are typically designed to accumulate and store flows over a number of years ('over year' reservoirs). However smaller towns and private land owners may also operate smaller 'within year' reservoirs that would be largely depleted at the end of each dry season and replenished annually. While larger reservoirs are typically designed on the basis of interannual variation in flows, their yields are also affected by intra-annual variability (Adeloye *et al.* 2003, McMahon *et al.* 2007). Smaller reservoirs are relatively more sensitive to intra-annual variation in flows, which is the component of variation that is more likely to be influenced by land use and ecosystem characteristics in the catchment areas. Particularly vulnerable are the run-of-river users, who have very small storage (e.g. a weir) or no storage capacity.

Ecosystems can reduce temporal variation in water flows, particularly on an intra-annual basis, relative to the variation in rainfall (Figure 4.17). Without this service, dry season flows would be expected to be lower, increasing the need for storage. Therefore, water supply infrastructure, and reservoir capacity in particular, can be treated as a substitute for the service provided by ecosystems.

Seasonal variation in river flows is primarily determined by seasonal patterns in rainfall, with higher flows being experienced in months of higher rainfall. However, the seasonal variation in surface runoff from a river basin may be lower than the rainfall variation, since some of the rainfall that falls within the rainy season percolates into the ground, flows underground at a slower rate than surface flows, then enter rivers further downstream via springs or seepage areas (Figure 4.18). These groundwater-derived flows, or base flows, help to maintain river flows during periods of lower rainfall.

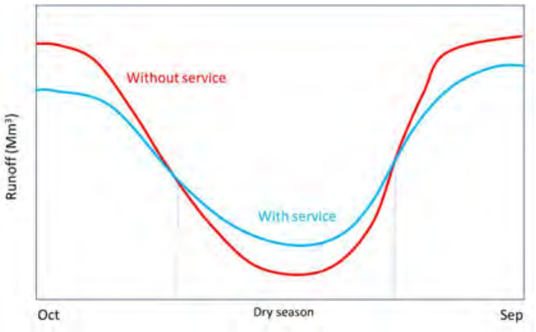

Figure 4.17. Schematic diagram of the effects of infiltration and temporary storage by river basin ecosystems on the seasonal patterns of surface water flow from the river basin.

The relationship between precipitation in a river basin and surface water runoff at the bottom of the basin depends on how much of the precipitation is lost to evaporation and transpiration, how much infiltrates to different depths, and how much enters lateral flows that eventually re-join surface flows, with all of these values making up the 'water balance' (Figure 4.18). Ecosystem characteristics such as the structure of the vegetation, rooting depths, soil depth and soil permeability, affect the water balance within a river basin by influencing the degree of interception, evaporation, infiltration and storage (Brauman *et al.* 2007, Nedkov & Burkhard 2012).

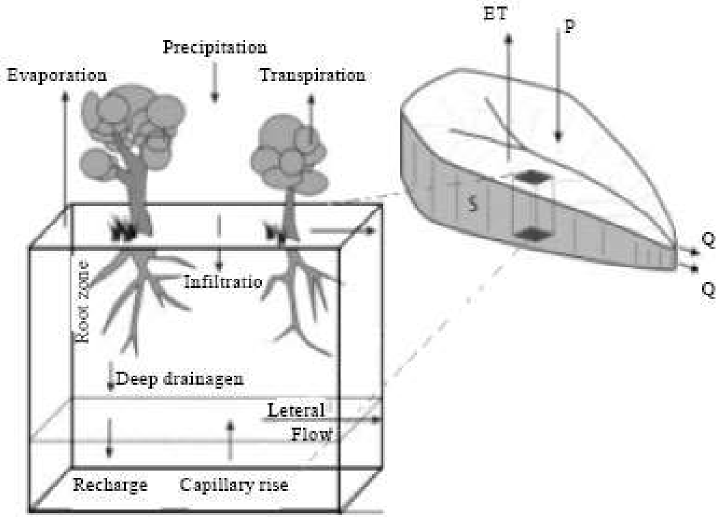

Figure 4.18. Schematic diagram of water balance for a root zone and a catchment. Source: Ghandhari & Alavi-Moghaddam 2011.

Measuring this ecosystem service therefore requires that (a) one estimates the effect of ecosystems on variation in surface runoff (taking groundwater contributions into account) at a suitable spatial and temporal scale, and then (b) estimates what additional storage would have to be built in order to maintain the system yield, and (c) costs this in capital and annualised terms. An additional consideration is whether to peg this calculation to the current system yield (for the accounting year), or to the full potential yield, taking into account that water demands are likely to be growing.

4.7.2 Data and methods

Review

Flow regulation is a complex ecosystem service that has not been well studied, particularly in Africa (Pattanayak & Kramer 2001, Lele 2009). Relatively little work has been carried out on the different aspects of flow regulation, and most of this is based on modelling rather than empirical analysis, at various levels of rigour. Indeed, there are very few comprehensive studies that have quantified the effects of natural vegetation on dry season flows either in physical or monetary terms, and those that have, have done so at relatively small scales. The effects of degraded vegetation on base flows tend to be highly context-dependent and quantifying these changes highly complex. In some cases, baseflows are seen to decrease with increases in natural vegetation cover or improved condition but this is generally because of the complex interaction of vegetation cover and condition with topography, climate and land use variables that are specific to individual catchments.

In South Africa, existing information on groundwater recharge rates has been used to estimate the loss of recharge that might occur in the absence of vegetation cover, and this has been valued using replacement costs, under the very simple assumption that this service could be replaced by storage (see Turpie *et al.* 2017a). In South Africa, there are limited comprehensive modelling studies or empirical valuation work in this area. As part of the Maloti Drakensberg Transfrontier Project (2008), Mander *et al.* (eds) used hydrological and economic modelling to demonstrate how changes in land management would result in additional winter baseflows, representing a 23% increase in allocable water in the Thukela basin. More recently there has been a growing body of work being undertaken in the uThukela and uMgeni catchments. For example, the Southern African Program on Ecosystem Change and Society (SAPECS) research program has an ongoing project looking at the ecosystem services in the Upper Thukela and through the Green Fund there has been the development of an Investment Plan for securing ecological infrastructure to enhance water security in the uMngeni River catchment (see Pringle *et al.* 2015).

Using the ACRU (Agricultural Catchments Research Unit) hydrological model Hughes *et al.* (2018a, b) explored and illustrated the current level of delivery of water-related ecosystem services in different parts of the uMgeni catchment in KwaZulu-Natal, with potential hydrological benefits of rehabilitation and protection of ecological infrastructure. Overall volume of dry-season baseflow and delivery per hectare was found to be highest from natural vegetation, and much lower from degraded vegetation and areas infested by invasive alien plants (Hughes *et al.* 2018b). Effective rehabilitation of overgrazed areas could result in a maximum potential gain of 260 m^3/ha during the dry season and following rehabilitation of invasive alien plants, maximum potential gain was estimated to be 70 m^3/ha (Hughes *et al.*

2018b). While the improvements in dry season baseflow volumes per hectare were lower than expected, the study noted the importance of the value of this ecosystem service – the sustained flow of water during the dry season is vital for the health of the ecosystem in terms of maintaining ecological processes such as the provision of animal habitats and refugia, assimilation of pollutants and nutrient cycling (Hughes *et al*. 2018b).

Lele (2009) provides a review of economic valuation studies from tropical regions that have used alternative land use scenarios to estimate the impacts of natural ecosystems on streamflow (and other catchment effects). However, the methods used for valuation in these studies are varied and often crude, and, in most cases, do not align with an accounting framework in that they follow a consumer surplus approach. Many of these studies value the change in flows by quantifying loss of agricultural production (e.g. Kumari 1995, Vincent *et al.* 1995, Kadekodi *et al.* 2000, van Beukering *et al.* 2003). Furthermore, the trade-offs are not analysed spatially.

Kaiser & Roumasset (2002) quantified the effect of degraded forest on groundwater recharge by valuing the expected reduction in urban water availability. Using shadow prices obtained from an optimisation model with a demand function they were able to quantify the cost of a change in the production capability of the natural capital. Pattanayak & Kramer (2001) used hydrological modelling and applied micro-econometric techniques to establish a relationship between baseflow and household agricultural production in Indonesia. Specifically, they determined the drought mitigation provided by tropical forested catchments to agrarian communities using a profit function to estimate the marginal profit that accrues to agricultural households. They found that baseflow makes a positive contribution to agricultural products with a mean marginal annual profit of US$ 0.36 per mm of baseflow. They also find that where increased catchment protection mitigates droughts (i.e. protects dry season base flows), the economic benefits can be sizeable (as much as 10% of annual agricultural profits), even though the physical increase in baseflow is small (Pattanayak & Kramer 2001). Mashayekhi *et al.* (2010) used a scenario-based approach and replacement cost method to estimate the economic value of water storage of forest ecosystems in Iran. They valued the water retained by forests based on a replacement cost spent on dam construction for storing the equivalent amount of water. The results showed that by reforesting the catchment each hectare could retain on average 84.3m^3 of water with a value of about US$ 43 per year (Mashayekhi *et al.* 2010).

Hydrological modelling

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 (Arnold *et al.* 1998, Arnold & Fohrer 2005; see Box 4.1). The model was run using rainfall data for 1979 to 2015, with monthly outputs generated for 1985 to 2015. Flow outputs were generated for a total of 565 sub-basins in the study area (Table 4.39).

The model was calibrated manually using flow data from gauging stations in the province. A detailed calibration exercise was also undertaken in the Mooi River sub-catchment of the Thukela watershed. In this sub-catchment, consisting of six sub-basins, observed flow from three gauged weirs were contrasted with modelled flows for the simulation period.

Box 4.1. Overview of the SWAT modelling tool

SWAT is a physically-based, semi-distributed hydrological model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. The model is set up for a catchment area or basin (= watershed in USA). The catchment is divided into multiple sub-catchments, which are further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the sub-catchment area and are not identified spatially within a SWAT simulation.

Climatic inputs include daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data, which can be input from measured records and/or generated. The overall hydrologic balance is simulated for each HRU, including canopy interception of precipitation, partitioning of precipitation, snowmelt water, and irrigation water between surface runoff and infiltration, redistribution of water within the soil profile, evapotranspiration, lateral subsurface flow from the soil profile, and return flow from shallow aquifers. Water that recharges the deep aquifer is assumed lost from the system.

Crop yields and/or biomass output can be estimated for a wide range of crop rotations, grassland/pasture systems, and trees. Nitrogen and phosphorus applications can be simulated in the form of inorganic fertilizer and/or manure inputs. Biomass removal and manure deposition can be simulated for grazing areas. Selected conservation and water management practices can also be simulated. Water transfer can also be simulated between different water bodies, as well as “ consumptive water use” in which removal of water from a watershed system is assumed. HRU - level and in - stream pollutant losses can be estimated for sediment, nitrogen, phosphorus, pesticides, and bacteria. Sediment yield is calculated with the Modified Universal Soil Loss Equation (MUSLE) developed by Williams & Berndt (1977). The transformation and movement of nitrogen and phosphorus within an HRU are simulated as a function of nutrient cycles consisting of several inorganic and organic pools. Losses of both N and P from the soil system occur by crop uptake and in surface runoff in both the solution phase and on eroded sediment.

Flows are summed from all HRUs to the sub-catchment level, and then routed through the stream system. Sediment, nutrient, pesticide, and bacteria loadings or concentrations from each HRU are also summed at the sub-catchment level, and the resulting losses are routed through channels, ponds, wetlands, depressional areas, and/or reservoirs to the watershed outlet. Contributions from point sources and urban areas are also accounted for in the total flows and pollutant losses exported from each sub-catchment. Sediment transport is simulated as a function of peak channel velocity. Simulation of channel erosion is accounted for with a channel erodibility factor. SWAT also has an automated sensitivity, calibration, and uncertainty analysis component.

The outputs of the SWAT model are provided for each watershed, sub-catchment and HRU, for each time step. These include evaporation and percolation, surface flows, lateral flows and groundwater contribution to streamflow, sediment yields and nutrient loads.

SWAT has been applied and tested in hundreds of scientific publications dealing with small sub-catchments to very large basins from all around the world. It is now considered one of the most capable and reliable models for the types of application being used here.

A thousand simulations of this sub-catchment were run using SWAT-CUP, where each simulation executed a unique combination of parameter ranges, resulting in an associated modelled flow series for the 35-year study period (1985-2013). The objective function (Nash-

Sutcliff, PBIAS, R^2), and the 95% prediction uncertainty for all observed variables, were calculated in SWAT-CUP, allowing for the adoption of an iterative approach through informed modification of parameter ranges (Abbaspour *et al.*, 2015).

Table 4.39. Characteristics of the river basins. Note that T is the most southerly basin.

Primary basin area	**Main rivers**	**Number of sub-basins**
Mzimvubu (T)	Slang, Xuka, Mtata, Tsitsa, Pot, Mooi, Inxu, Wildebees, Gatberg	109
Mkomazi (U)	Mgeni, Mvoti	137
Thukela (V)	Thukela, Mooi, Sundays, Bushmans	183
Mfolozi (W)	Umfolozi, White Umfolozi, Black Umfolozi, Pongola, Mkuze	135
Total		**565**

Simulations were run using each of the 2005 and 2011 KZN Land Cover data sets, and for corresponding land cover datasets that were generated with natural land cover classes and cultivated land being converted to bare ground, i.e. a barren scenario.

The service was quantified and valued based on differences in infiltration and surface flows between the actual and barren version of the land cover datasets for each period. Details of the SWAT modelling process, assumptions, limitations and calibration are given in Appendix 5.

Physical quantification of the service

The infiltration and temporary storage that is facilitated by ecosystems has the effect of changing the seasonal pattern of surface flows lower in the catchment. The service was measured in physical terms as the difference in infiltration relative to a barren scenario, in m^3 per ha. This was obtained from the SWAT output “Percolation”, given in mm.

Determination and valuation of the formal water supply benefits

The benefits generated from the service were considered in terms of the avoided costs of water supply infrastructure for existing supply systems, and in terms of the avoided costs of obtaining water for people that depend on instream flows for their domestic water supplies. At this stage the estimates do not include run-of-river abstractions for commercial agriculture or other purposes.

The location and capacity of all reservoirs larger than 1 000 m^3 were mapped in relation to the sub-basins used in the SWAT model (Figure 4.19). From this, catchment areas were defined that served single or multiple reservoirs. In cases where there are multiple large reservoirs within the same overall catchment area, these tend to be managed as in concert so as to maximise yields from the overall system.

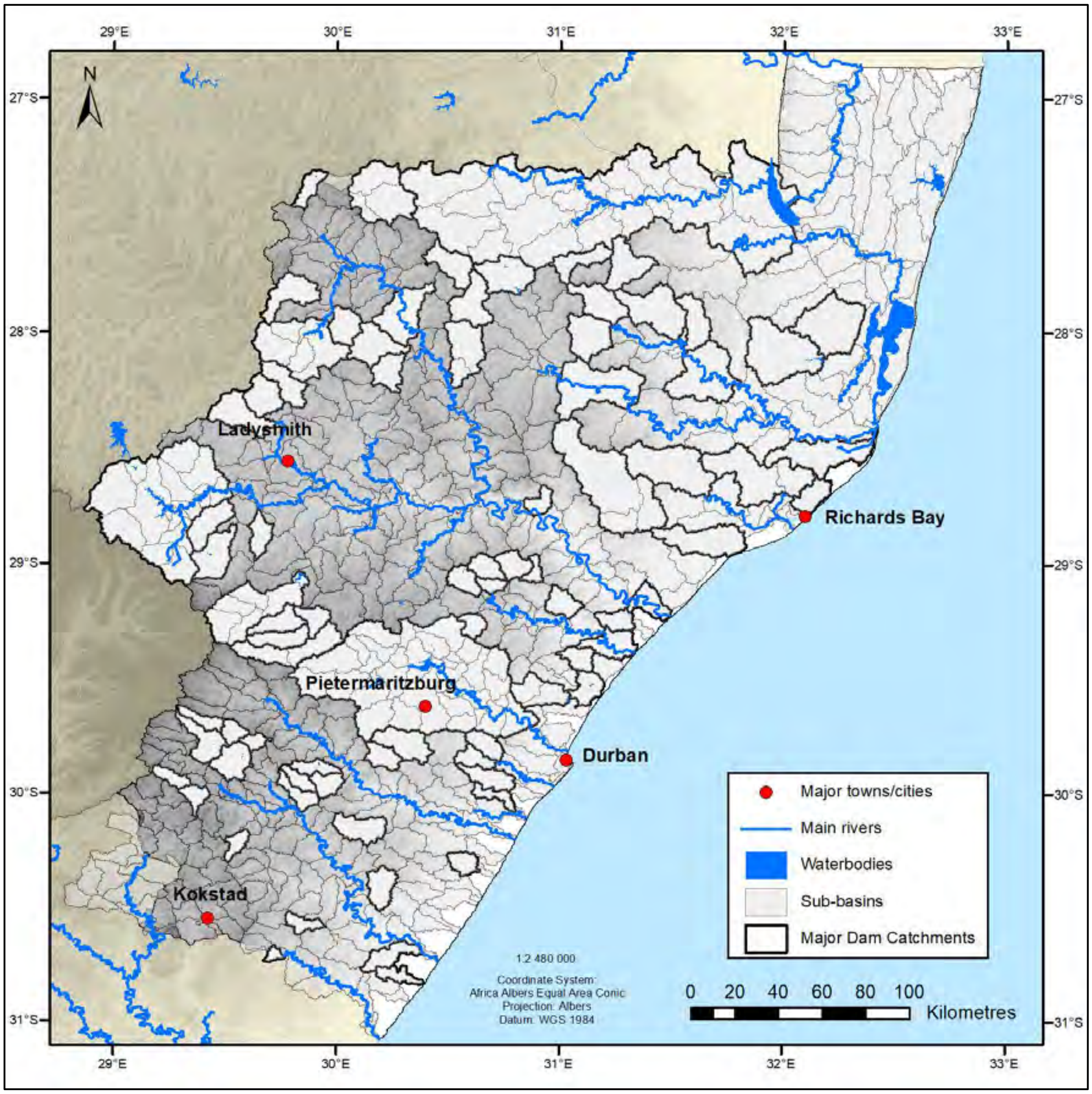

Figure 4.19. Catchment areas containing one or more reservoirs larger than 1000 m^3 capacity.

For each area, the overall storage capacity was calculated, and the modelled runoff for the lowest sub-basin (SWAT ouput “Flows_in” or “Flows_out” as appropriate, given in m^3/s) was analysed.

The benefit of the service was valued based on the ecosystem effects on flow variation, and the influence of this on storage requirements, for the existing yield and reliability requirements. A method was developed based on the theoretical relationship between storage, yield and reliability (the S-R-Y relationship) for a standardized reservoir.

Dam designers seek to determine the optimal size of a reservoir to produce a given yield at a desired level of reliability (based on failure rate), which is a challenging calculation requiring stochastic modelling of inflows. For a given reservoir of size V, with inflow I and outflow Q (also known as the Yield or Draft), reservoir storage S (the stock of water) over a particular time step is $S_{t+1} = S_t + I_t - Q_t$, where I_t is the total inflow to the reservoir between time steps t and t+1, Q_t is the total outflow from the reservoir in the same period. Since V is finite, S is constrained, and Q is limited by S. Using a synthetic time series data on inflows with an appropriate statistical distribution, this relationship can be used to determine the relationship between inflows (I), storage capacity (V) and yield (Q) for a particular location. The relationship between these parameters can be standardised using the standard deviation of the inflows (Gomide 1975). A standard reservoir size C is defined as $C = \frac{V}{\sigma}$, where σ is the standard deviation of the inflow. The corresponding standardized net mean inflow, also called the 'drift', is defined as: $\varepsilon = \frac{\mu - D}{\sigma}$, where μ is the mean of inflow and D is the draft (yield; Pegram 1980), and the standardised net inflow is defined as $N_t = \frac{I_t - D}{\sigma}$. The concept of the standardised reservoir recognises that reservoirs with different characteristics give the same result if the ratios of their parameters to the standard deviations of inflows are the same (Gomide 1975, Hamed 2014). Given that for a standard reservoir, V is directly proportional to σ, this means that one can produce a reasonable estimate of the change in dam volume required to deal with a change in the variation of inflows. We thus estimate the benefit of the ecosystem service as:

$$B_i = V_i . u . \left(1 - \frac{\sigma_d}{\sigma_s}\right) . (c + m)$$

Where B = monetary benefit of the service performed in the ith catchment in Rands per year, V_i is the total storage capacity in the ith catchment, u is the unit cost of storage capacity (R/m^3), σ_d and σ_s are the standard deviation of monthly inflows in the without service (degraded land cover) vs with service scenario, and c and m are the costs of capital and operation and maintenance costs, respectively, expressed as a proportion of capital costs.

The unit cost of storage was based on Preston (2015) and adjusted to 2010 Rands (R5.93/m^3). Marginal costs are likely to increase as storage levels increase, and thus average costs can also provide an under-estimate.

Determination and valuation of the informal water supply benefits

In addition to the benefits in terms of reservoir design, maintenance of low flows also benefits people living in the catchments that depend on rivers and springs for collecting water for domestic and agricultural use. In order to determine this value, the number of households depending on rivers and springs for water supply was extracted from Census 2011 at the sub-place level, and matched to the sub-basins based on spatial data on human settlements. Using the Basic Human Needs allowance of 6000 litres per household per day as stipulated in South Africa's National Water Act, we estimated the monthly water demands by these households within each sub-catchment. These were then compared with the modelled monthly inflows into each sub-basin for the actual land cover 2005 and 2011 and the corresponding barren (without service) scenarios.

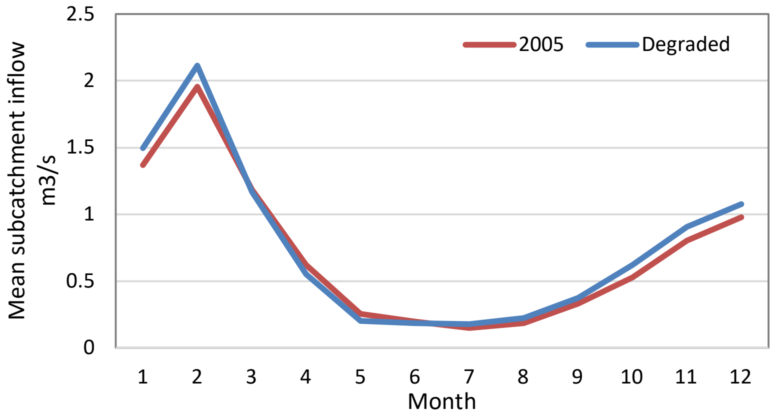

Figure 4.20. Example output of change in mean monthly inflows for 2005 land cover versus a degraded scenario for a subcatchment.

Assuming a yield ratio of 0.2, we determined the number of months in which demands were not met in each sub-catchment under the no-service scenario, and then computed the extent to which the with-service scenario mitigated these shortages. These differences were valued at the cost of purchasing water from water vendors, which is the most common reality for areas where water shortages occur. The costs were taken from Turpie *et al.* (2010a).

4.7.3 Results and discussion

The average increment in infiltration (m^3/ha/y) by ecosystems relative to a fully degraded situation is shown Figure 4.21. Note that there is still some infiltration in the without ecosystems situation, so the service does not equal the total value for infiltration. The value of this service in terms of infrastructure cost savings was estimated to be **R3.25 billion** in 2005 and **R3.12 billion** in 2011. The results are summarised by biome in the supply tables below (Table 4.41, Table 4.42). The biggest change in the estimated average increment in water retention by ecosystems was observed in the grassland and forest biomes.

In addition, it was estimated that the flow regulation service performed by catchment ecosystems contributed an annual cost savings to poor households of some **R3 million** in 2005, and **R2.6 million** in 2011 (Table 4.40), which is significant in terms of the income levels of the beneficiary households. These values have not been mapped and are not included in the accounts at this stage. The most hard-hit areas, with more than 60% of the total instream value, are in the Mfolozi primary catchment which is the most northerly catchment in KwaZulu-Natal. Households situated in the sub-catchments in the interior of the Mfolozi catchment within the Nongoma and Hlabisa municipalities and the sub-catchments that form part of Nkandla and uMlalazi municipalities in the south and Umhlabuyalingana municipality in the north appear to have the largest decline in base flows where instream yields fall short of household demand.

Table 4.40. Estimated value of flow regulation (2010 Rands) in terms of water availability in the dry season, measured as the value of avoided costs in purchasing water from vendors in months where instream yields fall short of demand.

Primary Catchment	2005 Total instream value (2010 Rands)	2011 Total instream value (2010 Rands)
T – Mkomazi	180 109	146 843
U – Mzimvubu	381 730	312 244
V – Thukela	551 350	484 934
W – Mfolozi	1 937 598	1 666 737
Total	**3 050 787**	**2 610 758**

The results from this analysis are lower than those estimated for flow regulation in the national scale study by Turpie *et al.* (2017a). In their study, the facilitation of rainfall infiltration by natural vegetation cover in KwaZulu-Natal was estimated to be worth R9.6 billion per year. This was based on the cost of replacement storage capacity equivalent to the total annual infiltration and was therefore a likely overestimate of the service. For this analysis, we have used a more detailed method to estimate the additional storage requirement in the absence of the service by assessing variations in dry season flows and the relationship between storage, yield and reliability. However, this is based on a rapid methodology which need to be replaced by more sophisticated modelling. We recommend that these approaches are discussed in a think tank and further refined and tested if necessary, to settle on the most suitable method for estimating this service, taking data needs and time constraints into account.

Based on our more conservative estimate, the contribution of this service to the asset value of ecosystems in KwaZulu-Natal was estimated to be **R52.6 billion** in 2005 and **R51.3 billion** in 2011 (Table 4.43). There was a 2.5% reduction in this value over the six-year period. The largest reductions in value were associated with the Indian Ocean Coastal Belt, Grassland and Savanna biomes.

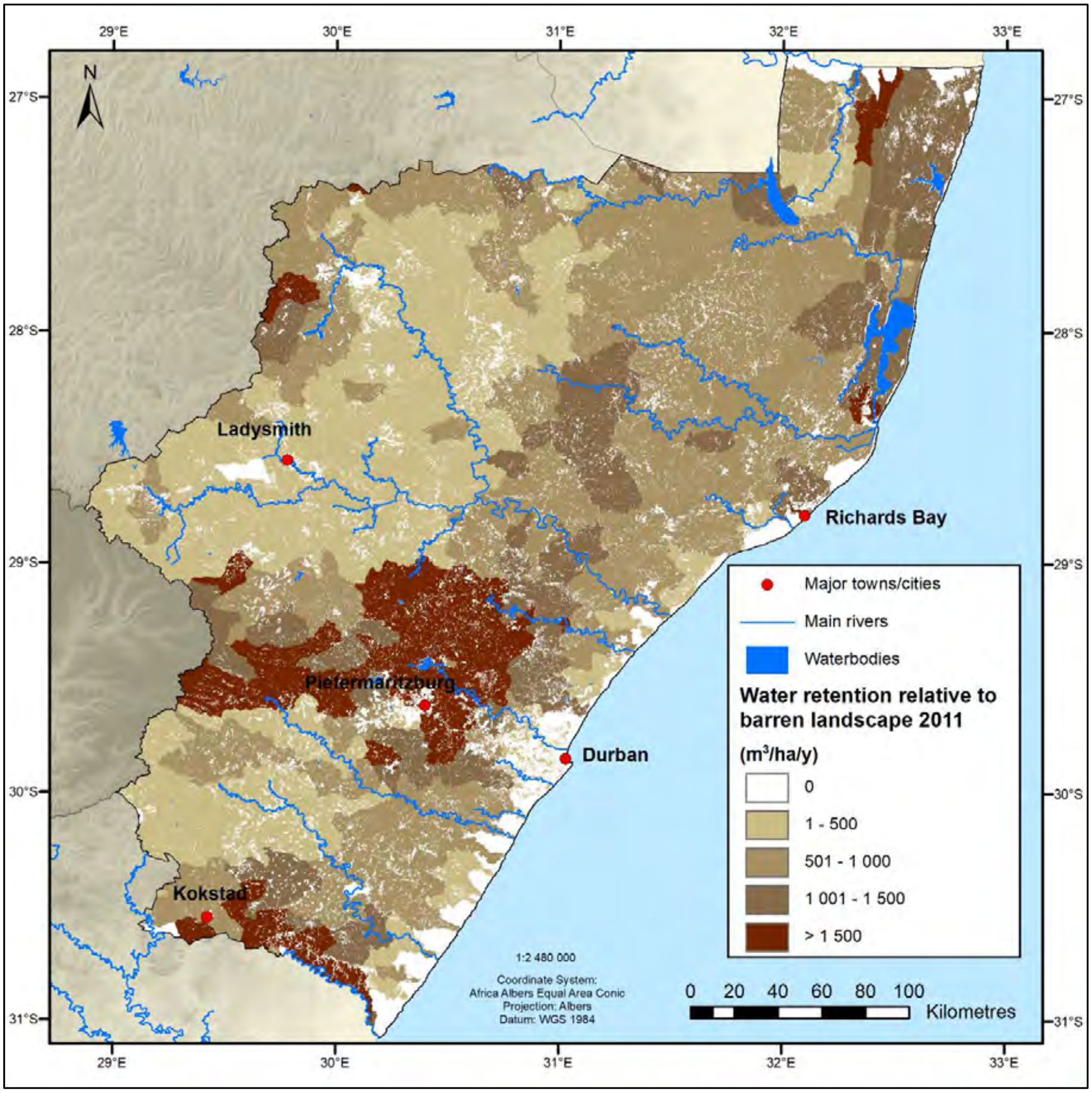

Figure 4.21. Estimated average increment in water retention by ecosystems, per sub-catchment area in 2011 (m^3 per ha per year) relative to a barren catchment.

Table 4.41. Physical supply table of flow regulation, for 2005 and 2011

Biome Service	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	TOTAL
2005							
Flow regulation (million m^3)	77.61	3 315.00	421.23	2 197.98	634.09	36.12	**6 682.03**
2011							
Flow regulation (million m^3)	50.19	3 235.91	445.90	2 223.97	156.61	0.67	**6 113.25**

Table 4.42. Monetary supply table for replacement cost of extra storage, for 2005 and 2011; values in 2010 R millions

Biome Service	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	TOTAL
2005							
Replacement cost of extra storage	0.74	2 112.36	27.19	1 078.64	28.93	-	**3 247.87**
2011							
Replacement cost of extra storage	23.29	2 014.08	22.61	1 020.55	85.19	1.06	**3 166.78**

Table 4.43. Ecosystem monetary asset account 2005-2011 for flow regulation. NPV calculated using an asset lifespan of 25 years and a discount rate of 3.66%. Values are net present value in R millions.

	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	Total
Opening stock (2005)	**12.02**	**34 218.02**	**440.47**	**17 472.93**	**468.68**	**0.00**	**52 612.12**
Additions	365.23	0.00	0.00	0.00	911.24	17.24	1 293.71
Reductions	0.00	-1 592.06	-74.20	-941.02	0.00	0.00	-2 607.28
Net change	365.23	-1 592.06	-74.20	-941.02	911.24	17.24	-1 313.57
Closing stock (2011)	**377.25**	**32 625.96**	**366.27**	**16 531.91**	**1 379.92**	**17.24**	**51 298.55**
Net change %	3039.1%	-4.7%	-16.8%	-5.4%	194.4%		-2.5%

4.8 Sediment retention

4.8.1 Overview of the service

Human activities within the landscape can lead to increased soil erosion and the introduction of nutrients into river systems from agricultural activities and human wastes. Agricultural expansion, encroachment into natural wetlands and the removal of natural vegetation result in elevated levels of erosion and subsequent increases in sediment loads being carried downstream. The total sediment load being transported in rivers is made up of bed load, suspended load and dissolved load. The bed load is the portion that is transported along the riverbed, is coarse and generally moves at velocities slower than the flow. The suspended load is particulate sediment that is held in the water column and is made up of smaller particles such as clay and fine silt. The dissolved sediment load is the material that is chemically carried in the water. When flow speeds drop—when rivers enter reservoirs, lakes, wetlands or estuaries—the loads that are carried tend to drop out of suspension and accumulate, with the smallest particles taking longest to settle out. In this section, we focus on the problem of sedimentation of man-made structures. Elevated loads of suspended sediments also contribute to water quality problems, which are addressed in Section 0.

The extent to which sediments end up in river systems is determined by several factors including soils, rainfall patterns (amount and intensity), slope and the type and amount of vegetative cover. Vegetative cover prevents erosion by stabilizing soil and by intercepting rainfall, thereby reducing its erosivity (De Groot *et al.* 2002). This is particularly valuable where soils are highly erodible. Vegetated areas, especially wetlands, may also capture the sediments that are eroded from agricultural and degraded lands and transported in surface flows, preventing them from entering streams and rivers (Blumenfeld *et al.* 2009, Conte *et al.* 2011). This protects downstream areas from the impacts of sedimentation, which can include impacts on water storage capacity, hydropower generation and navigability of rivers (Pimentel *et al.* 1995). While some level of sedimentation of reservoirs is expected under natural conditions and planned for, elevated catchment erosion either incurs dredging costs or shortens the projected lifespan of reservoirs and related infrastructure. Globally, anthropogenic sedimentation has been estimated to account for about 37% of the annual costs of reservoirs (i.e. $21 billion) in terms of replacement costs (Basson 2009). In urban contexts, elevated sediment loads also have to be removed from sewerage systems, storm water drainage systems and harbours.

In KwaZulu-Natal, natural sediment transport from catchments is also the main source of beach sand and maintains the productive offshore Thukela Banks. Most of the sand that is supplied to the coast comes from river bed loads, with very little contributed by the suspended load (CSIR 2008). However, both reservoirs and sand mining cut off the supply of sand to the coast, with reservoirs trapping almost 100% of coarse sediments that flow into them (CSIR 2008). This is not a problem that can be solved by the conservation of landscapes in the province but can only be solved by expensive engineering solutions such as off-channel dams, and the control or elimination of sand mining. Notwithstanding their contribution to beach erosion problems, the fact that the reservoirs trap sediments is also costly, and this cost is elevated when sediment yields from the catchment are elevated by human activities. Here, ecosystem services do play a role in reducing the potential extent of these costs due to increasing human activity in their catchments.

4.8.2 Data and methods

Review

Several studies have been published on sediment yields in South Africa (e.g. Rooseboom 1978, Dedkov & Mozzherin 1984, Rooseboom *et al.* 1992, Scott *et al.* 1998, FAO 2008, Milliman & Farnsworth 2011, Baade *et al.* 2012, Foster *et al.* 2012) but there are very few empirical studies that have linked these to ecosystem condition or change. For example, Scott *et al.* (1998) related sediment yields to afforestation and fire, Foster *et al.* (2012) related sediment yields in the Eastern Cape over to changes in livestock stocking densities the last 150 years, and Manjoro *et al.* (2017) have investigated the role of erosion gullies in sediment yields from a degraded Eastern Cape catchment. Outside of South Africa, Kauffman *et al.* (2014) explored the potential of green water credits (a form of payment for ecosystem services) to enhance ecosystem services by reducing soil erosion in the Upper Tana basin, Kenya. The study related the introduction of soil conservation measures to changes in soil erosion by quantifying erosion processes as a function of land use, modelled in SWAT. Palao *et al.* (2013) used SWAT to quantify the impacts of existing land use and land use change on sediment concentrations and yields in the Layawan catchment in the Philippines using a land use scenario modelling approach. Swallow *et al.* (2009) used integrated outputs from geographic, hydrological and economic analysis to assess temporal and spatial trade-offs in sediment yields in the Nyando and Yala basins in Kenya.

The benefits of this service include reduced impacts on reservoir storage capacity, water transport areas, water treatment costs and hydropower maintenance costs. The service is usually valued using the avoided costs or replacement cost approach. As with the other hydrological services, few attempts have been made to value this service in South Africa. Turpie *et al.* (2007, 2017a) used the replacement cost methods in terms of the construction cost of the amount of storage that would have to be constructed to prevent a similar amount of sediment from reaching downstream aquatic ecosystems, based on the national inventory dams (available from DWS on request). Blignaut *et al.* (2010) used the value of water per m^3 as a proxy for the lost storage capacity of dams from a cubic metre of sediment. At a smaller scale, Turpie *et al.* (2017b) used a damages avoided method by estimating the avoided cost of loss of dam storage capacity in Durban, and in terms of the avoided cost of dredging of Durban harbour, in these cases using information specific to those facilities.

Physical modelling

Sediment outputs were modelled in both SWAT (described in Appendix 5) and InVEST. The initial results from the SWAT model were higher than expected, potentially as a result of the use of default land cover classes in the SWAT modelling. In the case of InVEST, prior work with this model meant that land cover classes were more closely aligned with the study area in terms of their specifications. Nevertheless, the results obtained were a similar order of magnitude, but the InVEST model also has certain advantages in terms of mapping and are reported here. Further work is needed to better align the land cover classes to the local context and to compare the outputs of these two approaches.

The InVEST Sediment Delivery Ratio model was used to estimate the average annual soil loss from the quaternary catchments of KwaZulu-Natal and the extent to which natural vegetation retains and captures sediment. Total sediment loss for each quaternary catchment was calculated in 2005 and 2011 relative to a barren landscape scenario in which the retention capacity of the natural vegetation and cultivated land was reduced to that of a barren land class. The difference in the sediment loss between the baseline and barren scenario provided the total amount of sediment being retained by the natural vegetation in each catchment. The model was run using the standalone InVEST platform, version 3.7.0.

The sediment retention model estimates potential soil loss based on geomorphological, land-use factors, and climate conditions. It uses the Universal Soil Loss Equation (Wischmeier & Smith 1978) to estimate average soil loss in tons per hectare on an annual basis. The inputs used included a hydrologically corrected Digital Elevation Model (Jarvis *et al.* 2008), KZN land cover 2005 and 2011, land cover and management factors associated with each land use class, rainfall erosivity (Le Roux *et al.* 2008) and soil erodibility (Schulze & Horan 2007). The model establishes a measure of current erosion potential using these surface layers and the Universal Soil Loss Equation. It assesses the ability of vegetation types and land management practices typically associated with land cover classes to retain soil in place, based on our understanding of vegetation cover and potential erosion rates. Vegetation has the ability to trap sediments that have been eroded in upstream environments. The model includes this factor by routing all the estimated erosion downstream via a flow path. This approach provides an estimate of how much of the sediment is both eroded and retained in all the upstream hillslopes and catchments, and is trapped by downstream vegetation, based on the ability of this vegetation to capture and retain sediment. The total retained sediment is equal to the sum of the sediment retained by the catchment and the sediment retained through routed water flow.

Both erosion control by vegetation and trapping of eroded sediments by downstream vegetation and wetlands help to avoid sedimentation of downstream reservoirs, harbours and aquatic ecosystems. We estimated that when natural vegetation cover becomes denuded, sediment yields would increase by 1300%.

Valuation

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 of lost storage capacity (e.g. through raising the dam wall, constructing a substitute dam at a new site to make up the reduction in capacity or constructing check dams) to estimate its value. 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 capital replacement cost of R5.93 per m^3 (2010 Rands, Preston 2015). The volume of sediment was estimated from mass using a density of 1.35 t/m^3 (Rooseboom 1992, Haarhoff & Cassa 2009).

Within each quaternary catchment, the replacement value of the service in that catchment was then mapped to natural vegetation and cultivated land using an estimate of the relative contribution of different land parcels to sediment retention from the InVEST model. This provided the relative sediment retention score given to each grid cell within KwaZulu-Natal based on rainfall, soil and landcover. The value per pixel was then determined for natural vegetation and cultivated land (based on the 2005 and 2011 landcover), total sediment retention value for each catchment, the retention score given to the pixel and the sum of all pixel retention scores. The value per pixel was then divided by the area of the pixel to arrive at a sediment retention value per hectare estimate for all vegetated areas in each catchment.

4.8.3 Results and discussion

A map of sediment retention (tons/ha/y) in 2011 is shown in Figure 4.22. Sediment retention by biome and replacement costs of extra storage per biome for 2005 and 2011 are summarised in the supply tables below (Table 4.44, Table 4.45). Loss of natural vegetation and crop cover would increase sediment yields by an average of 1947% (0.23-45.92 tons/ha/y) in 2005 and 1538% (0.15-44.03 tons/ha/y) in 2011. The sediment yield varied by sub-catchment between 0.04 tons/ha and 5.72 tons/ha in 2005 and between 0.04 tons/ha and 5.55 tons/ha in 2011. Under a denuded landscape the sediment yield varied between 0.29 tons/ha and 51.65 tons/ha in 2005 and between 0.19 tons/ha and 49.58 tons/ha in 2011. The difference in sediment loss between the baseline and barren scenario provides the total amount of sediment retained by the natural vegetation and cultivated land. Sediment retention varied between 0.30 and 233.90 tons/ha/y (mean = 24.94 tons/ha/y) and between 0.17 and 233.06 tons/ha/y (mean = 17.52 tons/ha/y) in 2005 and 2011, respectively.

The results from this study align well with other studies. The US Soil Conservation Service sets limits for “tolerable” erosion in the range of 2.2-11.2 tons/ha/y with a general classification of Low = <2 tons/ha/y, Moderate = 2-10 tons/ha/y and High = >10 tons/ha/y (Young 1989). In the Nyando basin in Western Kenya, the average sediment yield was estimated to vary between 0.01 and 104 tons/ha/y (Gathenya *et al*. 2011). Similarly, Swallow *et al.* (2009) estimated the sediment yield in the Nyando and Yala river basins in Kenya to vary between 0.01-80 tons/ha/y and 0.01-25 tons/ha/y, respectively. Kauffman *et al.* (2014) estimated the effect of 11 soil conservation measures on soil erosion in the Upper Tana basin in Kenya using SWAT. Following soil conservation measures such as terracing and ridging, there was a reduction in erosion of between <1 ton/ha/y and 50 tons/ha/y across the basin. These soil conservation measures were found to reduce sediment inflow into the Masinga Reservoir by 20% which resulted in significant cost savings in terms of water supply and hydroelectricity (Kauffman *et al.* 2014). Palazon *et al.* (2014) evaluated soil erosion processes in the central Spanish Pyrenees and found that sediment yields varied between 0.01 and 3.73 tons/ha/y depending on the soil type. Palao *et al.* (2013) modelled sediment in the Layawan Watershed in the Philippines and investigated the impacts of land use changes on sediment retention under two scenarios. The results show that under a degraded scenario sediment yields increased from between 17.6% and 200% (~22.76 to 294 tons/ha/y) across sub-catchments (Palao *et al.* 2013).

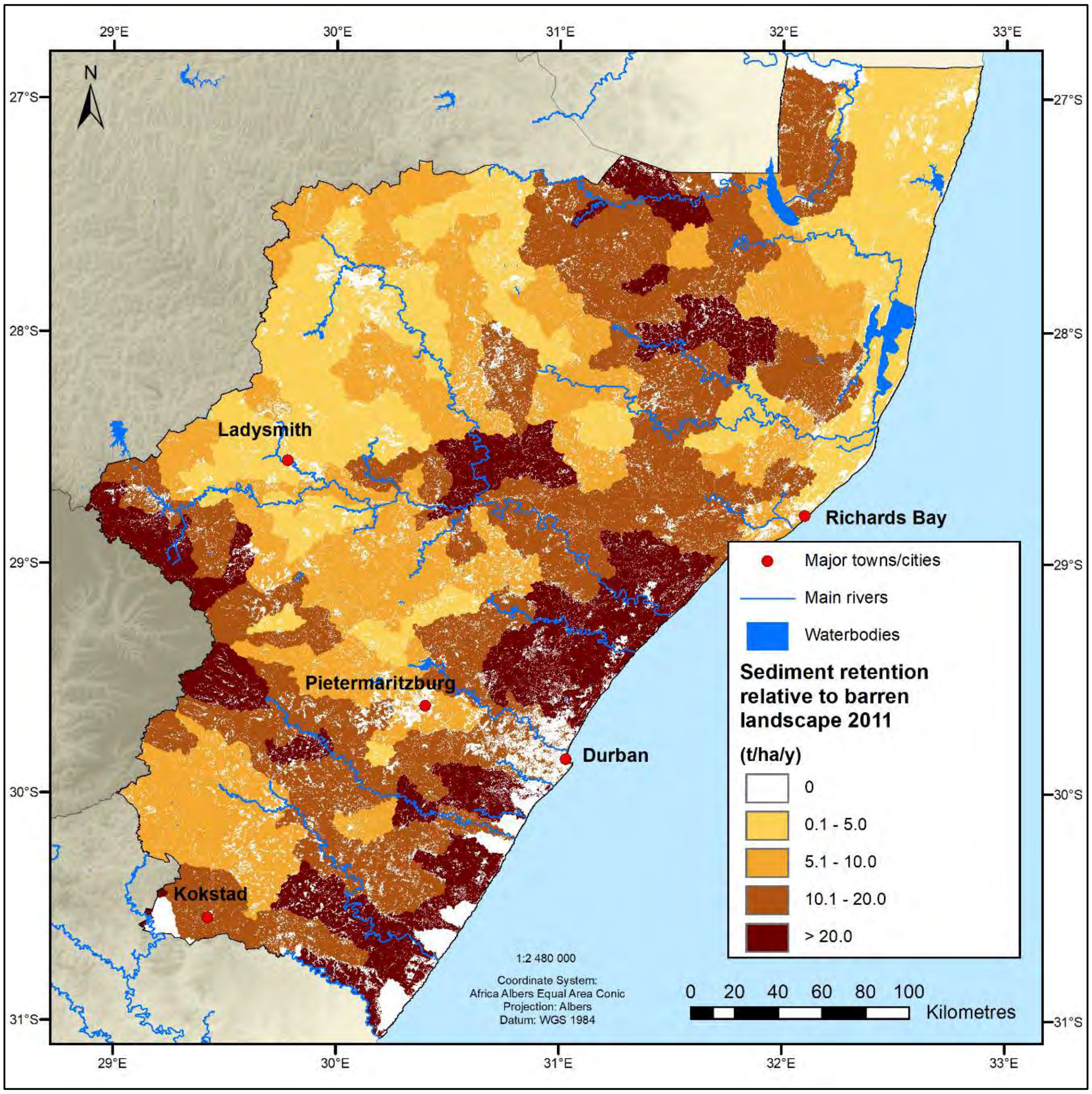

Figure 4.22. Estimated average sediment retention by ecosystems per sub-catchment area in 2011 (tonnes per ha per year) relative to a barren catchment.

Table 4.44. Physical supply table of sediment retention (million tonnes), for 2005 and 2011

Biome Service	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	TOTAL
2005 **Sediment retention (million tonnes)**	1.95	44.62	5.78	26.72	18.02	1.78	**98.87**
2011 **Sediment retention (million tonnes)**	1.36	38.19	5.07	21.53	8.99	0.07	**75.22**

Table 4.45. Monetary supply table for replacement cost of extra storage, for 2005 and 2011; values in 2010 R millions

Biome Service	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	TOTAL
2005 **Replacement cost of extra storage**	12.26	204.30	20.66	107.30	86.83	4.43	**435.79**
2011 **Replacement cost of extra storage**	5.99	167.75	22.28	94.58	39.50	0.30	**330.40**

The value of erosion control by natural vegetation and cultivated land was estimated to be **R435.8 million** in 2005 and **R330.4 million** in 2011. The average per ha value in 2005 was R109.56 (R1.31-R1 027.44) compared to R88.61 per ha in 2011 (R0.80-R1 011.86). This is due to a loss in natural vegetation, in particular from the grassland and savanna biomes, between 2005 and 2011. The upper sub-catchments of the uThukela catchment and the sub-catchments of the Mvoti River north of Durban are particularly important for retaining sediments. Turpie *et al.* (2017a) used a similar approach for the national assessment where the retention capability of the natural vegetation was removed completely. That study found that the value of erosion control in South Africa by vegetation cover was estimated to be R2.1 billion per year, with an average value of R27 per ha per year for natural areas in terms of their ability to retain sediment.

The contribution of sediment retention to the asset value of ecosystems in KwaZulu-Natal was estimated to be **R7.06 billion** in 2005 and **R5.35 billion** in 2011, representing a reduction in value of R1.7 billion or a negative net change of 24% (Table 4.46). Most of the loss in value was from the forest biome where R767 million was lost between 2005 and 2011, followed by losses in the grassland and savanna biomes (Table 4.46).

Table 4.46. Ecosystem monetary asset account 2005-2011 for sediment retention. NPV calculated using an asset lifespan of 25 years and a discount rate of 3.66%. Values are net present value in R millions.

	Freshwater ecosystems	**Grassland**	**Indian Ocean Coastal Belt**	**Savanna**	**Forests**	**Estuaries**	**Total**
Opening stock (2005)	**198.61**	**3 309.46**	**334.72**	**1 738.13**	**1 406.53**	**71.84**	**7 059.28**
Additions	0.00	0.00	26.18	0.00	0.00	0.00	26.18
Reductions	-101.50	-592.01	0.00	-206.07	-766.74	-66.97	-1 733.29
Net change	-101.50	-592.01	26.18	-206.07	-766.74	-66.97	-1 707.11
Closing stock (2011)	**97.11**	**2 717.44**	**360.90**	**1 532.07**	**639.79**	**4.87**	**5 352.18**
Net change %	-51.1%	-17.9%	7.8%	-11.9%	-54.5%	-93.2%	-24.2%

4.9 Water quality amelioration

4.9.1 Overview of the service

Water quality amelioration is the removal of some of the excess pathogens, nutrients and suspended sediments that are generated through anthropogenic processes in the landscape and transported in surface water runoff and/or groundwater systems, reducing the damages they cause in terms of human health and/or water treatment costs, or in terms of the supply of downstream ecosystem services (Graham 2004, Rangeti 2014; Figure 4.23). It is important to note that the sediment retention services of ecosystems are closely related to water quality amelioration services, in that suspended sediments are an element of water quality, and nutrients such as phosphorous which attach to sediments can be prevented from reaching downstream ecosystems as a result of sediment retention. This study focuses on the water treatment cost benefits of the service.

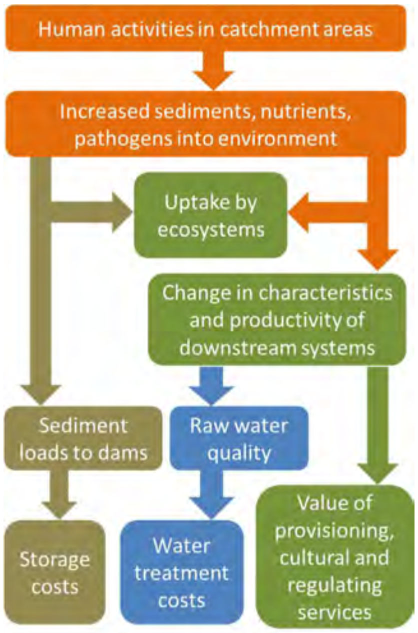

Figure 4.23. Schematic diagram of the consequences of anthropogenic effect on water quality and their amelioration by natural systems. Source: Turpie et al. (2017b)

In the absence of the service, increasing anthropogenic activity in water supply catchment areas leads to increasing water treatment costs in the following ways. Increases in pathogens, which usually come from waste-water treatment outputs and particularly from under-serviced human settlements, require the addition of chemicals such as chlorine. Increases in nutrients, which typically come from waste water (as above) and fertilizers, result in increased phytoplankton growth, particularly in slower flowing rivers and in reservoirs. Increased phosophorus is typically the problem in freshwater systems, where this nutrient is naturally limiting. Higher abundance of phytoplankton increases the requirement for chemical flocculants such as aluminum phosphate (“alum”), dredging of settlement ponds and backwashing of filters with treated water, all of which also increase labour and energy requirements. Eutrophication also leads to toxic algal blooms that have to be treated with additional chemicals. Increases in suspended sediments have a similar effect, and are likely to be more relevant for water treatment works that take their raw water from smaller reservoirs or directly from rivers. Suspended sediments tend to settle out in larger reservoirs.

Water quality amelioration occurs through a number of biophysical processes. Pathogens, for which the main indicator is the bacteria *Escherichia coli*, are destroyed by exposure to ultraviolet light. There are a number of different processes through which natural systems remove nutrients from surface and sub-surface flows (Figure 4.9). Nitrogen removal is mainly through denitrification and also to some extent by plant uptake (Hill 2000). Nutrients that are introduced in dissolved form can be taken up directly by plants and incorporated into plant tissue as they grow. Most of the phosphorous that is transported by flows is attached to sediment and settles out, where it can remain inactive (Brinson 2000). However, if sediments that settle in aquatic systems are stirred up again then some of this phosphorous can go back into solution and become available for use by plants. Therefore, plant uptake uses up different nutrients in different systems. The uptake of nutrients will continue as long as there is room for further plant growth (in terms of space, oxygen or plant size limits), after which the system will reach some kind of equilibrium in which the uptake is balanced by the senescence, death and rotting of plant material which reintroduces nutrients into the water column (remineralisation). At this point there would be no further net uptake of nutrients by the ecosystem unless nutrients are being exported out of the system (e.g. by harvesting plants or dredging and removal of sediments), or unless there is a natural process of peat formation.

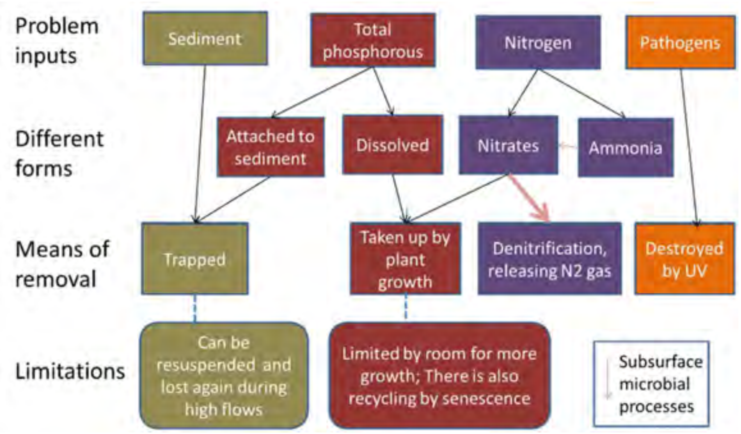

Figure 4.24. Summary of water quality amelioration services by natural systems (Source: Turpie 2015)

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 & 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, Zhang *et al.* 2010, Weller *et al.* 2011, Sweeney & Newbold 2014).

4.9.2 Data and methods

Review

Very little empirical work has been carried out in South Africa on ecosystem capacity to supply this service. Turpie *et al.* (2010b) carried out a landscape scale empirical study to isolate the effects of wetlands on water quality in 100 small catchment areas. The service was then valued using an empirical analysis of water treatment costs. The biophysical elements of the study were lacking in temporal variation, however, reducing its reliability. Other studies have relied on modelling, using physical parameters taken from international studies. Various models have been used, including InVEST and ACRU, which is a similar type of model to SWAT, but set up for South African catchments. Dabrowski (2014) applied SWAT to identify important sources of orthophosphate loading in the Olifants catchment and predict changes in the trophic status of four reservoirs. However, there was no estimation of the physical water quality amelioration service. In most cases the valuation has been in terms of treatment costs avoided, based on empirical models of the relationships between nutrient levels and treatment costs (see Dennison & Lynne 1997, Graham 2004, Friedrich *et al*. 2009, Gebremedhin 2009, Graham *et al.* 2012, Rangeti 2014, Turpie *et al*. 2017b). However, in some cases, it has taken the form of damage costs avoided, where the downstream impacts would be on ecosystems.

Outside of South Africa, Liu *et al.* (2013) investigated the effects of land use change, climate change and land use management practices on water quality in the Beaver River catchment in the US. Using SWAT, water quality was measured by total annual loadings of nitrogen and phosphorous. However, valuation was done using a simple benefit-transfer method where a damage cost function for both drinking water treatment and recreation losses from Ancev *et al*. (2006) was applied. Liu *et al.* (2019) use a novel method that links water quality indicators derived from SWAT (including total phosphorous) with housing sales data to estimate the marginal value of water quality change in the Upper Big Walnut Creek catchment in Ohio. Vincent *et al.* (2016) used a panel dataset from Malaysia to rigorously estimate the effect of tropical forests on water treatment costs. Grossmann (2012) estimates the costs required to reach a reduction target in nutrient loads in the Elbe River in Germany. Nutrient retention by restored floodplains can in principle substitute for other measures to reduce nutrient loads in a river catchment (Grossmann 2012). Grossmann (2012) uses the replacement cost approach based on the shadow price of floodplain nutrient retention measures to estimate the marginal costs for load reductions (i.e. the nutrient retention value of the floodplain). Chiang *et al.* (2010) evaluated the impacts of land use changes and agricultural management practices on water quality in the Lincoln Lake watershed in the US by comparing SWAT simulation results for different land use scenarios. Similarly, Bi *et al.* (2018) quantified changes in total nitrogen and phosphorous loads across a range of climate and land cover scenarios in the Luanhe River Basin in China. Poudel *et al*. (2013) used SWAT to identify critical areas of nonpoint source pollution in the Bayou Plaquemine Brule catchment in Louisiana by assessing seasonal and spatial variability in water quality parameters, including total phosphorous. However, the phosphorous loads were not linked to changes in ecosystem extent or condition and the study did not include a valuation component. Other studies that have successfully applied SWAT to predict total phosphorous loads include Ullrich & Volk (2009), Daloglu *et al.* (2012) and Hanief & Laursen (2017).

Physical modelling

The water quality amelioration service was estimated using the SWAT hydrological model which was set up for KwaZulu-Natal (see Appendix 5 for details). Phosphorous load balances were available at the reach scale (entry and exit points of sub-catchments). The model was set up to estimate changes in phosphorous loads at raw water treatment extraction points relative to a barren landscape scenario in which the retention/absorption capacity of the natural vegetation and cultivated land areas was reduced to that of a denuded landscape. The value of the service was then estimated in terms of the avoided costs to water treatment works.

The monthly phosphorous load outputs from the SWAT model were compared with water quality data from the Department of Water and Sanitation (DWS) for several points in each of the primary catchments. The simulated phosphorous loads were found to be significantly higher than the observed loads, especially during the wet season months. Using the data from DWS the simulated phosphorous loads were adjusted downwards using an adjustment factor calculated for the wet and dry season months. Water quality data from more sites across the province would help to significantly improve the calibration of nutrients in the SWAT model. Therefore, the results presented here should be considered preliminary.

In KwaZulu-Natal, water treatment plants either extract raw water for treatment from water supply reservoirs or they abstract directly from rivers (run of river). Using data from Umgeni Water, Thukela Water, Mhlathuze Water and several district municipalities, a list of 51 water treatment plants was generated (see Table 4.47). This list is not exhaustive but represents the reservoir-based and run-of-river water treatment plants in the province with a total treatment capacity of 2 339 Ml/day. For each treatment plant, we had information on the location of raw water abstraction and the average daily volume of water treated. Based on this we were able to identify the sub-catchment from which water was being extracted and the phosphorous load at a specific point along the reach within that sub-catchment. Water treatment cost savings were estimated for all water treatment plants based on a model developed by Turpie *et al.* (2017b) from data supplied by Umgeni Water on the Durban Heights water treatment plant that abstracts water from Nagle Reservoir. The model relates phosphorous loads entering the water supply reservoir to the water treatment cost at the water treatment plant (see Box 4.2). The modelled impact of the degradation of natural habitats on phosphorus loads and water treatment costs was used to estimate the water quality amelioration value of natural vegetation in the catchment areas of each reservoir or abstraction point. This was calculated as the difference (cost saving) between the baseline land cover (2005, 2011) and barren land cover for each year as a monthly R/ML cost saving. This was then multiplied by the average monthly volume treated to get an annual cost saving for each water treatment plant.

Table 4.47. The 51 reservoir-based and run-of-river water treatment plants included in the water quality amelioration valuation, the source of raw water and their daily treatment capacity.

Authority (primary catchments of operation)	Water Treatment Plant	Source of raw water	Treatment capacity (Ml/day)
Umgeni Water (uMkomazi, uThukela)	Durban Heights	Nagle Reservoir	615
	Wiggins	Inanda Reservoir	350
	Midmar	Midmar Reservoir	395
	DV Harris	Midmar Reservoir	130
	Maphephethwa	Nagle Reservoir	5
	Hazelmere	Hazelmere Reservoir	75
	Lower Thukela	uThukela River	55

Authority (primary catchments of operation)	Water Treatment Plant	Source of raw water	Treatment capacity (Ml/day)
	Maphumulo	iMvutshane Reservoir	6
	Ixopo	Ixopo Reservoir	4.7
	Amanzimtoti	Nungwane Reservoir	22
	Umzinto	Umzinto/EJ Smith Reservoir	13.6
	Mtwalume	Mtwalume River	7.5
	Mhlabatshane	Mhlabatshane Reservoir	4
	Ezakheni	uThukela River	32
	Tugela Estates	uThukela River	1.2
	Olifantskop	Olifantskop Reservoir	10
	Appelsbosch	Small reservoir in Appelsbosch	0.25
	Lidgetton	Lions River	0.5
	Mpofana	Mooi River	6
	Rosetta	Mooi River	0.25
Thukela Water (uThukela)	Makhabaleni	uThukela River	0.8
	Greytown	Craigie Burn Reservoir	3.09
	Sampofu	uThukela River	2.38
	Qudeni Plant	Gubazi River	0.5
	Isandlwana	Ngxobongo River	0.62
	Utrecht	Local Utrecht reservoir	2.04
	Nquthu	Buffalo River	4.18
	Ngagane	Ntshingwayo Reservoir	108
	Keat's Drift	Mooi River	0.7
	Biggarsberg	Buffalo River	19.3
	Dannhauser	Ntshingwayo Reservoir	3.4
	Durnacol	Ntshingwayo Reservoir	3
uThukela DM (uThukela)	Moyeni	Khombe River Weir	5
	Langkloof	uThukela River	0.1
	Bergville	Driel Barrage	4
	Loskop	Little uThukela River	1.2
	Winterton	Little uThukela River	1.3
	Colenso	uThukela River	2.6
	Ladysmith	Klip River & Spionkop Reservoir	23
	Archie Rodel	Bushmans River Weir	14
	George Cross	Wagendrift Reservoir	21
	Weenen	Bushmans River	1.45
Mhlathuze Water (Mfolozi/Pongola)	Nsezi	Lake Nsezi & Mhlathuze River	205
Ugu DM (Mzimvubu)	Mtamvuna	Mtamvuna River	20
	Bobhoyi	Mzimkhulu River	54
eThekwini (uMkomazi)	Ogunjini	Mdloti River	2.3
	Tongaat	uThongathi River	23
iLembe DM (uMkomazi, uThukela)	Ngcebo	uThukela River	4
	Mvoti	Mvoti River	17
uMkhanyakude DM (Mfolozi/Pongola)	Shemula	Pongola River	20
	Jozini	Pongolapoort Reservoir	40

Box 4.2. Summary of method used to estimate avoided water treatment costs. Source: Turpie et al. (2017b)

Water treatment cost models created by Turpie *et al.* (2017b) were used to estimate the water quality amelioration value associated with natural vegetation in the catchments of water supply abstraction points. Water treatment cost data and water quality data were provided for a five-year period for two of the largest water treatment plants in Durban. It was expected that higher nutrient loads, in particular phosphorous, would result in increased water treatment costs as a result of increased algal growth and associated changes in water colour and odour.

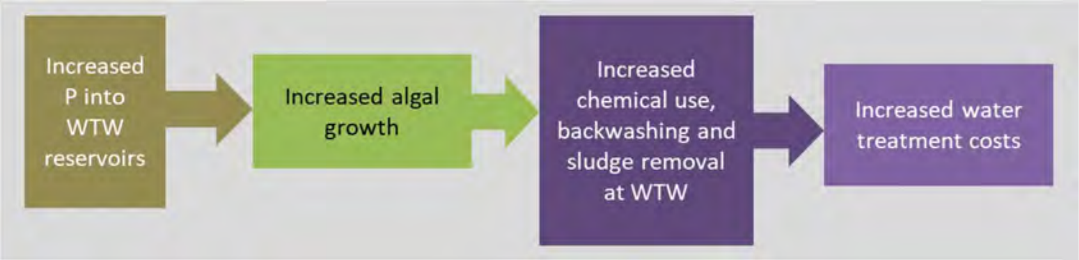

Figure 4.25. Schematic summary of the linkages from phosphorous loads in water supply reservoirs to increased water treatment costs as a result of deteriorating water quality.

The first set of regression models investigated the relationship between treatment costs (R/m^3 of treated water) and a range of water quality variables in the water being abstracted from the supply reservoir. The results indicated that the increase in suspended solids and algal blooms, especially during the summer rainfall months from November through to March, are the main reason for heightened treatment costs. The rising costs associated with these factors are a result of increased usage of coagulants and disinfectants needed to remove suspended sediments and algae, and associated odour and colour issues, during the treatment process. All regression models took the following form: $TC_p = f(x_s, x_n, x_e)$ where TC_w is the water treatment cost associated with treating 1 m^3 of water and x_n, x_c, x_a are the nutrient, chemical and algal water quality parameters related to TC_w.

The next set of models linked treatment costs to phosphorous loads and other water quality variables such as coliforms, colour, temperature and alkalinity in the river water entering the water supply reservoir. The results revealed that the phosphorous loads were positively and significantly correlated with water treatment costs. The model results had a reasonable fit to the actual supplied treatment cost data.

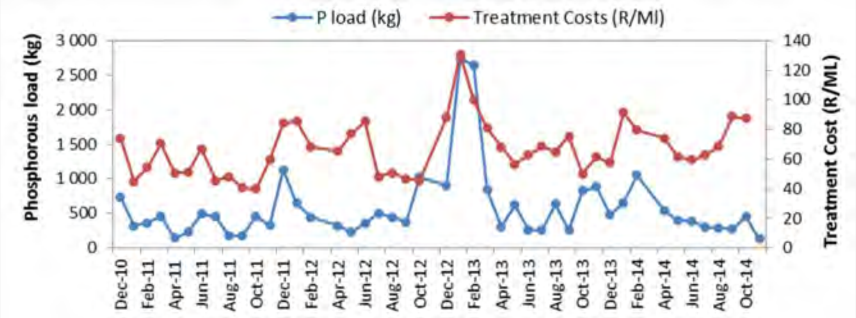

Figure 4.26. Average phosphorous loads (kg) in the uMngeni River above Nagle Reservoir and corresponding water treatment costs (R/ML) at Durban Heights water treatment plant.

The water treatment cost model was used to predict the outcome of catchment land-use changes, such as the impact that natural vegetation has on reducing nutrient runoff into surface waters. Using a simple scenario approach, modelled outputs of phosphorous loads can be related to the treatment costs using the above model and overall cost savings can be estimated.

Values derived from the above analyses were mapped to the natural vegetation and cultivated land within each sub-catchment where the service is demanded. All feeder sub-catchments (those sub-catchments that flow into the output sub-catchment and contribute to water quality amelioration) were identified for each sub-catchment where a water supply reservoir exists or where run of river abstraction occurs. The benefit value (water treatment cost saving) was then distributed to all feeder sub-catchments based on their weighting in terms of a phosphorous retention value (kg/ha/year). The values were summed for each sub-catchment and mapped to the vegetation using an estimate of the relative contribution of different land parcels to phosphorous retention, modelled using InVEST modelling software. The InVEST model provided the relative phosphorous retention score given to each grid cell within KwaZulu-Natal based on rainfall, soil and landcover. The value per pixel was determined for natural vegetation and cultivated land classes based on total phosphorous retention value for each catchment, the retention score given to the pixel and the sum of all pixel retention scores. The value per pixel was then divided by the area of the pixel to arrive at a phosphorous retention value per hectare estimate for vegetated area in each sub-catchment.

4.9.3 Results and discussion

A map of phosphorous retention (kg/ha/y) in 2011 is shown in Figure 4.27. Phosphorous retention by biome and water treatment cost savings per biome for 2005 and 2011 are summarised in the supply tables below (Table 4.48, Table 4.49). A total of just over 9800 tonnes of phosphorous was retained by the natural vegetation in the water supply catchments of KwaZulu-Natal in 2005. In 2011, 7876 tonnes were retained. The average annual phosphorous loadings were 1.33 kg/ha and 1.75 kg/ha in 2005 and 2011, respectively (range 0.012-17.01 kg/ha in 2005 and 0.015-22.25 kg/ha in 2011); a 31% increase due to increasing upstream agricultural inputs. These loadings increased to 9.71 kg/ha and 9.72kg/ha when the landscape was degraded (range 0.085-475.28 kg/ha in 2005 and 0.10-455.50 kg/ha in 2011); a significant increase from the baseline.

We find our results to be reasonable when compared with other studies. Liu *et al.* (2013) estimated that the average total phosphorous loading in the Beaver River catchment in Rhode Island to be 0.48 kg/ha under the baseline scenario. When 16% of the forest in the catchment was converted to agricultural land the phosphorous loading increased to 1.04 kg/ha on average (Liu *et al.* 2013). Implementing best management practices on agricultural land, such as reduced fertilizer application, saw these loads decrease by almost half to 0.68 kg/ha and converting forest land to medium residential land use saw the average loading increase to 2.7 kg/ha (Liu *et al.* 2013). In the Bayou Plaquemine Brule catchment in Louisiana Poudel *et al*. (2013) found the total phosphorous loads varied from <1 kg/ha to >3 kg/ha across sub-catchments. Of the seven sub-catchments included in the analysis two of them had low loadings (<1 kg/ha), four had medium loadings (1-3 kg/ha) and one had high phosphorous loads (>3 kg/ha) as categorised by the authors. Chiang *et al.* (2010) estimated that total phosphorous losses from agricultural pastureland in the Lincoln Lake watershed in the US ranged from 0.7 to 4.1 kg/ha, whereas total phosphorous losses for the entire catchment ranged from 0.3 to 2.1 kg/ha. The study found that changes in land use, gradually decreasing pasture areas and improvement in pasture management between 1992 and 2007 resulted in a decrease in total phosphorous losses in

2007. Bi *et al.* (2018) examined the response of total phosphorous in the Luanhe River Basin in north-eastern China to changes in land cover and found that total phosphorous loads and pollution incidence increased with a decrease in natural land. The average annual phosphorous loads increased by 47% between 1985 and 2000 and by 27% between 2000 and 2014 (Bi *et al.* 2018).

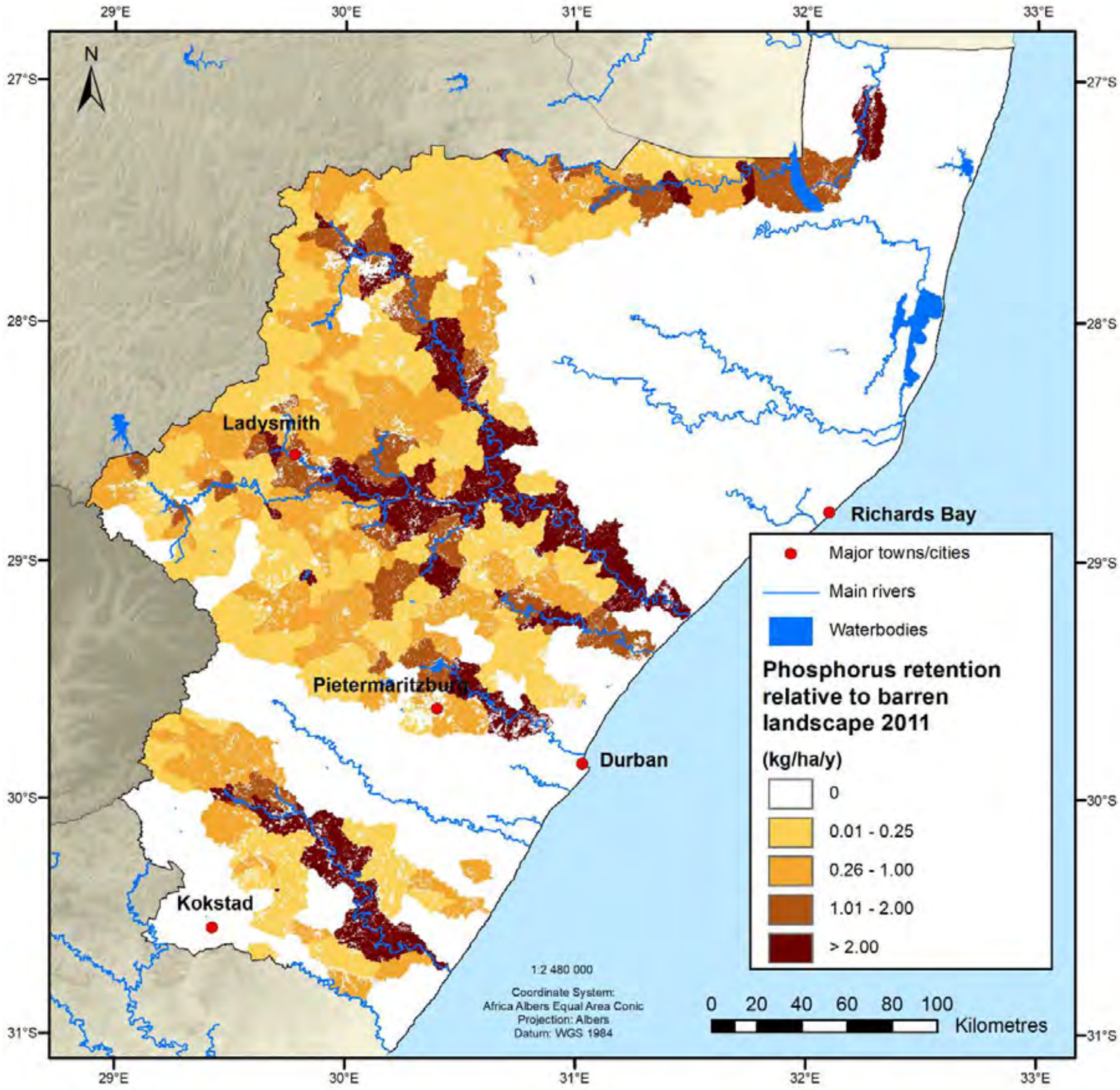

Figure 4.27. Phosphorous retention (kg/ha/y) in 2011 relative to a barren landscape based on the relative phosphorous retention values calculated from the InVEST nutrient retention service model (version 3.7.0)

In this study, the value of water quality amelioration was estimated to be a saving of **R20.4 million** (~59%) in 2005 and **R16.0 million** (~46%) in 2011, in the production cost of 667 000 ML provincially. The average per ha value ranged from < R1 to R352 in 2005 (mean = R9.56/ha) and from < R1 to R379 in 2011 (mean = R8.06/ha). The impacts of upstream land use on downstream municipal water treatment costs remain poorly understood (Vincent *et al.* 2016). Indeed, few studies have directly related catchment land cover to water treatment costs or investigated the link between nutrient loads entering water supply reservoirs and water treatment costs. Vincent *et al*. (2016) produced evidence that protecting forests against conversion to non-forest land uses can reduce the operating costs of water treatment plants. In Malaysia, a 1% increase in virgin forest was found to reduce treatment costs by 1.16% (Vincent *et al.* 2016). However, using empirical valuation based on land cover/use does not align with the EEA framework in that the service is not assessed in physical terms, i.e. the retention capability of natural ecosystems in terms of total phosphorous is not estimated. At the national scale Turpie *et al.* (2017a) conservatively estimated the value of water quality amelioration as ranging from < R1 to R100 per ha by natural buffer areas in different catchments, amounting to an approximately R9 million per annum saving in water treatment costs.

The contribution of water quality amelioration to the asset value of ecosystems in KwaZulu-Natal was estimated to be **R331 million** in 2005 and **R260 million** in 2011, representing a loss in value of R71 million (Table 4.50). Most (R59 million) of the loss in value was within the grassland biome.

Table 4.48. Physical supply table of phosphorous retention, for 2005 and 2011

Biome Service	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	TOTAL
2005 **Phosphorous retention (tonnes)**	-	3 829	525	5 394	96.67	5.73	**9 850**
2011 **Phosphorous retention (tonnes)**	-	3 068	381	4 348	75	4	**7 876**

Table 4.49. Monetary supply table for water treatment cost savings as a result of water quality amelioration services, for 2005 and 2011; values in 2010 R millions

Biome Service	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	TOTAL
2005 **Water treatment cost savings**	-	16.52	0.17	3.21	0.50	0.00	**20.39**
2011 **Water treatment cost savings**	-	12.89	0.08	2.65	0.41	0.00	**16.04**

Table 4.50. Ecosystem monetary asset account 2005-2011 for water quality amelioration. NPV calculated using an asset lifespan of 25 years and a discount rate of 3.66%. Values are net present value in R millions.

	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	Total
Opening stock (2005)	0.00	267.61	2.75	52.00	8.10	0.00	330.46
Additions	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reductions	0.00	-58.80	-1.46	-9.07	-1.46	0.00	-70.79
Net change	0.00	-58.80	-1.46	-9.07	-1.46	0.00	-70.79
Closing stock (2011)	0.00	208.80	1.30	42.93	6.64	0.00	259.67
Net change %	0.0%	-22.0%	-52.9%	-17.4%	-18.0%	0.0%	-21.4%

4.10 Flood attenuation (eThekwini only)

***Note**: this service could not be covered in full due to time and resource limitations of the study. However, it incorporates a recent estimate from eThekwini in order to provide a more complete coverage of examples for the pilot study. The following is largely drawn from the study by Turpie et al. (2017b). While their model had to incorporate the entire catchment area of the municipality, their study only tested the effects of the ecosystems within the municipality. Future studies will need to extend this to the rest of the catchment areas as well as to other flood risk areas in the province.*

4.10.1 Overview of the service

Flood attenuation is the reduction of flooding impacts through slowing down flows so that the quantity of water flowing at the peak is reduced, and flows are spread over a longer duration (flattening the curve). This regulation of high flows is governed by similar environmental factors as the regulation of low flows (described in section 4.7), but is treated separately because the spatial demand for the service may be different and because it is valued differently. The combination of weather-related (e.g. rainfall intensity, extent and duration) and geophysical (e.g. catchment size, geomorphology, soil and land use) characteristics are the main factors that influence flooding (Kareiva *et al.* 2011). Natural systems such as wetlands and rivers or ecosystems with deep permeable soils can regulate flows through the landscape by slowing flows by means of storage and vegetative resistance and facilitating infiltration into soils. In this way these systems ameliorate the potential impacts of flood events by reducing the flood peaks and lengthening the flood period at a lower level (Vellidis *et al.* 2003), and reducing the risk of flood damage in downstream areas. The key factors influencing storm peak mitigation are canopy interception, soil infiltration, soil water storage and location in the landscape.

Flood attenuation provides benefits to people wherever it lessens the risk of damage to downstream property. The benefits are therefore primarily felt in built up areas. In these areas, separating out ecosystem from other effects can be complex. Flood damages for a given size rainfall event are influenced by the amount of investment in drainage and flood conveyance systems and/or in flood retardation measures, the degree to which this is rendered ineffective by solid waste pollution, the degree to which people settle (legally or illegally) within floodplain areas, and the fact that those floodplain areas increase in size as hardening of catchment areas proceeds.

4.10.2 Data and methods

Physical modelling

Based on the fact that the eThekwini municipality responds to increasing flood risk through incremental investment in flood conveyance infrastructure, the physical modelling was geared to estimating how the dimensions of the infrastructure would differ in the absence of the ecosystem service within the eThekwini municipal area. There is substantial natural habitat within this municipality, much of which is outside of the urban boundary.

Turpie *et al.* (2017b) set up a hydrological model for the entire catchment area of the eThekwini Municipality using the US-EPA SWMM5 hydrology and hydraulics engine, interfaced by the PC-SWMM software. The model was set up to run design flood events in order to determine the influence of natural vegetation on flood hydrographs at strategic points relating to the location of existing flood conveyance infrastructure in the city. The flood hydrographs generated under current conditions were compared with what they would be if the natural systems were converted to urban land use. This provided an indication of the impacts of loss of natural areas on flooding and the difference was construed as an estimate of the flood attenuation benefit obtained by retaining the natural ecosystems.

This modelling required far more detailed and accurate land cover data than are offered by either the KZN Land Cover or National Land Cover data series. For the area within the municipality, the study therefore used the eThekwini land cover and Durban Metropolitan Open Space System (DMOSS) spatial layers for 2008 and 2012, as well as detailed GIS data on built drainage infrastructure that was improved for the study. The Southern African National Land Cover dataset (2013/14) was used for the catchments outside of the municipality.

The area within the eThekwini municipality was subdivided into small sub-catchment areas in the order of 0.2 km^2. For the region outside of EMA, Shuttle Radar Topography Mission (SRTM – 30 x 30m cell size resolution) data were acquired and special analysis tools were used to discretise the model into 0.5 to 1 km^2 sized sub-catchments, with larger sub-catchments closer to the source areas (Drakensberg). The final SWMM model of the full EMA comprised about 30 000 sub-catchments. A spatial analysis tool was then used to process the flow paths, watershed boundaries, and river centre lines (Figure 4.28). The outlet points for the model were then identified and selected, in this case stormwater infrastructure.

A number of input parameters are required for SWMM5. These include hydraulic parameters, soil infiltration properties, rainfall and water quality parameters. The determination of the catchment characteristics was estimated using a spatial analyst tool for zonal statistics. Raster files were generated to represent the information required for the hydraulic and hydrological models, with reference to each sub-catchment. The most significant input hydraulic parameter is the percentage of impervious area. The hydraulic parameters were assigned to each landuse classification based on literature. The largest proportion of rainfall losses over pervious areas generally occur due to soil infiltration. The Green-Ampt method was adopted, which provides a soil memory as opposed to a broad brush coefficient approach. Three user-specified soil parameters were used; i.e. capillary suction head, saturated hydraulic conductivity, and the maximum available moisture deficit. Average daily abstractions and return flows/discharges were added as point sources at the appropriate junctions. Flows entering reservoirs were re-routed to an outfall, and a new flowpath was created downstream.

A user-defined hyetograph was used as the precipitation input into the model. The hyetograph was created using the total daily mean-areal precipitation depths derived by Smithers & Schulze (2000) for a 24-hour design storm. The temporal distribution was derived using a synthetic SCS

Type II distribution for 2-, 5-, 10- and 20-year return periods. The volume of the flood with and without the natural ecosystems was compared at the location of each flood conveyance structure, for the return period for which the structure was designed. Using a python model built for the purpose, the difference in dimensions required for each structure was computed.

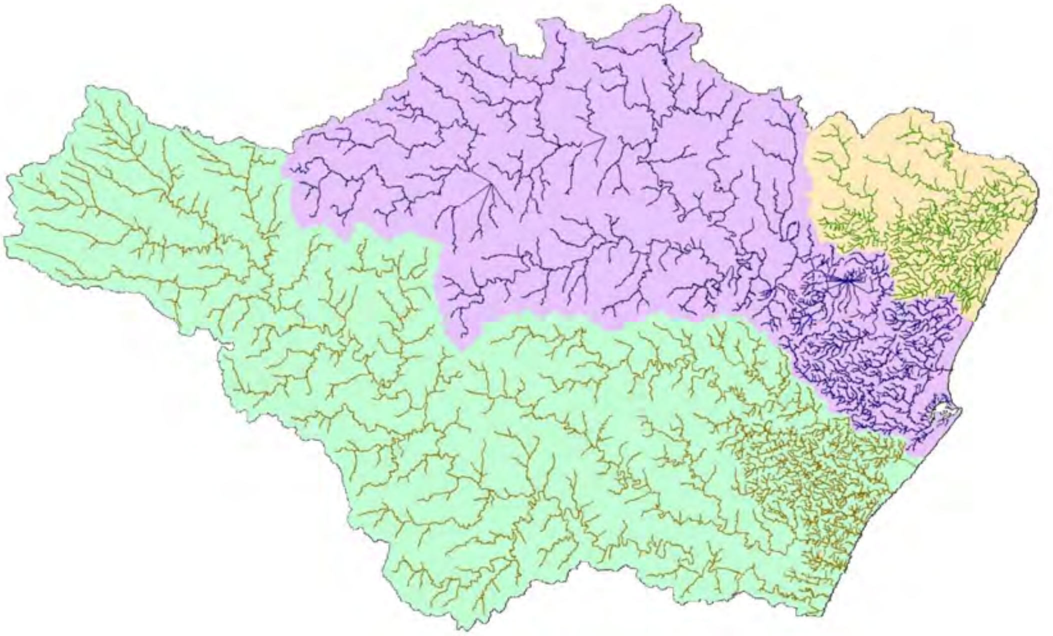

Figure 4.28. The full eThekwini catchments showing flow paths

Valuation

The flood attenuation service can be valued using the lower of either flood damages avoided the avoided costs of replacing the natural systems with alternative flood mitigation options. The avoided damage costs are the extra costs that would be incurred in the form of incremental losses from increased flooding if the natural ecosystems were lost and also includes the opportunity cost of having to increase setback lines in greenfields areas. The replacement cost method involves estimating the costs of infrastructure that would be required to provide the same level of flood mitigation as the natural systems. In the urban context, as more land becomes intensively modified, cities such as Durban tend to respond to the resultant increased flood risk by implementing engineering solutions such as changes to the stormwater infrastructure. Indeed, the city is already on a path to increasing the capacity of its infrastructure in preparation for anticipated increases in the size of storm events as a result of climate change (Schulze *et al.* 2010). Therefore, a replacement cost approach was used. This was based on the estimation of the difference in size, and therefore cost, of the city's flood conveyance infrastructure. In the Turpie *et al.* (2017b) study, costs were incorporated into the python model mentioned above. This model was devised with the assistance of one of the city's engineers, and was based on accurate and up-to-date cost estimates. The benefit of the ecosystem service was estimated as in terms of the capital cost saving. This was then annualised to provide an estimate of the ecosystem service benefit flow.

For this study, the estimate from the above study was taken to approximate the situation for 2011. In order to estimate a flood attenuation value for 2005, we used the simplified assumption that the value of the service was correlated to the amount of urban green open space in the municipal area and was adjusted based on the rate of change in urban green space between 2005 to 2011. As for the other services, these values were also expressed in constant 2010 Rands.

4.10.3 Results and discussion

The cost saving as a result of flood attenuation by ecosystems within the eThekwini Municipality was estimated to be R23.5 million per annum, with a contribution to the asset value of these ecosystems of R380.7 million. The corresponding values for 2005 were estimated to be R31.0 million and R502.2 million. Thus, it is estimated that between 2005 and 2011, the loss of approximately 1000 ha of open space resulted in a loss of some R7.5 million in terms of flood attenuation services. As natural systems are lost within the city, the higher the cost becomes to replace this with engineered solutions. Note that the value does not represent the flood attenuation value for the whole province but includes only the value of the service in the biggest urban centre in KwaZulu-Natal where flooding is now a frequent and growing problem.

This value was considered to be the minimum value of two options, being the flood damages avoided, or infrastructure costs avoided. Due to excellent data for the city, these estimates were considered to be fairly robust. Estimation of flood damages might be more appropriate in less developed countries, e.g. for a city such as Dar es Salaam, where flood damages are likely, and the response of building more flood infrastructure may be less likely (de Risi *et al*. 2018). Such models are different but no less complex, and may be confounded by lack of data.

5 ECOSYSTEM SERVICE AND ASSET ACCOUNTS

This section of the report provides a summary of the main findings and presents the ecosystem service supply and use accounts in both physical (Table 5.1 to Table 5.4) and monetary terms (Table 5.5 to Table 5.8) for 2005 and 2011 and the ecosystem monetary asset account (Table 5.9).

The ecosystem monetary asset account records the monetary value of opening and closing stocks of all ecosystem assets within an ecosystem accounting area and additions and reductions in those stocks (UN 2017). These are the net present values of annual flows of ecosystem service value over time. The ecosystem monetary asset account for KwaZulu-Natal is shown in Table 5.9. The row entries are simplified to basic asset account entries. More detail can be added if required to account for changes in assets, such as catastrophic losses (e.g. changes due to natural disasters), upward and downward reappraisals and reclassifications (UN 2017). A separate entry relating to revaluations can also be included to record changes in the value that are due solely to changes in prices rather than changes in volumes. Since all prices are expressed in 2010 prices, there are no revaluations included in this asset account.

The value of the ecosystem assets, as derived from the value of annual flows, was estimated to be **R737 billion** in 2005 and **R827 billion** in 2011 (both in 2010 Rands; Table 5.9). Change in value due to change in ecosystem capacity and/or service demand amounted to just under R90 billion with the most significant negative net change seen in the Indian Ocean Coastal Belt with a 4.9% loss in stock from 2005 to 2011 (Table 5.9).

It is important to note that change in the asset value of ecosystems can occur as a result of change in the extent and condition of ecosystems affecting the capacity to supply services, or a change in the demand for the services due to a number of socio-economic factors. A change in asset value is therefore not straightforward in its interpretation, and will need some careful analysis. In the example of KwaZulu-Natal, the asset value of inland ecosystems, which include highly modified ecosystems such as cultivated lands, has increased over time in constant 2010 Rand terms (i.e. even after correcting for inflation). This is the net outcome of the losses in value contribution of some services and gains in others. The increase in overall asset value masks the fact that some provisioning values have decreased. Therefore, it is important to tease apart the components of this value in order to formulate appropriate policy responses.

5.1 Ecosystem service supply and use accounts (in physical terms): Supply accounts

Table 5.1. Total biophysical supply per ecosystem type 2005

Biome Resource	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	Cultivated	Urban green space	Total
Wood products (m^3)	3 523	695 638	235 125	787 294	267 047	169			**1 988 796**
Non-wood products (tonnes)	834	46 494	11 489	34 952	2 911	38			**96 718**
Livestock production (LSU)	1 716	684 698	52 162	289 663	2 010	340			**1 030 589**
Crop production (tonnes)							43 305 781		**43 305 781**
Experiential value (R millions)	14	237	179	218	55	24	85	885	**1 698**
Carbon storage (Tg C)	5	512	61	348	33	0	279		**1 237**
Pollination (R millions)	0	12	6	31	2	0			**51**
Flow regulation (million m^3)	78	3 315	421	2 198	634	36			**6 682**
Flood attenuation (R millions)								31	**31**
Sediment retention (million tonnes)	2	45	6	27	18	2			**99**
Water quality amelioration (tonnes P)	-	3 829	525	5 394	97	6			**9 850**

Table 5.2. Total biophysical supply per ecosystem type 2011

Biome Resource	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	Cultivated	Urban green space	Total
Wood products (m^3)	3 801	606 438	209 311	711 853	247 102	190			**1 778 695**
Non-wood products (tonnes)	797	41 514	8 544	26 819	3 054	27			**80 755**
Livestock production (LSU)	1 931	649 341	46 529	228 654	2 629	284			**929 368**
Crop production (tonnes)							43 611 653		**43 611 653**
Experiential value (R millions)	21	326	194	297	81	36	162	1 009	**2 127**
Carbon storage (Tg C)	5	459	49	312	31	0	341		**1 197**
Pollination (R millions)	0	11	5	30	2	0			**48**
Flow regulation (m^3)	50	3 236	446	2 224	157	1			**6 113**
Flood attenuation (R millions)								24	**24**
Sediment retention (million tonnes)	1	38	5	22	9	0			**75**
Water quality amelioration (tonnes P)	-	3 068	381	4 348	75	4			**7 876**

5.2 Ecosystem service supply and use accounts (in physical terms): Use accounts

Table 5.3. Total biophysical use per economic user (2005)

Economic user Ecosystem service	Agric, Forestry & Fisheries	Water supply	Trade, catering & accommodation	Other sectors	House-holds	Govern-ment	Rest of world	Total
Wood products (m^3)					1 988 796			**1 988 796**
Non-wood products (tonnes)					96 718			**96 718**
Livestock production (LSU)	669 423				361 166			**1 030 589**
Crop production (tonnes)	41 859 229				1 446 552			**43 305 781**
Experiential value (R millions)			812	885				**1 698**
Carbon storage (Tg C)							1 237	**1 237**
Pollination (R millions)					51			**51**
Flow regulation (million m^3)	6 682							**6 682**
Flood attenuation (R millions)					31			**31**
Sediment retention (million tonnes)		99						**99**
Water quality amelioration (tonnes P)		9 850						**9 850**

Table 5.4. Total biophysical use per economic user (2011)

Economic user Ecosystem service	Agric, Forestry & Fisheries	Water supply	Trade, catering & accommodation	Other sectors	House-holds	Govern-ment	Rest of world	Total
Wood products (m^3)					1 778 695			**1 778 695**
Non-wood products (tonnes)					80 755			**80 755**
Livestock production (LSU)	640 389				288 977			**929 366**
Crop production (tonnes)	39 659 499				4 006 242			**43 665 741**
Experiential value (R millions)			1 117	1 009				**2 127**
Carbon storage (Tg C)							1 197	**1 197**
Pollination (R millions)					48			**48**
Flow regulation (million m^3)	6 113							**6 113**
Flood attenuation (R millions)					24			**24**
Sediment retention (million tonnes)		75						**75**
Water quality amelioration (tonnes P)		7 876						**7 876**

5.3 Ecosystem service supply and use accounts (in monetary terms): Supply accounts

Table 5.5. Total supply per ecosystem type 2005 in monetary values (R millions). Note: Built includes man-made parks, value pertains to parks, area to all built area.

Biome (ha)	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	Cultivated	Built	Total
Resource	57 127	3 677 202	434 070	2 549 702	185 908	39 531	1 822 632	564 354	9 330 526
Wood products	3.03	598.13	202.09	677.90	233.39	0.15			**1 714.69**
Non-wood products	22.08	982.22	238.23	715.06	49.09	0.78			**2 007.47**
Livestock production	2.60	1 038.27	106.73	521.00	3.75	0.64			**1 672.99**
Crop production							6 456.70		**6 456.70**
Experiential value	14.08	236.77	178.92	218.22	55.47	24.18	84.79	885.37	**1 697.80**
Carbon storage	121.15	12 375.43	1 473.67	8 407.37	797.29	4.91	6 742.74		**29 922.56**
Pollination	0.07	11.87	6.07	31.35	1.88	0.00			**51.26**
Flow regulation	0.74	2 112.36	27.19	1 078.64	28.93	-			**3 247.87**
Flood attenuation								31.02	**31.02**
Sediment retention	12.26	204.30	20.66	107.30	86.83	4.43			**435.79**
Water quality amelioration	-	16.52	0.17	3.21	0.50	-			**20.40**
Total R millions	**176.02**	**17 575.86**	**2 253.74**	**11 760.04**	**1 257.14**	**35.10**	**13 284.23**	**916.39**	**47 258.53**
Value R/ha	**3 081.20**	**4 779.68**	**5 192.11**	**4 612.32**	**6 762.16**	**887.88**	**7 288.49**	**1 623.79**	**5 064.94**

Table 5.6. 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)	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	Cultivated	Built	Total
Resource	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			**1 532.71**
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**
Crop production							7 535.43		**7 535.43**
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**

5.4 Ecosystem service supply and use accounts (in monetary terms): Use accounts

Table 5.7. Total use per economic user (2005) 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					1 714.69			**1 714.69**
Non-wood products					2 007.47			**2 007.47**
Livestock production	849.35				823.63			**1 672.98**
Crop production	5 855.99				600.71			**6 456.70**
Experiential value			532.83	1 164.97				**1 697.80**
Carbon storage							29 922.56	**29 922.56**
Pollination					51.26			**51.26**
Flow regulation	3 247.87							**3 247.87**
Flood attenuation					31.02			**31.02**
Sediment retention		435.79						**435.79**
Water quality amelioration		20.40						**20.40**
Total	**9 953.21**	**456.19**	**532.83**	**1 164.97**	**5 228.78**	**-**	**29 922.56**	**47 258.52**

Table 5.8. 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					1 532.71			**1 532.71**
Non-wood products					1 647.54			**1 647.54**
Livestock production	815.45				657.43			**1 472.88**
Crop production	5 954.69				1 580.74			**7 535.43**
Experiential value			798.83	1 327.78				**2 126.60**
Carbon storage							34 579.34	**34 579.34**
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**	**-**	**34 579.34**	**52 478.90**

5.5 Ecosystem monetary asset account

Table 5.9. 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	Savanna	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%

6 DISCUSSION

6.1 Completeness and reliability of estimates

6.1.1 Provisioning services

Provisioning services were the most comprehensively valued services, although they did not include the legal commercial harvest of natural resources (likely to be small), or the illegal harvesting of high value, endangered species (likely to be large but unsustainable). We also did not have an estimate for the value, if any, of provision of genetic resources of use in horticulture, medicine or other areas. Little, if any, research has been carried out in this regard.

Determining use of **wild resources** was limited by accessibility factors in that the levels of availability were capped within local areas. This is unlikely to be the case as it is to be expected that entrepreneurs with access to transport will bring resources from more distant areas. The total size of the source area used to meet demand should be determined by economics as well as accessibility and future accounting efforts should seek to incorporate these factors into the analysis. Furthermore, on the supply side, a more dynamic model is required to fully capture the change in use of resources over time. A dynamic model would include assumptions on harvesting rates, population growth rates and changes in annual stocks and yields. A repeated comprehensive, nation-wide household survey on wild resource use would address standardisation issues and would provide accurate, site-specific information.

Data on **livestock production** were inconsistent and patchy, particularly for the communal rangelands. There was also limited information on rangeland condition with which to adjust estimates of productivity. Thus, the sustainability adjustments applied to harvested resources were not applied to livestock production at this stage. These data need to be summarised and available at the lowest possible resolution for accurate spatial allocation of the values. A national online mapping tool, such as *CapeFarmMapper*[9] would be particularly useful for determining what agricultural products are being farmed where and how the extent and types of crops being farmed changes over time. While there is some information on game farms, it is very patchy and inconsistent. Data on the type of game farm and the numbers of wildlife units kept on these farms would be useful. The agricultural census should be repeated at a regular time step.

While the value of **crop production** was taken from provincial statistics and therefore align closely with the national accounts, the spatialization of these values was challenging due to a mismatch between statistical classification of crop types, and the land cover classification. Data on reared animal production and plantation forestry were not very suitable for the analysis and need to be produced in a way that allows for more consistent spatial and aggregate estimates.

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[9] CapeFarmMapper (https://gis.elsenburg.com/apps/cfm/) is a product of the Western Cape Department of Agriculture and is an online mapping tool designed to assist with spatial information queries and decision making in the fields of agriculture and environmental management.

Our analysis used the highest resolution data where possible but, in some cases, had to rely on provincial averages. Our estimates for 2005 were not as reliable as those for 2011. This is because 2005 fell between two census periods and in order to estimate production in this year we relied on interpolation of census data between 2001 and 2011.

Livestock production and crop production were valued using the resource rent approach which is the residual value after man-made inputs have been subtracted. This should be considered a minimum estimate of the service, since the overall sectoral production would not be possible without the land/ecosystem inputs.

6.1.2 Cultural services

Our valuation of cultural services focused on the use value aspect, which we termed experiential value. Non-use values are not included in the SEEA EA although allowance is made for recording relevant physical information related to non-use flows in the physical supply-use tables, under a separate flow "ecosystem and species appreciation." This is to allow compilers to record data that can be directly associated with non-use values. In monetary terms, estimates of non-use can be shown as complementary valuations in separate tables.

Experiential value is partly reflected in market values, through tourism expenditure and the premiums paid on properties. Our study was able to estimate these values satisfactorily, except that it did not include the unrecorded use of ecosystems by people living nearby that is not captured in property value. While the values that were captured are likely to account for a large percentage of experiential value, our estimate is therefore still on the conservative side.

The aggregate tourism estimates can be considered reliable, in that they are based on the tourism satellite accounts. The initial disaggregation was not to nature-based tourism or biodiversity tourism, which is difficult to do reliably, but rather to attraction-based tourism (as opposed to other functions of tourism such as visiting family or doing business). The statistics with which to derive these estimates are available at national scale, but are not consistent across provinces, and required some assumptions in this case. Such information should be collected at regional tourist offices and collated at both provincial and national levels. The use of geotagged photographs to assign the value of attraction-based tourism to ecosystems produced very plausible results. This method has been tested in various locations in southern Africa with good results. Thus, the mapped values with which one could derive local estimates were also considered to be relatively reliable. Unfortunately, the tourism statistics for the Ezemvelo KZN Wildlife parks, which would have provided the means for calibration, were embargoed for PhD research at the time of the study. Future iterations should make this comparison. As for livestock and crop production, nature-based tourism was valued using the resource rent approach (see above discussion on the potential limitations of this method). Furthermore, estimates of user costs, such as the costs of fixed capital, which are used to estimate resource rent, are not readily available or easily accessible for the tourism industry.

The estimated contribution of urban green space to property value was considered to be a relatively complete estimate for the province, in that all major urban areas were included. However, the actual estimates were a first-cut estimation based on benefits transfer from a detailed study of property value in eThekwini municipality. Given the good fit of the transfer model, the values are likely to be in the right order of magnitude. However, the values were not linked to specific green open space areas, and therefore the model cannot be used to track changes in value as these areas change. In order to conduct a hedonic analysis at scale, detailed property sales data and urban land cover is needed for all the main urban centres. The KZN land cover map does not provide enough detail within urban areas and therefore we cannot spatially allocate the values to the natural vegetation in these areas. To be able to map the value to the urban green open spaces, mapping of the urban areas at a higher resolution in KwaZulu-Natal (and at a national level) should be a priority. It is recommended that the urban land class should be added to the land cover map as an ecosystem asset.

6.1.3 Regulating services

While this study included a broad coverage of regulating services in order to pilot these methods, it has not captured all aspects and all locations. In some cases, such as the control of agricultural pests by animals living in neighbouring natural ecosystems, there was no information at all.

The value of carbon is among the more controversial values in this study. There is still much debate within the SEEA with regards to the framing of the carbon service and a consistent approach to its valuation in terms of the price used for valuing tCO_2. Some countries estimate carbon retention or carbon storage (as in this study), while others, such as the Netherlands and United Kingdom estimate carbon sequestration. There are numerous estimates of the global SCC, now ranging from \$10 to \$1000/tCO_2, with no concensus on the most appropriate/accurate estimate to use. Furthermore, the approach used to account for the carbon retention in physical terms may also be flawed in that the most productive alternative use of land is not necessarily going to have zero carbon per hectare (i.e. the risk of release may differ), as is inherent assumption in valuing all carbon stored. One way to account for the physical quantity retained would be to adjust for only the amount or carbon that is at risk of being lost. This should be subject to further peer review and comparison with other approaches in order to settle on the most suitable method for estimating the carbon service.

In the case of pollination, a lack of detailed data, including spatial data, on both commercial and subsistence crop production meant limiting the estimate of crop pollination services to the benefits to household subsistence cultivation. There is likely to be some additional pollination benefit to commercial and small-scale agricultural production. Our estimate of pollination value is therefore highly conservative.

Three of the four hydrological services were mainly considered for natural land, and not all agricultural or urban green space. Furthermore, the assessment of water quality amelioration did not include the role and value of wetlands, which is likely to add significant value to the estimation. Further work will be needed to fill these gaps. In addition, the maintenance of low flows was valued in terms of formal water supply and the availability of water for households that collect their water from rivers, but did not include an estimate of the value to commercial irrigators, which could be substantial, especially given the growth in irrigated crop area over time. Flood attenuation services were only considered for green open space within eThekwini municipality, so further work will be needed to extend this to all areas where the service might be of value. The catchment areas upstream of this, which stretch all the way to the inland border of KwaZulu-Natal, are likely to have a much higher value in this regard. There are also other large urban areas that are likely to benefit from flood attenuation. We have also excluded critical habitat value, including nursery value of the province's large number and area of estuaries. This was originally omitted due to concerns about intermediate services, but we have since resolved a method for dealing with this in the treatment of agriculture and pollination, and should be added in the next iteration.

In relative monetary terms, the value of hydrological services appeared low in comparison with other ecosystem services, compared with other studies in the literature. However, we feel that they were reasonable estimates of what we were attempting to value. The main difference is that our service definitions and methodology differ from other studies. In particular, the hydrological services value here do NOT include water supply, but rather the services that alleviate some of the costs of water supply. The value of water is, of course, far greater and would eclipse many of the values in this study, but water *per se* is not included as a provisioning service in this study since it is not produced by ecosystems. Our estimates of the value of nutrient and sediment retention services may also be conservative, in that our model lacked detail on wetlands that are expected to have additional holding capacity, and whose degradation can lead to considerable gully erosion.

The actual values generated were, however, on the basis of models that would benefit from more time in refinement and calibration. Both the SWAT and InVEST models require considerable amounts of data on the appropriate parameter input values. For the InVEST model most of the data drawn on in this study, in particular the underlying biophysical spatial data (i.e. soil erodibility - Schulze & Horan 2007, rainfall - Lynch 2004 and watershed and sub-watershed layers - Middleton & Bailey 2008) were all national level data sets and therefore quite course for application at this level. Much of the data relating to the biophysical components (such as, export coefficients, USLE factors) of services are also very general and based on international work. Likewise, for the SWAT model, default inputs for the land cover classes were used which are largely based on data for land cover classes in North America. More work needs to be done to tailor the land cover parameters to the local situation. In working around this issue, we used expert opinion to determine multiple factors relating to retention and export factors for both the sediment and nutrient models. Whilst the models appear intuitively correct errors may become compounded during the modelling processes. While DWS does monitor flows, sediments and water quality parameters across the country, the data are often inconsistent and patchy and the system to download this information faulty and inefficient. More can be done to improve the collection and dissemination of this monitoring data. Future studies should test the estimates against empirical analysis, but obtaining sufficient data for a robust panel data analysis from the multiple agencies involved is a challenge that will need to be overcome in order to do this.

Novel methods were used in this study to estimate the value of seasonal flow regulation. These methods provide a far more conservative estimate of value than basing values on water quantity, but we feel they provide a more realistic valuation of the service. Nevertheless, this approach should be subject to further peer review and comparison with other approaches in order to settle on the most suitable method for estimating this service.

6.2 Comparison with welfare value estimates

In this study we used exchange value methods for valuing ecosystem services which is the recommended approach to apply in SEEA ecosystem accounting, and which aligns with the measures of the SNA, such as GDP. This differs in theory from the welfare measures used in valuation of ecosystem services for economic analysis, such as cost-benefit analysis. Whereas national accounting is focussed on measuring changes in outputs, and natural capital accounting estimates the ecosystem contribution to this, economic analysis is focussed on changes in societal wellbeing, which is essential to understand in formulating policy. Changes in natural capital affect both production and societal wellbeing. The valuation methods used to estimate these effects are similar, and were primarily developed to obtain measures of wellbeing for cost-benefit analysis. The distinction is not widely understood, and in reality, many estimates of the value of ecosystem services that have been intended for cost-benefit analysis have in fact been exchange values, since they are often easier to compute.

Based on 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 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 are 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, on the other hand are where value estimates could differ substantially for accounting versus economic analysis, since valuation methods for economic analysis have focused on deriving consumer surplus, especially for cases where access to (or viewing) nature is free or undercharged. 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. In the case of tourism, an economic analysis would be interested in the producer surplus from tourism (similar to the value we obtained), and also in the consumer surplus of domestic tourists and of local recreational use that does not result in market transactions. The last two require additional information, often based on surveys. While the total value for tourism would therefore be higher in an economic analysis, there were no such studies available in KwaZulu-Natal from which we could derive the comparative estimate. In the case of property value, the same hedonic pricing method used in this study would need to be extended to a second stage analysis in order to estimate the consumer surplus. More importantly, an economic analysis would also be expected to include non-use value, which is estimated using stated-preference surveys. This captures people’s appreciation of ecosystem health and biodiversity irrespective of their direct consumptive or non-consumptive (experiential) use of it. 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.

6.3 Aggregate values

Table 6.1 presents the overall results for the province by type of service. 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 in those years if global carbon values are used, and R17.6 billion and R18.2 billion or 5% and 4% of provincial GDP if the national carbon value is used (Table 6.1). The value of the ecosystem assets was estimated at **R737 billion** and **R827 billion**, respectively. This is an increase in value of 12.2%.

The bulk of the annual value of ecosystem services in both 2005 and 2011 was attributed to the global value of carbon storage (63% and 66%), which is mostly an exported service in the form of cost savings to the rest of the world (Table 6.1). Provisioning services were dominated by crop production and hydrological services by flow regulation. Note, however, that these proportions are likely to change as the coverage of the ecosystem monetary accounts improves. Several services were only partially valued, and some have not been valued. While these are pointed out below, it would be impossible to estimate how their inclusion would have changed the above result.

Table 6.1. Value of ecosystem service flows and associated asset values in 2005 and 2011; values in 2010 R millions. Note that the table shows both the global carbon values as well as national carbon values and the respective total flows and asset values associated with each.

		2005		2011	
Class	**Ecosystem service**	**Annual flow R millions**	**Asset value R millions**	**Annual flow R millions**	**Asset value R millions**
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 (global value)	29 922.56	484 745.42	34 579.34	560 185.33
	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**
Value of flows and asset values in 2005 and 2011 when using national carbon values					
Regulating	Carbon storage (national)	236.39	3 829.49	273.18	4 425.46
Total		**17 572.38**	**256 391.56**	**18 172.74**	**271 303.59**

In the case of provisioning services, the net present value took sustainability of use into account. Unsustainable harvesting of wild resources was incorporated into the calculation of asset values where the stocks were eroded over time if harvesting was identified as being unsustainable. While this was done for woody and non-woody raw materials, it was not possible to incorporate for wild foods and medicines and animal resources due to inadequate data on stocks and/or productivity, nor for reared animal production or cultivation systems. The asset value contributions of the latter services will thus be overestimated in this study, and will need to be refined in future studies.

6.4 Sensitivity to discounting and time horizon

The values presented above are sensitive to both discount rate and time frame of discounting. Asset values were calculated as the net present value (NPV) over 25 years, using a social discount rate of 3.66%. This embodies assumptions on the future flow of ecosystem services, the discount rate, and the economic lifespan of ecosystem assets. A longer time horizon increases the value of any service which is assumed to be used at the same rate into perpetuity, especially at relatively low discount rates, as is the case with the social discount rate used in this study. For example, the asset values would be about 41% higher if a 50-year time horizon was used, or 64% higher if a 100-year time horizon was used, for all else equal. This effect is very much reduced if the rate of use or value at the time of assessment is unsustainable, since the value is reduced or potentially zero in the latter years. Thus, a longer time horizon highlights the cost of unsustainable practices relative to a sustainable scenario, but may provide a skewed policy message if sustainability is not taken into account. The conservative time horizon used in this study could be extended as methods evolve to improve the certainty of estimates and projections. There is a wide range of opinions on these choices in the literature, and at the time of this study, there was little formal guidance on the choice of these parameters for use in the SEEA. Going forward it would be useful to employ a standardised approach.

6.5 Attributing value to ecosystem types

The values listed above can be broadly allocated to cultivated land, natural vegetation (including within urban areas) and landscaped urban parks. Natural land held the highest aggregate value, followed by cultivated land and urban parks (Figure 6.1). When expressed in terms of average value per ha, urban parks are by far the most valuable, because of the high density of people and properties in urban areas in relation to the small area of parks, and hence the significant effect of parks on property value. In Durban, some 76% of the premium associated with public green open space areas was from parks, with the balance being from natural areas (Turpie *et al.* 2017b). Natural areas (in good or poor condition) make up about two thirds of the landscape in KwaZulu-Natal, and thus a relatively small average value per ha is expected.

In the case of cultivated areas, the ecosystem service was not broken down by crop type, since the service is input to crop production. A breakdown was presented by cultivated land cover class in section 4.3, but using such a table in the accounts could risk leading to confusion about what the service is. Furthermore, it is not in an ideal format, since there is a mismatch between classification of crop types in the land cover and in the agricultural statistics.

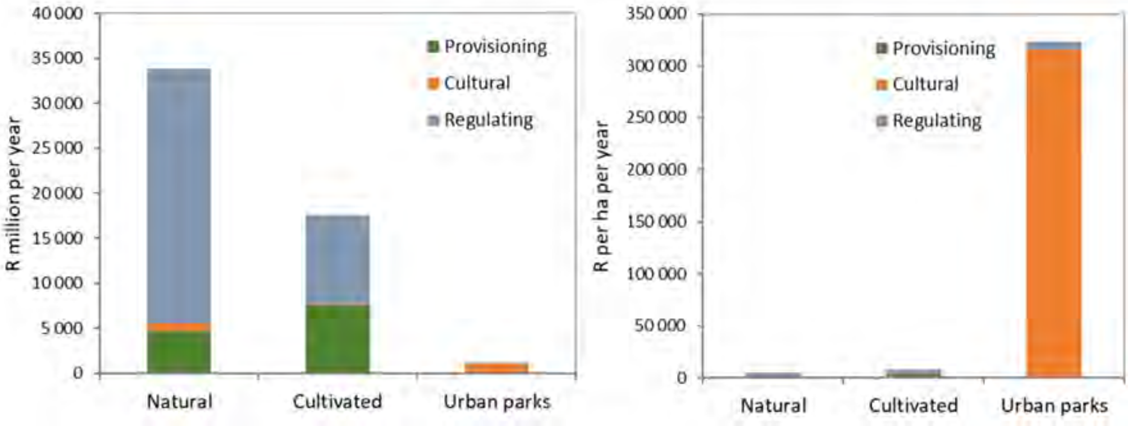

Figure 6.1. The total value of annual ecosystem service flows by broad category of service in 2011, within three main types of land cover (R millions, 2010 prices). Note that these estimates are preliminary, since not all services are covered, and the certainty of estimates varies among services.

At the level of broad ecosystem types (with natural ecosystem types broken down by biome), more than three quarters of the value of ecosystem services included in the study was produced by three ecosystem types (Figure 6.2), namely cultivated land (34.3%), grassland (34.1%), and savanna (22.7%).

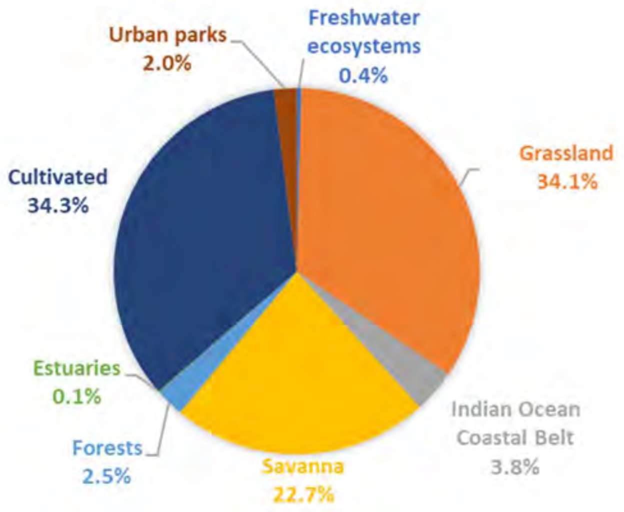

Figure 6.2. Percentage share of total ecosystem service value per broad ecosystem type in 2011

Figure 6.3 shows the percentage share of ecosystem types in the total estimated value of ecosystem services in 2011. Just under two thirds of the provisioning services value was produced by cultivated land (62%). Most of the value of regulating services was produced in the grassland biome (41%), savanna biome (27%) and cultivated land (26%). The Indian Ocean Coastal Belt biome accounted for 4% which was mainly due to the importance of forest and dense savanna vegetation in this biome for carbon storage and pollination services. Landscaped urban parks produced 48% of the value of cultural ecosystem services. Grassland and savanna 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.

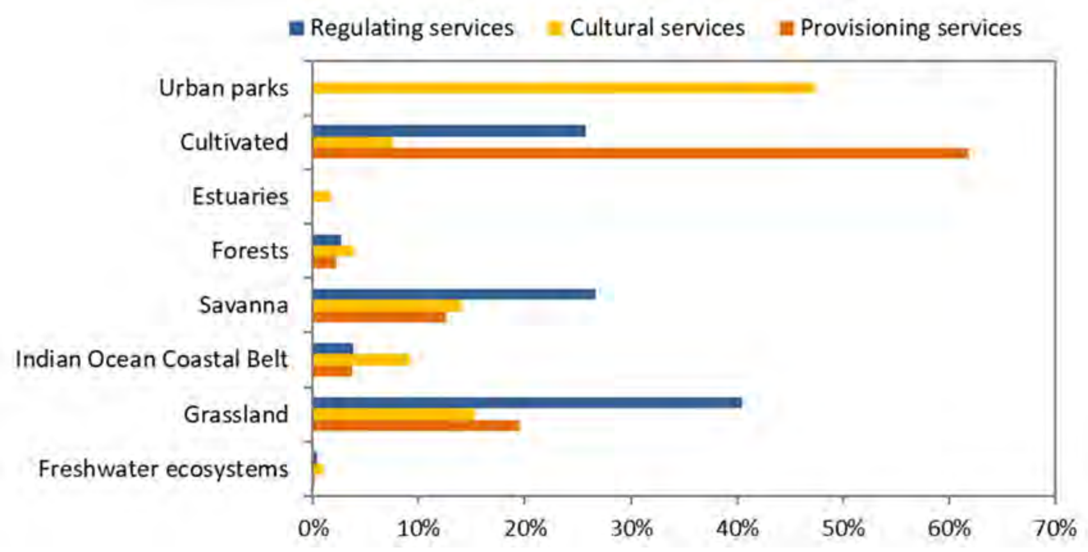

Figure 6.3. Percentage share of ecosystem types (with natural ecosystem types being delineated in terms of the South African biomes map) in the total value of provisioning, cultural and regulating services, respectively, in 2011.

In this study, which was carried out before there was any consensus in the SEEA on the delineation of ecosystems, we used the South African biomes to summarise our estimated values for natural ecosystems. Another option could have been to summarise the data by land cover type and other up-to-date ecosystem data. It should be noted that while the biomes align with the land cover classes to some extent, they are far from perfectly aligned. This is partly because some areas have been degraded to the extent that their structure has changed, and partly because the biomes are broadly delineated and incorporate smaller areas of ecosystem types that would not typically be considered typical. Thus, our study may report some forest ecosystem services being delivered from the grassland biome, for example.

It should be noted that biomes are delineated on the basis of the vegetation map of South Africa. The vegetation types have been mapped in terms of their historical distribution, which means that determining their extent is defined as how much of the historical distribution remains under natural or semi-natural land cover. In the literature, ecosystems are typically classified in terms of current (rather than historical) characteristics, and therefore in natural capital accounting efforts to date it is common to see ecosystems defined on the basis of land cover. For example, in the European Union, ecosystems have been delineated using land cover data, with classes such as 'urban' and 'cultivated' also treated as ecosystems (urban ecosystems, and agricultural ecosystems; EEA 2019). It is the authors' view that accounting for the remaining extent of vegetation types (and biomes) should be considered as an element of biodiversity accounting, which should eventually be expanded to incorporate floral and faunal species diversity and populations. Irrespective of how ecosystem extent accounts are compiled, it makes more sense to estimate ecosystem service flows on the basis of satellite-derived land cover data or more detailed delineation of ecosystems wherever possible, since these would be more accurate in estimating the characteristics of ecosystems and their changes over time. Thus, future work on the ecosystem services accounts should explore more meaningful ways of summarising the effects of changing landscape characteristics on ecosystem services.

6.6 Trends and relative effects of ecosystem extent vs capacity and demand

The value of provisioning and cultural services both increased from 2005 to 2011 (Table 6.1). The increase in provisioning service value was the result of increases in agricultural output. The increase in the cultural value of ecosystems was the result of growth in the property sector as well as increases in tourism value over the six-year period. The latter was not due to changes in ecosystems but reflects growth in the sectors, as recorded in the national accounts.

In contrast to provisioning and cultural services, and excluding the carbon storage value, the value of regulating services decreased by 5.3% from 2005 to 2011. This was largely attributed to the loss of natural vegetation due to land use changes (mainly expanding human settlements), and the degradation of remaining natural areas which is driven by poor land management activities such as overgrazing and the spread of alien invasive plants.

The overall changes are summarised by major ecosystem type/biome in Table 5.9 and graphically in Figure 6.4 below. Losses of value have occurred in all natural biomes due to reductions in the overall extent of the natural area of these biomes, particularly the Indian Ocean Coastal Belt, much of which has been lost to coastal development. The gains for other ecosystem types are larger, and likely dominated by growth in tourism demand and increases in carbon retention values. The value of cultivated areas had a significant net increase, largely due to the increase in extent of cultivated areas.

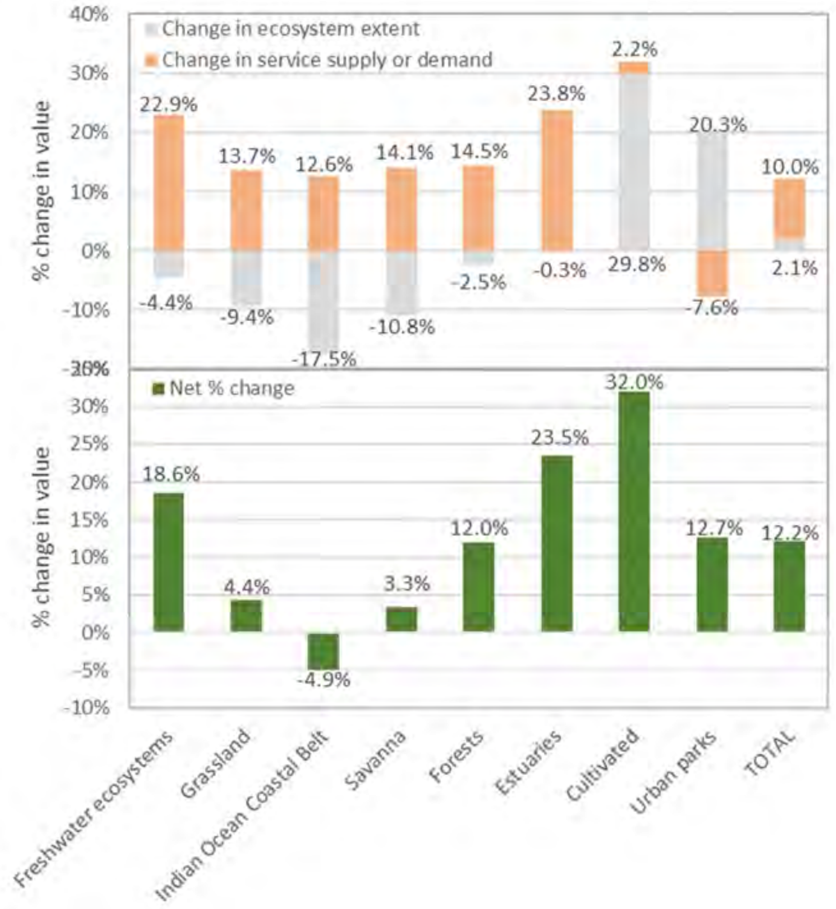

Figure 6.4. (a) Percentage change in the value of each major ecosystem type due to change in ecosystem extent versus due to change in capacity to supply ecosystem services or change in demand and (b) the overall net change in value. Based on data in Table 5.9

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Key findings and their implications

The results presented in this report are the first EEA experimental (or preliminary) outcomes for the province of KwaZulu-Natal in South Africa. They should therefore be interpreted with due caution and will need to be improved on in the future as data improve, valuation techniques develop and understanding and direction in the compilation in ecosystem accounts progresses.

This study has shown that it is feasible to compile monetary accounts for ecosystems on a large scale using various statistical data sources and valuation methods. It provides the framework for extending to a national scale in South Africa. However, important challenges remain in achieving this, especially with regards to refinement and standardisation of land cover and ecosystem condition data, the classification of ecosystem types used for summarising ecosystem service values, and in the refinement of assumptions, modelling techniques and valuation methods. Extending the analysis to include the gaps in ecosystem service types and in geographic coverage of certain services is also an important challenge that needs to be addressed going forward.

Although the values are preliminary and incomplete, this study demonstrates that the ecosystem supply and use accounts can be used to answer a number of key policy questions, such as how much ecosystems contribute to economic outputs, who the main users of ecosystem services are which ecosystems are most valuable, and where losses have been greatest.

The combined value of the annual flow of the ecosystem services valued was **R52.5 billion in 2011 which was equivalent to 12% of the provincial GDP.** The bulk of the annual value of ecosystem services was attributed to the global value of carbon storage (66%), which is mostly an exported service in the form of cost savings to the rest of the world. However, it is apparent that the values of many of the services have decreased over time, particularly the grassland and savanna biomes which dominate the landscape. The annual value of harvested wild resources decreased by over R500 million in these two biomes and ecosystem contribution to livestock production by just over R200 million. Hydrological services decreased by just under R200 million over this time. Nature-based tourism, property and carbon storage were the only values of natural habitats that increased from 2005 to 2011. While total ecosystem carbon declined by 40.1 Tg C from 2005 to 2011, the value of carbon retained in the environment increased in real value over this time. Cultivated land, on the other hand, increased in extent and aggregate value over the six-year period.

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), followed by the agriculture, forestry and fisheries sector (19%) and households (11%). Approximately 2% of the total value flows to the trade, catering and accommodation sector, which is also an important source of employment in the province. Reductions in ecosystem stocks and the associated loss in ecosystem services will have the highest impact for these economic users. This is an important result to consider given that a significant number of households across KwaZulu-Natal are reliant on natural ecosystems for maintaining livelihoods and food security.

The losses in the value of ecosystem services from natural ecosystems were 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, human settlements and other activities such as mining. While these trends are generally well-known, this study has shown that their aggregate economic impact can be substantial. Furthermore, these losses were not fully portrayed in this study, since the sustainability of use of provisioning services was only accounted for in the case of the informal harvesting of natural resources. Future studies would also need to consider the sustainability of reared animal and crop production. Habitat degradation and loss, which largely comes about in the poorly-managed pursuit of provisioning services, has had a measurable negative effect on the supply of every type of regulating service, including carbon storage which is of global concern. 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.

In contrast to the above, the tourism value of natural ecosystems increased by R189 million between 2005 and 2011 with increases in value across all of the biomes. This was, however, largely as a result of a national upswing in tourism, although local investment in nature-based tourism may also have contributed. About 40% of the total nature-based tourism value in 2011 was within the uMkhanyakude District Municipality in northern KwaZulu-Natal. Two of the province's three largest and most important protected areas, Hluhluwe-iMfolozi Park and iSimangaliso Wetland Park, are located in this district municipality. Indeed, most tourism value outside of urban areas was associated with protected areas, and some was in private game reserves. Only 15% of the total tourism value was within communal land areas. This is a missed opportunity that could be addressed through intensification of community-based natural resource management efforts as exemplified by Namibia's CBNRM programme. Currently nature-based tourism is almost non-existent in KwaZulu-Natal's communal areas due to a combination of land degradation, depletion of wildlife and lack of investment. Tourism development in these areas could potentially help to address both the loss of ecosystem services and the high levels of poverty in these areas.

Finally, we also note that, while there are theoretical differences in the values used for accounting (measuring changes in production) and economic analysis (measuring changes in societal welfare), there is a substantial overlap in the approaches used, and in general, the work undertaken in compiling ecosystem service accounts is likely to be very useful in feeding into economic analysis. The latter will require augmentation, however, particularly for the valuation of cultural services.

7.2 Recommendations for furthering natural capital accounting

This study has estimated the value of a range of ecosystem services, covering most broad types. While the scope is not yet comprehensive due to both data and time constraints, it provides a solid platform from which to progress. This study does not include all ecosystem services, and some are only partially valued, and the geographic coverage is incomplete. The study also does not extend in the marine environment and does not include some important estuarine services. Some of the methods used in this study are innovative and require further refinement and validation. In many cases, the data used in the study have not been ideal in terms of quality, time or spatial location. In some cases, time consuming work is needed to refine the data and assumptions in models. In addition, reliable spatial information to produce or validate estimates of ecosystem condition and sustainability of harvesting, grazing and cultivation practices is largely lacking.

Setting up monetary ecosystem accounts therefore requires a considerable effort in collating appropriate monitoring data as well as in compiling reliable modelling frameworks for the estimation of values. At least initially, the accounts require at least 15-20 person months over a 2- to 3-year period. This requires sufficient expertise given the highly technical nature of the work in a field that is rapidly evolving. An independent technical working group is necessary until the processes in developing monetary ecosystem accounts are more streamlined and automated. It is also useful to have rigorous peer review and input in the *initial* stages of producing the accounts to facilitate less revision at a later stage once the majority of the more time-consuming technical work has been completed. Although access to most required datasets in South Africa is low-cost or free and generally easily accessible, some were less so. Government agencies need clear specifications and mandates for data collection and distribution and these need to be freely accessible to entities working on accounts.

Further discussion is also needed to refine the way in which the accounting tables are compiled and summarised in order to be useful for decision and policy makers. Finally, there will be some considerations in terms of land cover data should this provincial-scale pilot be scaled up to a national-scale effort. The following recommendations elaborate on some of these points, in the light of scaling up to national level:

7.2.1 Produce an enhanced land cover data series

1. Accounts should be compiled using an official, **national** land cover series that employs **consistent methods of categorising land cover** (allowing for technological improvement). This national land cover product should be applicable at a sub-regional level and thus should be produced in consultation with provinces to ensure all relevant land cover classes are included;

2. The **land cover classes should be detailed** in urban, natural and cultivated areas, as in the recently-released 2018 National Land Cover, but should be improved in terms of their classification of cultivated areas;

3. The land cover should incorporate more accurate detail on **rivers and wetlands** from continuously-updated national spatial datasets already in existence in South Africa, and should distinguish natural waterbodies from reservoirs;

4. The land cover should incorporate **additional measures of condition or condition-related characteristics** relevant to ecosystem service supply where these are not discernible in terms of structural features or NDVI derived from satellite data, which might have to be provided from on-the-ground monitoring;

5. Ideally, the national land cover maps should incorporate **a measure of ecosystem health** for the remaining natural areas that is expressed relative to their reference condition (before significant human influence), as this would be required in any case for the ecosystem extent and condition accounts and would be useful in summarising and analysing changes in value; and

6. A **five-year interval** for the land cover series is likely to be sufficient, and better quality would be preferable to greater frequency.

7.2.2 Produce better agricultural and resource use statistics at a high spatial resolution

7. Develop a consistent and comprehensive set of data on commercial/larger scale agricultural and natural resource production, including land and livestock holding and other relevant data, at a high level of spatial resolution (local municipality), based on **an agricultural census** carried out at 5 year intervals, preferably in sync with the household census. Add a question on use of managed hives for pollination, and on the informal harvesting of wild resources, e.g. by staff.

8. Develop a consistent and comprehensive set of data on **small-scale subsistence agricultural and natural resource production**, including production areas and livestock holdings, at a high level of spatial resolution (local municipality), linked to the national census, and preferably at 5 year intervals. Include detail on a range of natural resources.

9. Augment census-based data on crop and livestock production with **additional estimates of crop areas by type and of extensively-farmed livestock** using appropriate technology (see the CapeFarmMapper data for example). The timing of data collection should be in sync with the censuses (ideally at 5-yearly intervals).

10. Develop a system to collect consistent statistics on legal and illegal natural resource **harvesting from state-owned protected areas**, using a classification system compatible with the above.

7.2.3 Produce nationally-consistent, fine scale tourism statistics

11. Collect **consistent tourism statistics at a local level**, to assist the downscaling of assumptions of tourism purpose. An example is the information collected at regional

tourist offices in the Western Cape (for each tourism region), although the questions are not completely consistent across offices. This needs to be designed and co-ordinated at national scale.

12. **Visitor statistics for all major paying natural attractions**, particularly protected areas, should be collected on a continuous basis and in a consistent manner, collated by managing agencies and made readily available for use. Again, this should be centrally co-ordinated.

7.2.4 Produce centrally collated statistics from water supply managers

13. A system needs to be devised for the **collation of relevant statistics from water treatment plants** in order to be able to detect the effects of environmental changes.
14. Data on the **sedimentation of reservoirs** and associated management interventions need to be collated in a consistent manner and centrally managed.

7.2.5 Undertake further research and modelling to improve methods and estimates and fill gaps

15. Improve the SWAT modelling of seasonal flows, nutrients and sediments, for example by incorporating improved land cover data and associated coefficients, incorporating better data on reservoirs and water management, and undertaking further calibration;
16. **Extend the SWAT modelling** to estimate the services associated with land cover classes other than natural land cover, especially cultivated areas;
17. Estimate the **flow regulation benefits for irrigation farmers**;
18. Extend the PC-SWMM model and/or develop new models to estimate and value **flood attenuation services** to the rest of the catchment area of eThekwini municipality as well as those of other built up areas that are flood prone;
19. Complete the estimation of **critical habitat value**, including nursery value of estuaries;
20. Extend the study to include **marine ecosystem services**;
21. Undertake **empirical studies** on a range of ecosystem services to validate or extend estimates, e.g. water quality amelioration, sediment retention and crop pollination services, using appropriate data and state of the art econometrics;
22. Hold a **think tank on methods for estimating hydrological services**. Novel methods were used in this study to estimate the value of seasonal flow regulation. These methods provide a far more conservative estimate of value than basing values on water quantity, but we feel they provide a more realistic valuation of the service. Nevertheless, this approach should be subject to further peer review and comparison

with other approaches in order to settle on the most suitable method for estimating this service.

7.2.6 Maintain a flexible approach

23. Guidelines should be in place, but **guidelines should not restrict methodological advances**. Allow for data and methodological improvements and undertake retrospective corrections where these significantly alter results.

7.2.7 Explore useful ways to summarise the findings

24. Future work on the ecosystem services accounts should explore more meaningful ways of summarising the effects of changing landscape characteristics on ecosystem services. The results in this study have been summarised by biome. Because biomes are delineated at a very broad level and can differ substantially from the structural vegetation groupings in the land cover data on which the assessment was based, some of the summaries produce seemingly odd results, such as pollination services within the freshwater biome. Future accounts should provide summary estimates at a higher level of resolution, such as for each type of wetland, or each type of forest, using an international system of classification to be recommended for the SEEA. Additionally, a higher level of resolution will provide improved spatial allocation of values. It would also be useful to explore potential policy messages that emerge from the monetary values associated with particular ecosystem services.

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A1 Appendix 1. Abbreviated summary of CICES 5.1

Table A1.1. Abbreviated summary of the CICES 5.1 classification of ecosystem services.

	Division	Group	Class
Provisioning - biotic	Biomass	Cultivated terrestrial plants, algae or fungi	for nutritional purposes
			for materials
			as a source of energy
		Cultivated aquatic plants	for nutritional purposes
			for materials
			for energy
		Reared animals	for nutritional purposes
			for materials
			as a source of energy
		Reared aquatic animals	for nutritional purposes
			for materials
			as a source of energy
		Wild plants, algae or fungi	for nutritional purposes
			for materials
			as a source of energy
		Wild animals	for nutritional purposes
			for materials
			as a source of energy
	Genetic material	Genetic material from plants, algae or fungi	collected for maintaining or establishing a population
			used to breed new strains or varieties
			used for the design and construction of new biological entities
		Genetic material from animals	collected for maintaining or establishing a population
			used to breed new strains or varieties
			used for the design and construction of new biological entities
Provisioning - abiotic	Water	Surface water	used for drinking
			used for non-drinking purposes
			used as an energy source (fresh/seawater)
		Ground water	used for drinking
			used for non-drinking purposes
			used as an energy source
	Minerals	Not detailed here	
	Energy	Not detailed here	

	Division	Group	Class
Biotic regulation & maintenance	Mediation	Mediation of anthropogenic wastes	Bio-remediation by living organisms
			Filtration/sequestration/storage/accumulation by living organisms
		Mediation of anthropogenic nuisances	Smell reduction
			Noise attenuation
			Visual screening
	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates
			Buffering and attenuation of mass movement
			Flow regulation (including flood control, and coastal protection)
			Wind protection
			Fire protection
		Lifecycle maintenance, habitat and gene pool protection	Pollination (or gamete dispersal in a marine context)
			Seed dispersal
			Maintaining nursery populations and habitats (including gene pool protection)
		Pest and disease control	Pest control (including invasive species)
			Disease control
		Regulation of soil quality	Weathering processes and their effect on soil quality
			Decomposition and fixing processes and their effect on soil quality
		Water conditions	Regulation of the chemical condition of freshwaters by living processes

			Regulation of the chemical condition of salt waters by living processes
		Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans
			Regulation of temperature and humidity, including ventilation and transpiration
R&M - abiotic	Mediation, dilution, regulation	Not detailed here	
Cultural - biotic	**Direct interactions with living systems**	**Physical and experiential interactions with natural environment**	**Characteristics that enable activities promoting health, recuperation or enjoyment through active or immersive interactions; nature based recreation**
			through passive or observational interactions; eco-tourism
		Intellectual and representative interactions with natural environment	Characteristics that enable scientific investigation or traditional knowledge
			Characteristics of living systems that enable education and training
			Characteristics of living systems that are resonant in terms of culture or heritage
			Characteristics of living systems that enable aesthetic experiences
	Indirect interactions	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning
			Elements of living systems that have sacred or religious meaning
			Elements of living systems used for entertainment or representation
		Other	Characteristics or features of living systems that have non-use value
Cultural - abiotic	Natural, abiotic characteristics of nature	Not detailed here	

A2 Appendix 2. Assumptions used to estimate household demand for wild resources

Table A2.1. Approach and assumptions used for each wild resource group to estimate total demand per Census sub-place.

Resource group	**Approach and assumptions used in calculations**
Fuelwood	Average household harvest of 3000 kg per year multiplied by the number of census households using wood for cooking and heating. Total demand per sub-place (kg/y) divided by an average wood density of 0.855 g/cm^3 (from FAO) to get total demand in m^3/y.
Poles and withies	Assume 66% of census households residing in traditional dwellings participate in harvesting poles and withies multiplied by average household harvest of 200 kg per year. Total demand per sub-place (kg/y) divided by an average wood density of 0.855 g/cm^3 (from FAO) to get total demand in m^3/y.
Timber and wood	Assume 4% of census households residing in traditional dwellings participate in harvesting timber poles and wood for crafts multiplied by an average household harvest of 900 kg per year. Total demand per sub-place (kg/y) divided by an average wood density of 0.855 g/cm^3 (from FAO) to get total demand in m^3/y.
Thatching grasses	Assume 33% of census households residing in traditional dwellings participate in harvesting grasses for construction and crafts multiplied by an average household harvest of 76 bundles per year. Total bundles per year multiplied by 4.9kg per bundle to get total grass demanded (kg/y).
Reeds and sedges	Linear model based on Turpie *et al.* (2010a) used to calculate the number of reed and sedge bundles demanded per household per year. The overall average amounts harvested per household were correlated with the percentage of people living in traditional houses as follows: *Reeds (bundles/hh) = 4.0452*%TradDwellings - 0.7885* The output from the model was multiplied by the number of census households to get total bundles per sub-place per year. This was then multiplied by a weight of 7kg per bundle to get total reeds demanded (kg/y).
Palm leaves	Assume 1.2% of households residing in traditional dwellings participate in harvesting palm leaves multiplied by an average household harvest of 660 leaves per year (leaves/y). Multiplied by 0.31kg to total weight of palm leaves demanded (kg/y).
Wild fruits	Linear model based on Turpie *et al.* (2010a) used to calculate kilograms of wild fruit demanded per household. The overall average amounts harvested per household were correlated with the percentage of people living in traditional houses as follows: *Wild fruits (kg/hh) = 53.128*%TradDwellings - 3.0889* The output from the model was multiplied by the number of census households to get total kilograms of wild fruit demanded per sub-place per year.
Wild vegetables	Assume 75% of census households residing in traditional dwellings participate in harvesting wild vegetables for nutritional purposes, multiplied by an average household harvest of 20kg per household per year to get total wild vegetables demanded (kg/y).
Wild medicines	Assume 26% of census households residing in traditional dwellings participate in harvesting medicines multiplied by an average household harvest of 32kg per household per year to get total wild medicines demanded (kg/y).

Wild animals	Linear model based on Turpie *et al.* (2010a) used to calculate kilograms of wild meat demanded per household. The average amount of wild meat harvested per household was positively correlated with the proportion of the population living in traditional dwellings as follows: *Wild meat (kg/hh) = 69.094*%TradDwellings) – 12.841* The output from the model was multiplied by the number of census households to get total kilograms of wild meat demanded per sub-place per year.
Wild birds	Linear model based on Turpie *et al.* (2010a) used to calculate kilograms of wild birds demanded per household. The average amount of wild birds harvested per household was positively correlated with the proportion of the population living in traditional dwellings as follows: *Birds (per hh) = 6.144*%TradDwellings – 0.878* The output from the model was multiplied by the number of census households and by an average bird weight of 0.9kg to get total kilograms of birds demanded per sub-place per year.
Inland fish	Linear model based on Turpie *et al.* (2010a) used to calculate kilograms of inland fish demanded per household. The average amount of fish harvested per household was positively correlated with the proportion of the population living in traditional dwellings as follows: Fish catch (kg/hh) = 14.186*%TradDwellings - 2.0439 The output from the model was multiplied by the number of households to get total kg of fish demanded per sub-place per year.

A3 Appendix 3. Assumptions on the stocks of natural resources

A3.1 Fuelwood, poles and timber

Woody volumes for each vegetation class within KwaZulu-Natal were calculated by using basal area and canopy height data collected by Glenday (2007). Glenday (2007) collected data on forest (coastal, scarp, riverine, swamp, transitional), thicket (dry valley thicket, broadleaved woodland, transitional) and woodland (closed, open) vegetation. From this data the cubic volume of wood for standing vegetation was then estimated (m^3/ha) for each vegetation class. Volume is generally estimated from dimensional variables such as diameter and height in the form of linear equations that take into account local vegetation form. However, in the absence of localised equations, cubic volume of wood for standing vegetation may be estimated using the following equation (Magnussen & Reed 2004):

$$Volume\ (m^3/ha)\ =\ basal\ area\ (m^2/ha) \times canopy\ height\ (m)/3$$

While this equation may somewhat overestimate or underestimate the volume of certain woody vegetation with different forms, it nevertheless provides a first approximation for determining stand volumes in KwaZulu-Natal.

The amount of standing woody volume that was physically utilisable was assumed to be 90% for fuelwood, 15% for poles and withies, and 2% for timber (Barnes *et al.* 2005), allowing for a component of the standing woody volume to be assumed unsuitable for harvesting. Multiplying the woody volume estimates by the percentage suitability for harvesting provided estimated stocks (m^3/ha) for each land cover class. It was assumed that timber poles and wood was harvested only from indigenous forests and woodland and wooded grasslands where tree-based communities dominate and tree stumps/branches are large enough for the making of wooden crafts and curios.

Table A3.1. Stocks per unit area (m3/ha) for fuelwood, poles and withies and timber. Source: estimated this study using data from Glenday (2007) and Barnes et al. (2005).

Land cover class	Fuelwood m^3/ha	Poles & withies m^3/ha	Timber m^3/ha
Mangrove wetland	128.3	21.4	2.9
Forest (indigenous)	128.3	21.4	2.9
Dense thicket and bush	41.3	6.9	0.0
Medium bush	27.1	4.5	0.0
Woodland and wooded grassland	3.6	0.6	0.1
Bush clumps/grassland	13.0	2.2	0.0
Degraded forest	22.8	3.8	0.5
Degraded bushland	8.6	1.4	0.0

A3.2 Thatching grass, reeds, sedges and palm leaves

Estimates of standing stocks (kg/ha) were collated from the literature. For grasses estimates of stocks were taken from two studies that had been conducted in the grasslands of the Drakensberg and in the Eastern Cape. The average of these two studies was used. For reeds & sedges the average of the reported standing crop from five studies was used. These were based on studies conducted in northern KwaZulu-Natal (Maputaland and Hluhluwe) and other wetland areas in southern Africa. For palm leaves the standing crop was given as the number of leaves produced per ha as opposed to kg/ha. This was converted into a kg/ha value based on the assumption that each leaf provides 310g of material. This was based on a detailed study conducted by McKean (2003) in St Lucia. Thatching grass was assumed to be harvested from grasslands, woodland and wooded grassland and bush clump grassland where an open grass layer is present and dominant. In degraded grasslands stock was set to 10% of healthy grassland areas. Reeds and sedges were assumed to be harvested from natural wetland and floodplain areas and palm leaves were assumed to be harvested only from savanna/woodland areas that fringe wetlands and floodplains (mostly in northern KwaZulu-Natal). The distribution map for the Lala Palm (*Hyphaene natalensis*) from Moll (1972) was used to isolate these areas.

Table A3.2. Stocks per unit area (kg/ha) for thatching grass, reeds, sedges and palm leaves. Source: estimated this study based on data collated from the literature.

Land cover class	Thatching grass kg/ha	Reeds & sedges kg/ha	Palm leaves kg/ha
Wetland		58 600.0	
Woodland and wooded grassland	12.9		268.0*
Bush clumps/grassland	25.7		
Grassland	64.3		
Degraded grassland	6.4		
Forest glade	64.3		
Alpine grass – heath	6.4		

*within floodplain areas only

A3.3 Wild plant foods and medicines

Estimates of stocks of wild plant foods and medicines were difficult to find. As such we relied on information pertaining to production yields (kg/ha/y) instead. We collated information from the literature and where more than one estimate was available the average of these estimates was used. Where estimates were not available for KwaZulu-Natal, studies from other locations in South Africa with similar characteristics were used instead (e.g. from woodlands in Limpopo or grasslands in the Eastern Cape). Given the lack of data on stocks of wild plant foods and medicines, we assumed for this group of resources that actual use was undertaken sustainably.

Wild plant foods and medicines can be harvested from a range of habitats. However, indigenous forests are by far the most productive. Wild foods and medicines are also harvested from thickets and bushland areas, woodlands, grasslands and wetlands. Most of the information collected from the literature related to the harvesting of wild plant foods from woodland areas (or savannas) and wild medicines from woodlands and grasslands. These estimates were adjusted for other vegetation classes based on the linear relationship between habitat type and percentage tree cover and the assumption that standing stocks (kg/ha) of these resources increase with woody cover (more diversity in plant parts, e.g. bark, roots, berries, leaves, bulbs, etc). Wetlands were assumed to have the same productivity as woodland and wooded grassland areas. In degraded forests, bushlands and grasslands production was set to 10% of what was assumed in a healthy area with the same vegetation. Wild plant foods and wild medicines were treated as one provisioning service and values were combined per land cover class for geospatial analyses.

Table A3.3. Production yields (kg/ha/y) for wild plant foods and stocks per unit area (kg/ha) for wild medicines. Source: estimated this study based on data collated from the literature.

Land cover class	Wild plant foods (kg/ha/y)	Wild medicines (kg/ha/y)
Forest (indigenous)	302.8	126.3
Dense thicket and bush	211.9	88.4
Medium bush	166.5	69.4
Woodland and wooded grassland	121.1	50.5
Bush clumps/grassland	60.6	25.3
Grassland	30.3	12.6
Forest Glade	30.3	12.6
Wetland	121.1	50.5
Degraded forest	30.3	12.6
Degraded bushland	21.2	8.8
Degraded grassland	3.0	1.3

A3.4 Wild animal resources

Estimates of wild animal biomass (kg/ha) were collated from the literature for different vegetation classes. A total of ten studies were used. These studies were conducted in a range of habitats across southern Africa and the average of these was taken for small mammals and birds. Rural communities in South Africa make regular use of wildlife, in particular small-bodied rodents, birds and ungulates. Even in degraded woodland and grassland regions there are indications that rural communities harvest a variety of smaller wild animals and birds (Kaschula & Shackleton 2009). The literature provided estimates of biomass density (kg/ha) for a number of wild animals (e.g. rodents, shrews, hares, monkeys, small ungulates, bushpig, guineafowl) in a variety of habitats. In degraded forests, bushlands and grasslands production was set to 10% of what was assumed in a healthy area with the same vegetation.

For inland fishery resources (i.e. excluding coastal resources) estimates of average fish production (kg/ha) were obtained from the literature. The average of these estimates was used for natural water bodies (rivers, floodplains) and wetlands. In northern KwaZulu-Natal a number of detailed studies have been undertaken, for example, in Kosi Bay, St Lucia and the Pongola Floodplain. If estimates of fish production were available for these sites they were used instead of the average value. The large estuarine system of St Lucia was closed over the study period and therefore fish production was assumed to be zero.

Table A3.4. Stocks per unit area (kg/ha) for bushmeat and fish. Source: estimated this study based on data collated from the literature

Land cover class	Bushmeat (kg/ha)	Fish (kg/ha)
Water (natural)		3.0
Wetland	0.6	31.0
Estuaries		11.0
Forest (indigenous)	3.7	
Dense thicket and bush	1.4	
Medium bush	1.4	
Woodland and wooded grassland	2.7	
Bush clumps/grassland	2.5	
Grassland	1.6	
Forest Glade	1.6	
Degraded forest	0.4	
Degraded bushland	0.1	
Degraded grassland	0.2	

A4 Appendix 4. Detailed data sources for livestock

A4.1 Commercial farmland

- **Stats SA 2002 Census of Commercial Agriculture** (main source of information):
    - Aggregated at Magisterial District (43 districts in KwaZulu-Natal)
    - Financial data – gross income, expenditure
    - Numbers of cattle (dairy and beef), goats and sheep kept on farm in 2002
    - Numbers of cattle (dairy and beef), goats and sheep sold in 2002
    - Amount of livestock products (milk, cream, wool) produced
    - Gross income from sales of livestock and livestock products, average prices

- **Stats SA 2007 Census of Commercial Agriculture** (summarised this information but did not use it. Relied on Census 2002 data and DAFF livestock estimates):
    - Aggregated at Magisterial District (43 districts in KwaZulu-Natal)
    - Number of cattle and sheep kept per district in 2007
    - Numbers of cattle and sheep sold per district in 2007 and prices
    - Area of grazing land per district

- **Stats SA 2011 census data** (Agricultural Households) for KwaZulu-Natal province (data collated but not used as there was not enough detail):
    - Aggregated at the ward level (828 wards)
    - Number of households keeping livestock (cattle, goats, sheep)
    - Livestock numbers were collected as part of the survey by asking respondents whether they kept 1-10, 11-100 or 100+ cattle/sheep/goats etc. Summarised per ward as the number of households per farm area keeping 1-10, 11-100, 100+ cattle, goats, sheep etc.
    - Not very comprehensive, not disaggregated into dairy vs beef, no information on livestock products, limited financial data.

- **Meissner *et al.* (2013)** estimated the total number of cattle, goats, sheep and game per province for commercial and communal sectors for the whole of SA for 2010.
    - Estimates were based on statistics provided by the 2010 Abstract of Agricultural Statistics (DAFF, 2010a), DAFF Directorate of Agricultural Statistics Newsletter (DAFF, 2010b) and farmer support bodies (Milk SA, 2011; Mohair SA, 2011; NWGA, 2011a; RPO provincial offices, 2011; SAFA, 2011; SAGRA, 2011; SAPA, 2011; SA Pork, 2011), which were cross-checked with other references, auction sales and slaughter data (Du Toit *et al.*, 2013a; b; c; d).
    - The Meissner *et al.* (2013) estimates for KwaZulu-Natal were used to determine the percentage split between communal and commercial livestock. This was then applied to the DAFF livestock statistics to get total commercial livestock numbers for each type of livestock group from 1996-2018. These estimates were used for triangulation.

- **DAFF livestock statistics** (https://www.daff.gov.za/daffweb3/Home/Crop-Estimates/Statistical-Information/Livestock)
    - Numbers of cattle, sheep and goats per province for each quarter from 1996-current.
    - Not disaggregated into communal and commercial. Used Meissner *et al.* (2013) estimates to disaggregate data to get commercial numbers in 2005 and 2011.

- **DAFF Abstract of Agricultural Statistics 2012** (not particularly useful as not disaggregated to the provincial level)
    - Not disaggregated to province. Reported at national level.
    - Cattle, sheep and goat numbers for 2005 and 2011 (these match those in the DAFF quarterly statistics)
    - Slaughter numbers and prices for 2005 and 2011.
    - Value of goods and services purchased (intermediate production)
    - Gross and net farm income and gross value added by the agricultural sector

- Ezemvelo KZN Wildlife Private Game Ranch GIS spatial layer
    - Location and size of the private game farms in KwaZulu-Natal.
    - Used to isolate the livestock farms

- **Data gaps:**
    - Regular estimates of livestock numbers at smaller resolution than province are limited. Financial data also limited.
    - Information pertaining to the number of farms and size of farms included in the agricultural census was not available.

A4.2 Communal areas

Detailed estimates of communal livestock production are limited. The Agricultural Census data collected in 2002 and 2007 does not include communal areas. The valuation therefore relied on information from a number of sources. The main data source was the Agricultural Households census data collected during the 2011 Census. This was then adjusted to 2005 using interpolations from 2001 Census to 2011 Census.

The following data were collated and used for estimated livestock production in communal areas in 2005 and 2011:

- **2011 Agricultural households census data** for KwaZulu-Natal province:
    - Data is aggregated at the ward level (this is the lowest level of resolution)
    - Separated into geotype – communal, urban or farm. Communal areas are areas owned by the government but managed under the juridication of a tribal authority and were used to define the communal livestock areas.
    - Number of households keeping livestock (cattle, goats, sheep)

  - Livestock numbers were collected by asking respondents whether they kept 1-10, 11-100 or 100+ cattle/sheep/goats.
  - Summarised per ward as the number of households in communal area keeping 1-10, 11-100, 100+ cattle, goats, and sheep.

- **Meissner *et al.* (2013**) estimated the total number of cattle, goats, sheep, pigs and game per province for commercial and communal sectors for the whole of SA for 2010.
  - Estimates were based on statistics provided by the 2010 Abstract of Agricultural Statistics (DAFF, 2010a), DAFF Directorate of Agricultural Statistics Newsletter (DAFF, 2010b) and farmer support bodies (Milk SA, 2011; Mohair SA, 2011; NWGA, 2011a; RPO provincial offices, 2011; SAFA, 2011; SAGRA, 2011; SAPA, 2011; SA Pork, 2011), which were cross-checked with other references, auction sales and slaughter data (Du Toit *et al.*, 2013a; b; c; d).
  - The Meissner *et al.* (2013) estimates for KwaZulu-Natal were used to **determine the percentage split between communal and commercial livestock**. This was then applied to the DAFF livestock statistics to get total communal livestock numbers for each type of livestock from 1996-2018.
  - These estimates were used for triangulation.

- **DAFF livestock statistics** (https://www.daff.gov.za/daffweb3/Home/Crop-Estimates/Statistical-Information/Livestock)
  - Numbers of cattle, sheep and goats per province for each quarter from 1996-current.
  - Not disaggregated to communal and commercial. Used Meissner *et al.* (2013) estimates to disaggregate data.

- **KwaZulu-Natal household survey data** collated from the literature. The following studies provided useful household livestock data for various communal areas in KwaZulu-Natal.

Source	Location	Data
Kunene & Fossey 2006	Enseleni District, Northern KwaZulu-Natal	Average number of stock per household, average production and % offtake.
Turpie *et al.* 2010a	Usutu-UMhlathuze Water Management Area, Northern KwaZulu-Natal	Average number of stock per household, % households keeping livestock, average production and % offtake, price per head.
Turpie *et al.* 2014	St Lucia, Northern KwaZulu-Natal	Average number of stock per household, % households keeping livestock, average production and % offtake, price per head.
Mahlobo 2016	Umvoti Municipality, KwaZulu-Natal (Greytown area)	Average number of stock per household, % households keeping different types of livestock
Nkosi 2017	uThungulu District Municipality, KwaZulu-Natal	Average number of stock per household, % households keeping different types of livestock

The following data were summarised from these studies and used in the analysis:

- Percentage households keeping cattle, sheep and goats;
- Average number of cattle, sheep and goats per livestock keeping household;
- Average annual production rate and percentage offtake of cattle, sheep and goats per livestock keeping households; and
- Average price per head of cattle, sheep and goats – adjusted to 2011 and 2005 Rands using CPI index.

- **Data gaps:**
    - There are no data available for 2005 or any prior year (to 2011) with regards to the number of communal households keeping livestock. The 2007 Agricultural Census collected information about commercial livestock only. The 2001 SA household Census did not collect information about agricultural activities at the household level.

    - Therefore, assumptions were made in order to estimate livestock numbers in 2005. Adjustment factors were calculated using the SA household Census data collected in 2001 and 2011. The rate of change for variables such as the number of traditional households were used as a proxy to determine the rate of change in livestock keeping households, with the assumption being that traditional households lead a subsistence lifestyle and partake in agricultural activities. See below for the detailed approach.

A5 Appendix 5. Modelling of hydrological services

A5.1 Introduction

In order to estimate flow regulation, sediment retention and water quality amelioration services in physical terms, hydrological models were set up for each of the basins in the study area using the Soil and Water Assessment Tool (SWAT) model (Arnold *et al.*, 1998; Arnold and Fohrer, 2005). SWAT was selected because of its capability of generating outputs for number of hydrologically-linked ecosystem services at a reasonable temporal and spatial resolution. The third-party software extension ArcSWAT was used to couple the ArcGIS software (developed by ESRI) and the SWAT model.

The ecosystem services being modelled were biotic services associated with vegetative cover in combination with its physico-chemical setting. Models were set up for the 2011 and 2005 land covers, and the various outputs linked to hydrological services were compared to the modelled outputs under a hypothetical bare ground scenario (as opposed to a next most likely land use/land cover scenario). The choice of the “baseline” condition against which to quantify ecosystem services is contentious, mainly due to its hypothetical nature. However, comparisons between years of different recorded land cover will be the main issue of interest in the longer term.

A5.2 Overview of the SWAT model

SWAT is a physically-based, semi-distributed hydrological model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. The model is set up for a catchment area or basin (= watershed in USA). The catchment is divided into multiple sub-catchments, which are further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the sub-catchment area and are not identified spatially within a SWAT simulation.

Climatic inputs include daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data, which can be input from measured records and/or generated. The overall hydrologic balance is simulated for each HRU, including canopy interception of precipitation, partitioning of precipitation, snowmelt water, and irrigation water between surface runoff and infiltration, redistribution of water within the soil profile, evapotranspiration, lateral subsurface flow from the soil profile, and return flow from shallow aquifers. Water that recharges the deep aquifer is assumed lost from the system.

Crop yields and/or biomass output can be estimated for a wide range of crop rotations, grassland/pasture systems, and trees. Nitrogen and phosphorus applications can be simulated in the form of inorganic fertilizer and/or manure inputs. Biomass removal and manure deposition can be simulated for grazing areas. Selected conservation and water management practices can also be simulated. Water transfer can also be simulated between different water bodies, as well as “consumptive water use” in which removal of water from a watershed system is assumed. HRU‐level and in‐stream pollutant losses can be estimated for sediment, nitrogen, phosphorus, pesticides, and bacteria. Sediment yield is calculated with the Modified Universal Soil Loss Equation (MUSLE) developed by Williams and Berndt (1977). The transformation and movement of nitrogen and phosphorus within an HRU are simulated as a function of nutrient cycles consisting of several inorganic and organic pools. Losses of both N and P from the soil system occur by crop uptake and in surface runoff in both the solution phase and on eroded sediment.

Flows are summed from all HRUs to the sub-catchment level, and then routed through the stream system. Sediment, nutrient, pesticide, and bacteria loadings or concentrations from each HRU are also summed at the sub-catchment level, and the resulting losses are routed through channels, ponds, wetlands, depressional areas, and/or reservoirs to the watershed outlet. Contributions from point sources and urban areas are also accounted for in the total flows and pollutant losses exported from each sub-catchment. Sediment transport is simulated as a function of peak channel velocity. Simulation of channel erosion is accounted for with a channel erodibility factor. SWAT also has an automated sensitivity, calibration, and uncertainty analysis component.

The outputs of the SWAT model are provided for each watershed, sub-catchment and HRU, for each time step. These include evaporation and percolation, surface flows, lateral flows and groundwater contribution to streamflow, sediment yields and nutrient loads.

SWAT has been applied and tested in hundreds of scientific publications dealing with small sub-catchments to very large basins from all around the world. It is now considered one of the most capable and reliable models for the types of application being used here.

A5.3 Input data

The spatial data required to set up the model are a digital elevation model (DEM) raster, a soil raster, a land use raster and a suite of climate data (Table A5.1). Additional data to increase the resolution of the model and ensure the modelled flow follows true flow paths include a stream shapefile, reservoir shapefile, and catchment boundary shapefile. Where possible, these data are burned into the DEM raster during the watershed delineation process and validated against during the placement of sub-catchment outlets, inlets of draining watersheds, point source inputs, and reservoir locations. Watershed and sub-catchment boundaries are delineated based on the DEM data (with burned in streams) and sub-catchment parameters are calculated during the first step in setting up the model.

Pre-processing and formatting the available data into a readable format by ArcSWAT takes significant time and effort. For instance, in many cases the data available are not complete, cover different areas, or are in many different projections. Where possible, data has been sourced which is already in a format which is readable by ArcSWAT, such as using soil data from the Harmonized World Soil Database. By utilizing these resources, we avoided having to populate soil attributes for 16,328 unique combinations of soil layers in South Africa, as classified by the SOTER soils database.

Table A5.1. Main data sources required for SWAT analysis

Component	Sub-component	Description	Source
DEM		Shuttle Radar Topography Mission (STR) 1 Arc-Second (~ 30m resolution)	NASA
Soils	Soil parameters including hydraulic groups, rooting depths, available water content, clay, silt and sand contents.	Many of these parameters are recording in different databases held by the ARC. Some parameters will additionally need to be estimated from available data. *HWSD provides all parameters needed for SWAT model input.*	ARC-ISCW land types, hydraulic groups and soil profiles. Missing Parameters can be estimated from available parameters or using Global soil databases such as SOTER.
Land cover	47 classifications of land cover, which are translated to similar classifications already provided in the SWAT model.	Land cover data for KwaZulu-Natal 2005, 2008 & 2011	GeoTerraImage & KZN Ezemvelo
Climate data	Daily precipitation (mm), maximum and minimum daily temperature (°C), daily humidity (fraction), and daily solar radiation (Mj/m^2)	Daily measurements from stations throughout study area. The CFSR global atmosphere resolution is ~38 km (T382) and *provides all these data in the correct format for SWAT model input.*	Either historical rainfall data or global reanalysis data from NCEP- CFSR[10]

A5.3.1 History

SWAT soils characteristics can be divided into two groups, physical and chemical characteristics. The physical properties will define the movement of water and are through the soils profile, thus having a great influence on the cycling of water within the defined HRUs. Chemical characteristics, while not required for the model, are used to set initial levels of chemicals present in the soils. The Harmonized World Soil Database (v 1.21; Fischer *et al.* 2008) provides a 30 arc-second raster database with over 15,000 different soil mapping units at a worldwide scale that combines existing regional and national updates of soil information (Fischer *et al*.,

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[10] Lynch and Schulze 2007 provide 50-year daily rainfall series up to 1999 as well as other climate related data including temperature If possible, we would like Stats SA to obtain the raw data so that we have a wider choice of options. Alternatively, global rainfall from The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) have completed data for the 36-year period of 1979 through 2014 which can be used (https://globalweather.tamu.edu/).

2008). The original data are mapped at a scale of 1:5,000,000 as per the regional FAO SOTER data for Southern Africa. Other than a user defined look up table, the extracted data do not require any manipulation to be read into the SWAT model. This significantly reduces the time it takes to set up the model and allows for the scope of model to be easily expanded to other regions of Southern Africa.

The properties required by SWAT for each layer of soil type include the depth of the soil layer, soil texture, hydraulic conductivity, bulk density, organic carbon content and soil depth for the different layers of soil. These parameters are listed below, some are optional whereas others are required [in parenthesis]. Data from the HWSD includes all these parameters:

- SNAM: Soil Name (printed in the HRU summary tables) [optional] *Yes*
- HYDGRP: Soil Hydraulic Group (A, B, C, or D based on definitions concerning % sand/clay and depths) [required] *Yes*
- SOL_ZMX: Maximum rooting depth of soil profile (mm) [required] *Yes, effective depth*
- ANION_EXCL: Fraction of porosity (void space) from which anions are excluded [optional]. If no value is entered, the model will set = 0.50. *No*
- SOL_CRK: Potential or maximum crack volume of the soil profile [optional] *No*
- TEXTURE: Texture of soil layer [optional] *Yes*
- SOL_Z(layer #): Depth from soil surface to bottom of layer (mm) [required] *Yes, effective depth*
- SOL_BD(layer #): Moist bulk density (Mg/m³ or g/cm³). Values should fall between 1.1 and 1.9 Mg/m³. [required] *No*
- SOL_AWC(layer #): Available water capacity of the soil layer (mm H_2O/mm soil) [required] *No*
- SOL_K(layer#): Saturated hydraulic conductivity (mm/hr) [required] *No*
- SOL_CBN(layer #): Organic carbon content (% soil weight) [required] *No*
- SOL_CLAY(layer #): Clay content (% soil weight) [required] *Yes*
- SOL_SILT(layer #): Silt content (% soil weight) [required] *Yes*
- SOL_SAND(layer #): Sand content (%s soil weight) [required] *Yes*
- SOL_ROCK(layer #): Rock fragment content (% total weight) [required] *No*
- SOL_ALB(top layer): Moist soil albedo [required] *No*
- USLE_K(top layer): USLE equation soil erodibility (K) factor (units: 0.013 (metric ton m² hr)/(m³- metric ton cm)). [required] *No*

A5.3.2 Climate data

Climate data required included daily rainfall, maximum and minimum temperature, humidity, solar radiation, and wind for individual points across the study area. These data can be read from records of observed data or can be generated using a weather generator. For this study, we used the global data sets available for modelled climate between 1979 and 2014 from https://globalweather.tamu.edu/. These data are of uniform distribution, with very few missing data gaps, and can be downloaded for a large area in a format that makes it easy to input into ArcSWAT. Where there are gaps in observed data, we use a CFSR derived global weather generator to ensure there are no missing data during simulation. The relatively long time period of this data set allowed for model training, calibration and validation covering all years for which we have land cover. These data were used in preference to the 50-year daily rainfall series (1950-1999) developed by Schulze & Lynch (2007), because they included more parameters and data extending to the recent past. Another option was to get data from the South African Weather Service (SAWS), but these were too costly and would have required extensive manipulation.

MATLAB was used to determine if the precipitation data utilized in SWAT (the Climate Forecast System Reanalysis (CFSR) (swat.tamu)), was representative of the precipitation in our study region. This product was compared to locally sourced precipitation data from Schulze & Lynch (2007). A conditional interpolation scheme was applied, considering the location of a given hydrology station. Across 5 weather stations within the upper Mooi River catchment, the CFSR data with respect to the locally-sourced data exhibited on average a correlation coefficient (R^2) of 0.65, and the differences in mean and standard deviation for the two products were < 0.1 mm. This suggested that the rainfall data used in the model was a good approximation of the actual rainfall.

A5.4 Watershed delineation

The first step in developing an ArcSWAT model is delineating the watershed area of interest. The watershed delineation tool uses and expands the ArcGIS and Spatial Analyst extensions to perform DEM pre-processing which includes filling sinks/ pits, flow accumulation, flow direction, and burning in stream files to the DEM to ensure proper flow path representation. Once the DEM has been pre-processed, then the user defines a minimum sub-watershed threshold area (also known as the critical source area). For this study, this is set to 15,000 ha. The watershed is delineated based on this element, and subsequent sub-catchment outlets are automatically assigned throughout the watershed. The user can then modify, add or remove outlets and inlets to best represent the actual stream network points. Sub-catchment outlets are added at the drainage region of major reservoirs, so that further input variables can be assigned to them. These variables include reservoir capacity, surface area, and spillway release records. Based on the automatically and manually assigned sub-catchment outlets, ArcSWAT then calculates sub-catchment parameters.

A5.5 Definition of Hydrologic Response Units (HRUs)

Hydrologic Response Units (HRUs) were defined using land use, soils, and slope classifications (derived from the DEM). HRUs are defined as areas that have a discrete response to hydrologic dynamics, i.e. portions of sub-basins that possess unique combinations of land use, soil and slope attributes and respond similarly to one another. The number of HRUs that are defined depend on the slope thresholds that are set, as well as the limitation on the size of the HRUs (in terms of percentage of basin size). When setting the thresholds of the HRUs, only those HRUs which were > 0.1% of the watershed area (~3 km^2, or 300 Ha) were considered. Additionally, exemptions were set for the land use classes of Barren, Degraded Bushland, Degraded Grassland, Wetlands, and Subsistence Farming which meant that HRUs which included those land classes were not excluded, no matter how small they were. This resulted in ~7,000 – 10,000 HRUs per major watershed area modelled.

A5.6 Simulation and model calibration

A5.6.1 Manual calibration of model

The models were first set up for the Thukela basin using the KwaZulu-Natal land cover dataset for 2011, and run for the time period 1979 to 2014, using a "run-up" period of 6 years. The outputs were thus generated for the period 1985-2014. The simulation provides monthly output data for every sub-catchment modelled (564 in total), as well as hydrologic and sediment data for every reach segment per sub-catchment. The degraded scenarios modelled to estimate changes in flow, nutrients and sediments were created by assigning the following land use updates: range-grass became degraded-grassland; range-brush became degraded bushland; forest became barren; and wetland became barren. A default simulation was run with no land use update and compared to a degraded simulation with the aforementioned land use update assigned to happen in 1985. The output variables from each simulation are listed in Table A5.2 and Table A5.3 below.

Table A5.2. A list and description of output variables from SWAT at the sub-catchment level.

Variable name	Definition of Output (SUB-CATCHMENT LEVEL)
PRECIP	Total amount of precipitation falling on the sub-catchment during time step (mm H2O).
SNOMELT	Amount of snow or ice melting during time step (water-equivalent mm H2O).
PET	Potential evapotranspiration from the sub-catchment during the time step (mm H2O).
ET	Actual evapotranspiration from the sub-catchment during the time step (mm).
SW	Soil water content (mm). Amount of water in the soil profile at the end of the time period.
PERC	Water that percolates past the root zone during the time step (mm). There is potentially a lag between the time the water leaves the bottom of the root zone and reaches the shallow aquifer. Over a long period of time, this variable should equal groundwater
SURQ	Surface runoff contribution to streamflow during time step (mm H2O).
GW_Q	Groundwater contribution to streamflow (mm). Water from the shallow aquifer that returns to the reach during the time step.
WYLD	Water yield (mm H2O). The net amount of water that leaves the sub-catchment and contributes to streamflow in the reach during the time step. (WYLD = SURQ + LATQ + GWQ – TLOSS – pond abstractions)
SYLD	Sediment yield (metric tons/ha). Sediment from the sub-catchment that is transported into the reach during the time step.
ORGN	Organic N yield (kg N/ha). Organic nitrogen transported out of the sub-catchment and into the reach during the time step.
ORGP	Organic P yield (kg P/ha). Organic phosphorus transported with sediment into the reach during the time step.
NSURQ	NO3 in surface runoff (kg N/ha). Nitrate transported by the surface runoff into the reach during the time step.
SOLP	Soluble P yield (kg P/ha). Phosphorus that is transported by surface runoff into the reach during the time step.
SEDP	Mineral P yield (kg P/ha). Mineral phosphorus attached to sediment that is transported by surface runoff into the reach during the time step.
LATQ	Lateral flow contribution to streamflow during timestep (mm H2O)
LAT_Q_NO3	Lateral flow nitrate contributions to streamflow (kg/ha)

GWMO3	Groundwater nitrate contributions to streamflow (kg/ha)
TNO3	NO3 IN TILE FLOW IN DAY IN SUBBASIN (kg N/ha)

Table A5.3. A list and description of output variables from SWAT at the reach level.

Variable name	**Definition of Hydrological Output (REACH LEVEL)**
FLOW_IN	Average daily streamflow into reach during time step (m3/s).
FLOW_OUT	Average daily streamflow out of reach during time step (m3/s).
EVAP	Average daily rate of water loss from reach by evaporation during time step (m3/s).
TLOSS	Average daily rate of water loss from reach by transmission through the streambed during time step (m3/s).
SED_IN	Sediment transported with water into reach during time step (metric tons).
SED_OUT	Sediment transported with water out of reach during time step (metric tons).
SEDCONC	Concentration of sediment in reach during time step (mg/L).
ORGN_IN	Organic nitrogen transported with water into reach during time step (kg N).
ORGN_OUT	Organic nitrogen transported with water out of reach during time step (kg N).
ORGP_IN	Organic phosphorus transported with water into reach during time step (kg P).
ORGP_OUT	Organic phosphorus transported with water out of reach during time step (kg P).
NO3_IN	Nitrate transported with water into reach during time step (kg N).
NO3_OUT	Nitrate transported with water out of reach during time step (kg N).
NH4_IN	Ammonium transported with water into reach during time step (kg N).
NH4_OUT	Ammonium transported with water out of reach during time step (kg N).
NO2_IN	Nitrite transported with water into reach during time step (kg N).
NO2_OUT	Nitrite transported with water out of reach during time step (kg N).
MINP_IN	Mineral phosphorus transported with water into reach during time step (kg P).
MINP_OUT	Mineral phosphorus transported with water out of reach during time step (kg P).
ALGAE_IN	Algal biomass transported with water into reach during time step (kg chl-a).
ALGAE_OUT	Algal biomass transported with water out of reach during time step (kg chl-a).
CBOD_IN	Carbonaceous biochemical oxygen demand of material transported into reach during time step (kg O2).
CBOD_OUT	Carbonaceous biochemical oxygen demand of material transported out of reach during time step (kg O2).
DISOX_IN	Amount of dissolved oxygen transported into reach during time step (kg O2).
DISOX_OUT	Amount of dissolved oxygen transported out of reach during time step (kg O2).
SOLPST_IN	Soluble pesticide transported with water into reach during time step (mg active ingredient)
SOLPST_OUT	Soluble pesticide transported with water out of reach during time step (mg active ingredient).
SORPST_IN	Pesticide sorbed to sediment transported with water into reach during time step (mg active ingredient).
SORPST_OUT	Pesticide sorbed to sediment transported with water out of reach during time step (mg active ingredient).
REACTPST	Loss of pesticide from water by reaction during time step (mg active ingredient).
VOLPST	Loss of pesticide from water by volatilization during time step (mg active ingredient).
SETTLPST	Transfer of pesticide from water to riverbed sediment by settling during time step (mg active ingredient).

RESUSP_PST	Transfer of pesticide from riverbed sediment to water by resuspension during time step (mg active ingredient).
DIFFUSEPST	Transfer of pesticide from water to riverbed sediment by diffusion during time step (mg active ingredient).
REACBEDPST	Loss of pesticide from riverbed sediment by reaction during time step (mg active ingredient).
BURYPST	Loss of pesticide from riverbed sediment by burial during time step (mg active ingredient).
BED_PST	Pesticide in riverbed sediment during time step (mg active ingredient).
BACTP_OUT	Number of persistent bacteria transported out of reach during time step (# cfu/100 mL).
BACTLP_OUT	Number of less persistent bacteria transported out of reach during time step (# cfu/100 mL).
CMETAL#1	Conservative metal #1 transported out of reach (kg).
CMETAL#2	Conservative metal #2 transported out of reach (kg).
CMETAL#3	Conservative metal #3 transported out of reach (kg).
TOT_N	Total nitrogen transported with water out of reach during time step (kg N).
TOT_P	Total phosphorus transported with water out of reach during time step (kg P).
NO3CONC	Nitrate concentration transported with water out of reach during time step (mg/l).
SED_IN	Total sediment transported into reach during time step (tons)
SED_OUT	Total sediment transported out of reach during time step (tons)
SAND_IN	Sand transported into reach during time step (tons)
SAND_OUT	Sand transported out of reach during time step (tons)
SILT_IN	Silt transported into reach during time step (tons)
SILT_OUT	Silt transported out of reach during time step (tons)
CLAY_IN	Clay transported into reach during time step (tons)
CLAY_OUT	Clay transported out of reach during time step (tons)
SMAG_IN	Small aggregates transported into reach during time step (tons)
SMAG_OUT	Small aggregates transported out of reach during time step (tons)
LAG_IN	Large aggregates transported into reach during time step (tons)
LAG_OUT	Large aggregates transported out of reach during time step (tons)
GRA_IN	Gravel aggregates transported into reach during time step (tons)
GRA_OUT	Gravel aggregates transported out of reach during time step (tons)
CH_BNK	Bank erosion (tons)
CH_BED	Channel degradation (tons)
CH_DEP	Channel deposition (tons)
FP_DEP	Floodplain deposition (tons)
TSS	Total suspended sediments (mg/L)

The distribution of land classes per major catchment area within KwaZulu-Natal are displayed below (Figure A5.1). For all catchments, after applying the land use update to simulate degradation, ~ 70% of the entire watershed area was classified as either degraded or barren (T catchment = 74.47%, U catchment = 68.58%, V catchment = 78.55%, W catchment = 78.66%).

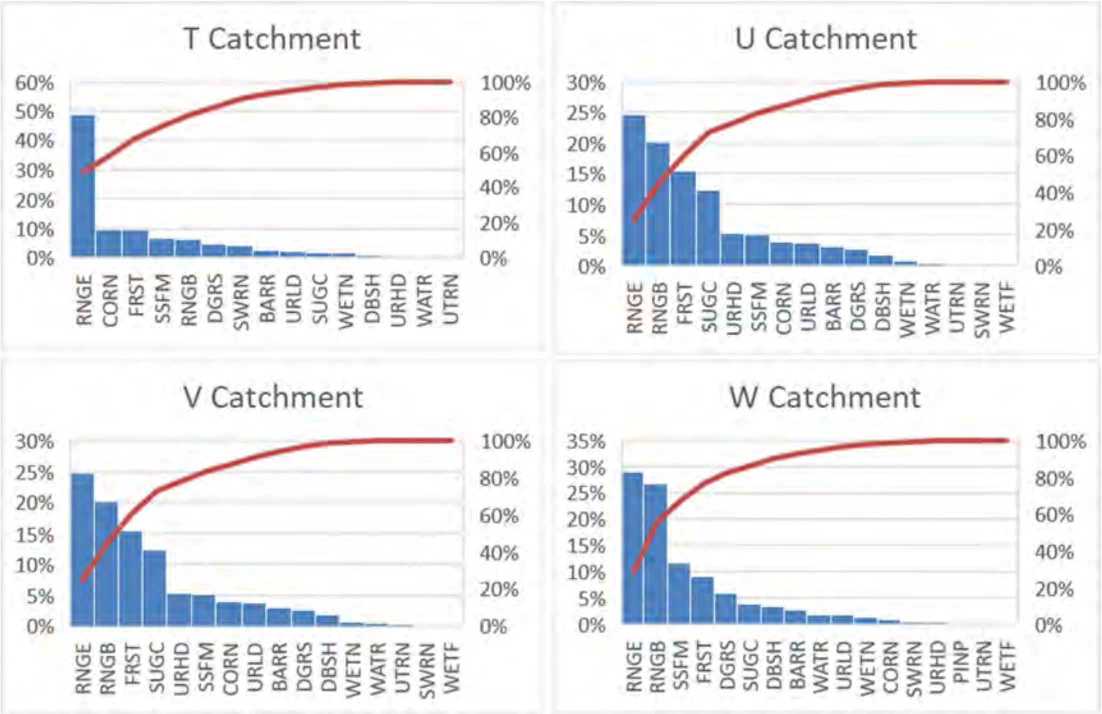

Figure A5.1. Distribution of land classes per major catchment area within KwaZulu-Natal.

This model was then calibrated using flow and water quality data which are available for a number of monitoring stations in KwaZulu-Natal (Figure A5.2) and monitoring data on sediment deposits and dredging of reservoirs, all of which were obtained from the Department of Water and Sanitation (DWS). These data included measures of phosphorus, nitrogen, turbidity and *E. coli*. Once the Thukela model was satisfactorily calibrated, the model setup was extended to the rest of KwaZulu-Natal, and another round of calibration was performed.

A model which consistently under-predicts the flows but has the right variability would suggest low surface flow. This would be calibrated by adjusting the curve number for specific land uses, decreasing the water holding capacity, and increasing the soil evapotranspiration compensation factor (see Figure A5.3). Alternatively, this could also indicate low baseflow with too much evapotranspiration. This would be calibrated by decreasing deep percolation loss, decreasing the groundwater revap coefficient, and/or increasing the threshold depth of water in shallow aquifer for revap to occur.

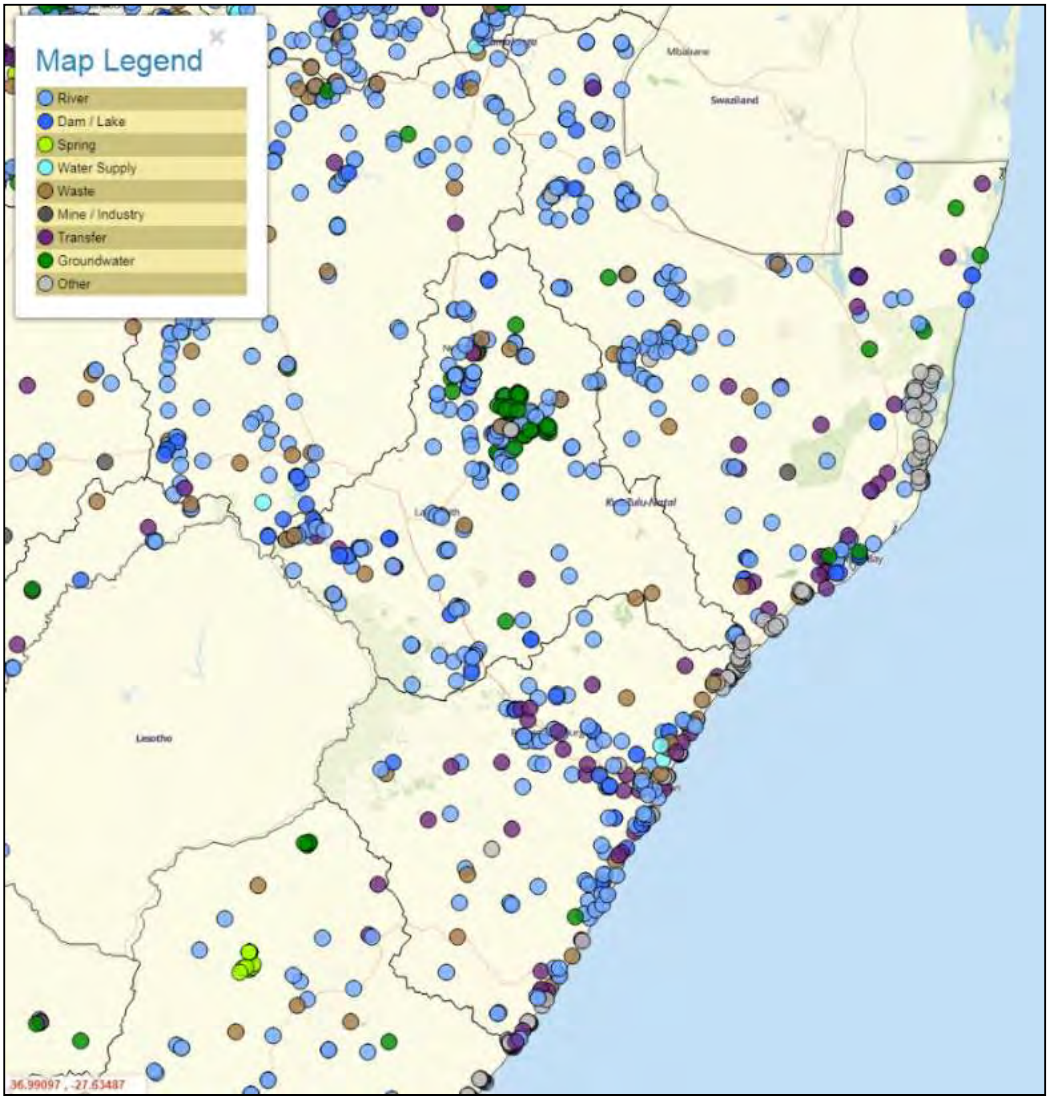

Figure A5.2. Department of Water and Sanitation Water Quality Monitoring Network in the Thukela, Usutu to Mhlathuze and Mvoti to Umzimkulu Catchments (Source: DWS)

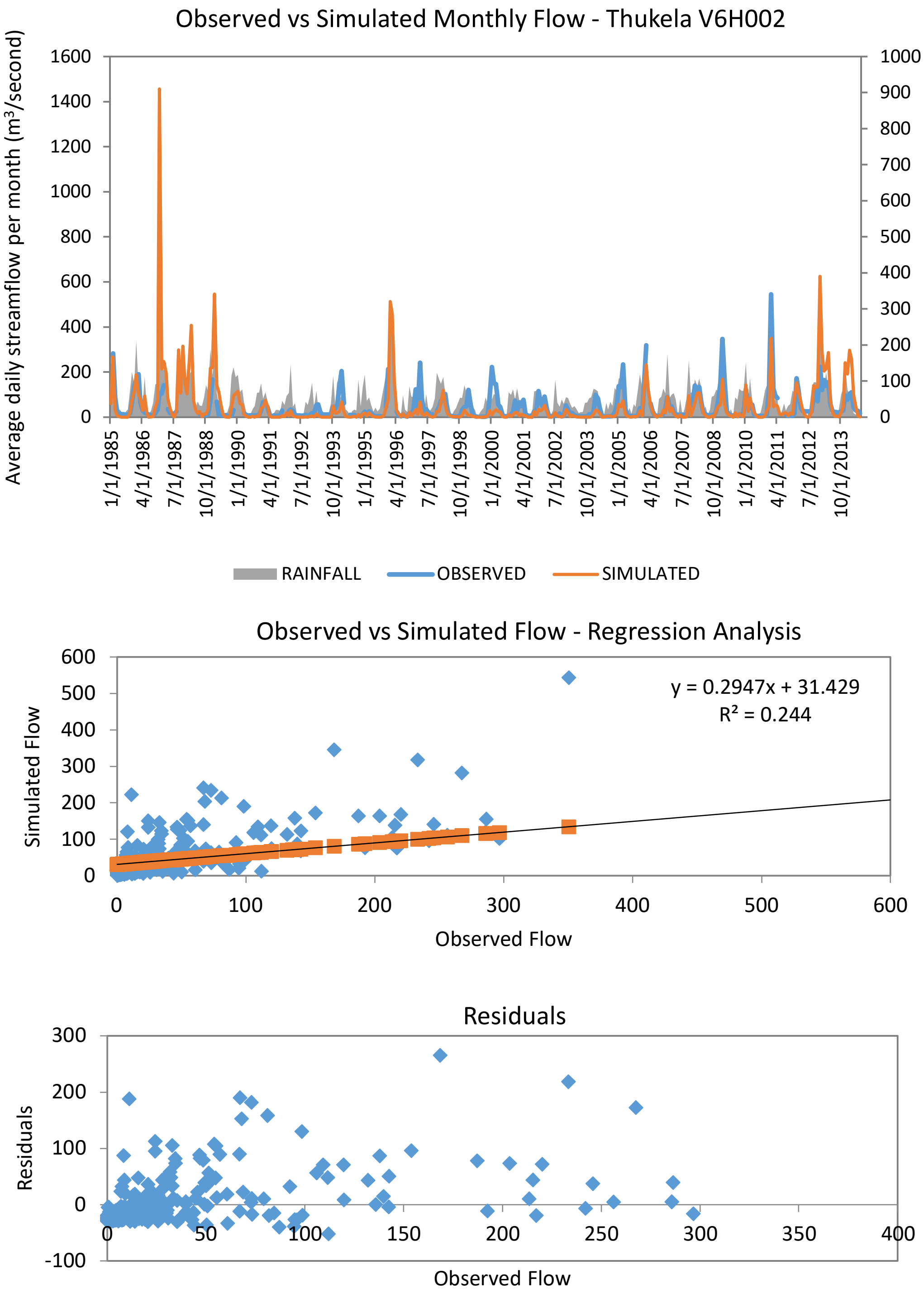

Figure A5.3. An example of flow calibration at a point in the Thukela basin.

A5.6.2 SWAT-CUP calibration

Based on the distribution of reliable observed hydrologic data (gauged stream flows), an area of approximately 5% the size of the Thukela catchment was chosen for fine scale model parameter calibration (Figure A5.4). This area in the upper Mooi River catchment, comprised of six sub-basins, had three gauging stations and observed streamflow records that covered our simulation period. A watershed model of the upper Mooi River catchment was built in ArcSWAT using the same sub-basin, reach and HRU structure as the Thukela model. Initial model parameters were determined from available research and data within swat.tamu's databases.

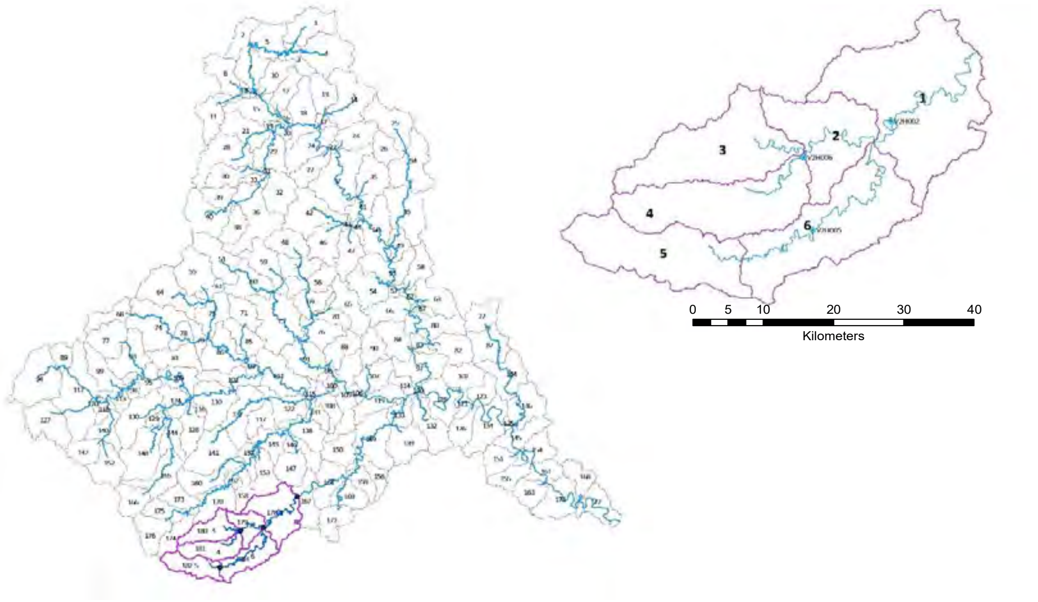

Figure A5.4. Selected upper Mooi River sub-catchment for fine scale calibration.

The SUFI-2 algorithm in the SWAT-CUP software package was used for the upper Mooi River model calibration, sensitivity, and uncertainty analysis. This algorithm maps uncertainty of the model parameters (expressed as uniform distributions or ranges) and tries to capture most of the measured data within the 95% prediction uncertainty (95PPU) using an iterative process (Abbaspour *et al.*, 2015). Based on the performance of the upper Mooi River model at three outlet stations (V2H002, V2H005, and V2H006), 9 relevant parameters in the upstream sub-basins were selected for parameterization.

- CN2 [Curve Number]
- ALPHA_BF [Baseflow Alpha Factor (1/days)]
- GWQMN [Threshold depth of water in shallow aquifer required for return flow to happen]
- GW_REVAP [Groundwater "revap" coefficient]

- ESCO [Soil evaporation compensation factor]
- EPCO [Plant uptake compensation factor]
- SOL_AWC [Available water capacity of the soil layer (mm H2O/mm soil)]
- RCHRG_DP [Deep aquifer percolation fraction]
- REVAPMN [Threshold depth of water in the shallow aquifer for “revap” or percolation to the deep aquifer to occur (mm H20)]

Initial ranges were assigned to these identified parameters. In addition, user-defined absolute parameter ranges were also defined for all SWAT parameters (Abbaspour *et al.* 2015). Guidance in establishing these parameters was provided by Dr. Srinivasan of Texas A&M University.

SWAT-CUP was used to produce 1000 simulations of the upper Mooi River model. Each simulation was executed using a unique combination of parameter ranges which produce 1 000 combinations of parameter-specific associated flow for the study period (1985-2013). Post processing in SWAT-CUP calculated the objective function (Nash-Sutcliff, PBIAS, R^2) and the 95PPU for all observed variables in the selected objective function. New parameter ranges were suggested by the program for further iterations, model refinement, and selection of the best parameter set (Abbaspour *et al.* 2015). The best parameter set is presented in Figure A5.5 below.

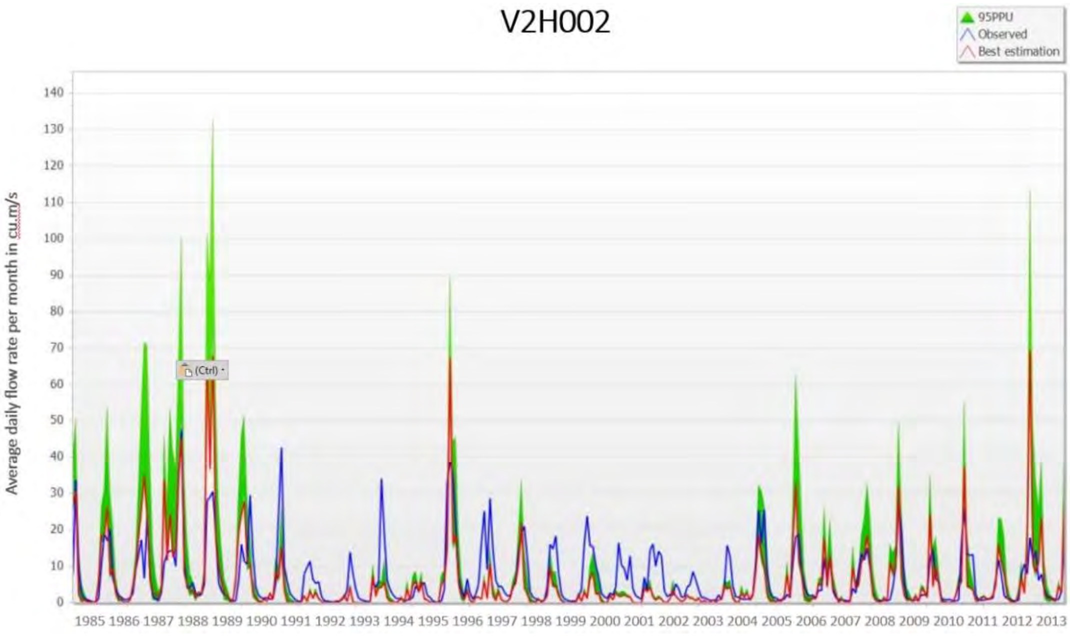

Figure A5.5. Model output for the upper Mooi River sub-catchment showing observed flow, best estimate modelled flow, 95PPU for all observed variables.

A5.7 Limitations

As with all hydrological models, there are a number of limitations involved in an analysis of this scale. We did not have good data on point sources of pollution or water abstraction throughout the province. The area being modelled was too large to include these as are the data requirements to do so. Furthermore, only limited wetlands and large, on-channel dams can be considered within the model. The limitation on wetlands is imposed by the model (2 per sub-catchment), so only large wetlands will be considered. In-dam processes will not be modelled separately and only those considered inside the SWAT model were taken into account. Furthermore, specific information on fertiliser and pesticide addition will not be able to be taken into accounts. Generic assumptions about these will be made across the catchments. Despite these limitations and constraints, given the broad scale of this project and the limited time frame, using a SWAT model provides a good approximation of the physical ability of the ecosystems in question to regulate flows and retain sediment and nutrients. There is always scope for refinement of these models with finer resolution data in future studies.