Ecosystems services in South Africa: a research theme that can engage environmental, economic and social scientists in the development of sustainability science?

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South Africa is grappling with balancing the demands placed on natural resources by economic development, especially for the poor, with the reality of severe natural resource limitations. Sustainability science is an emerging research field that seeks to find ways of resolving these conflicts to make progress towards sustainable development. Research on ecosystem services focuses on the links between ecosystems and society, and how society benefits from them. This paper introduces the concept of ecosystem services for a broad scientific readership and argues that its attendant research provides a theme that is wide enough for the engagement of a diverse range of scientific disciplines and stakeholders in the development of sustainability science. We provide an overview of published ecosystem service studies that have explicitly dealt with South Africa and found that there were large gaps in the information on these services. Only a few have been assessed and most studies focused on particular services or specific biomes or areas, notably the Cape Floristic Region. Many studies emphasized production processes (those which yield harvestable products) but several have addressed regulatory services (notably water quantity and quality), and a few have assessed cultural services. There are few estimates of monetary values and these found that ecosystem services make substantial contributions to the economy. Research shows that human activities are, directly and indirectly, contributing to a decline in the quantity and quality of these services, with major implications for people's livelihoods and well-being, particularly for the poor. More direct interaction and development of an interdisciplinary understanding, common language and shared values between the different domains of science are required if the potential of research on ecosystem services for the understanding of complex, socio-ecological systems and to sustainable development are to be realized.

Introduction

South Africa, like many other countries, is grappling with the difficulties of finding an appropriate balance between the demands of economic development and its finite supplies of natural resources. This tension is acknowledged in South Africa's Constitution[1] and is at the heart of the much-debated concept of sustainable development.[2,3] The need to achieve this balance is not just a concern for government, society and the private sector, it poses a significant challenge to the fragmented, single-discipline-based model for doing science.[4,5] The heart of the scientific challenge lies in the fact that no single scientific discipline has all the knowledge and tools that are needed to address the complex socio-ecological issues that sustainable development and intergenerational equity raise. The new field of sustainability science has been proposed as the inter- or trans-disciplinary (see Box 1) meeting ground for addressing these issues.[6–8] Sustainability science is an evolving field of research which recognizes that the different domains of science have multiple, and often divergent, epistemologies (theories of knowledge and how it is assembled).[5–8] Goals such as sustainable development address issues relating to both 'What should be done?' and 'Why?' The second question addresses the diversity of norms and values held by society, and requires an understanding of non-scientific views of the world—views which may differ markedly from the objective knowledge scientists believe they offer. Sustainability science aims to find ways of bridging these differences because it recognizes that each has a role to play in enabling society to find solutions to complex problems and progress towards sustainable development. Burns *et al.*[5] describe the characteristics which define sustainability science as: use-inspired basic research, located at the interface between society and its sustaining natural environment, focused on the resilience of complex social ecological systems, having a transdisciplinary approach to understanding system complexity and resilience, acknowledging the validity of multiple epistemologies, and emphasizing learning and adaptation. We believe that the same features can be found in ecosystem service research as we define it later in this paper.

Box 1

There is confusion about the meaning of the terms multi-, inter- and trans-disciplinary. Science can be seen as having four levels: the basic or purposive level (e.g. biology, economics, sociology), the pragmatic or technological level (e.g. engineering), the normative level (e.g. planning, law) and the value level (e.g. philosophy).[4] In the context of this paper, we use multidisciplinary to describe situations where disciplines contribute towards a solution but operate independently with little integration or synthesis. Inter-disciplinary requires knowledge interchange, integration and synthesis between disciplines both within and across levels, but interactions across levels are primarily between adjacent levels (e.g. when ethical values define the purpose of a medical research project). Trans-disciplinary extends inter-disciplinary to include similar and concurrent interactions within and across all the levels.

While we fully support the goals and the approaches being developed for sustainability science (see ref. 5 for a review), we believe scientists need more than a meeting ground to overcome disciplinary barriers. They also have to find a research theme which simultaneously challenges each discipline and compels them to engage fully with each other, to develop a shared language and a respect for the value added by each discipline.[9–11] The creation of a shared language, understanding and mutual respect among scientists can generate the kinds of scientific insights required to interact with other role players (such as policy makers, legislators, and politicians) to find ways to redesign economic development, to align it with environmental realities and to work towards the goal of sustainable development.[12]

This paper proposes that the research theme of ecosystem services can help bridge the divergent world views and approaches that are entrenched in the different sciences as it addresses ecosystems, ecosystem services and human well-being, both individually and collectively. Our aim is to introduce the concept of ecosystem services to a wide scientific audience, and to sketch the South African context by providing an overview of the research that has been conducted in the country. In doing so, we highlight the importance of human well-being, call to scientists from a range of disciplinary backgrounds to engage in developing an

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inter- and (potentially) trans-disciplinary theme of sustainability science using ecosystem services as a common research theme.

What are ecosystem services?

The term 'ecosystem services' is shorthand for the products or goods and services that ecosystems provide to society. It embraces both the ecosystems which deliver the services and the people who benefit from them. These services range widely from products like food through to stabilizing and regulatory services such as disease control, and life-enhancing functions such as environments for recreation and spiritual inspiration[13–16] (see Table 1). Ecosystem services are interlinked and often inter-dependent.[17] For example, regenerating services such as soil formation and the maintenance of soil fertility underpin the creation of goods such as food and medicines.

The fact and delivery of ecosystem services is the outcome of both the way in which ecosystems function and the kinds and combinations of the species they contain. Changes in species composition and ecosystem function due to conversion of natural grassland to cultivated croplands, for example, can alter the scale and delivery of services. Cultivated lands may provide the additional service of crop production and yield more water than natural vegetation, but pesticides used on the crops may pollute the water, affecting river ecosystems and, possibly, the health of downstream ecosystems and human populations. Degradation of ecosystem integrity (such as by reduced water flow, soil erosion, and vegetation loss) leads to a decline in service provision.[18] The links between the state of an ecosystem, its function, and service delivery are very complex and poorly understood.[19–23]

Human well-being, although buffered against environmental vagaries by culture and technology, is ultimately dependent on the sustained supply of services derived from healthy and functional ecosystems.[24,18] Most people, including many scientists, are unaware of the extent of their dependence on these services. In many cases, it seems that they are overlooked because they are not properly valued, priced or paid for, and their contributions to the formal economy, although vital, are not acknowledged.[12,25–29] In economic terms there are no markets for most of them. Over the last ten years, however, scientific interest in ecosystem services has increased both locally and abroad. Evidence of this trend can be seen in the adjustment and incorporation of concepts of ecosystem services into university courses and shifts in the focus areas of research organizations to incorporate this research direction. Publications naturally reflect this trend, including prominent works such as the Millennium Ecosystem Assessment (MA).[18] Ecosystem services have been assessed at both international and national levels for various regions in several countries.[30] We have seen the ecology of particular services demonstrated, monetary values derived (at both national and global scales) and, most recently, a greater focus on their delivery as a means of moving towards sustainable development.[5,31,32,33] These benefits have not, however, been matched in the private and public decision-making arenas, where performance continues to be based primarily on short-term socio-economic gains.

The South African context

The growing global recognition of the value of ecosystem services and their importance to human well-being is mirrored in South Africa, where there are clear links between biodiversity and human welfare in both commercial (such as in 'Big 5' tourism) and subsistence (for instance, food and water) sectors. This country has a wealth of both biological and cultural diversity. Although it comprises only 2% of the Earth's surface, it contains a wealth of biodiversity (10% of global plant species and 7% of all vertebrates) within its borders, which is unequalled by other temperate regions, and is home to three of the world's 34 global biodiversity hotspots.[34] South Africa's rich cultural diversity is reflected by the mix of peoples and cultures of African, European and Asian origin, for example. Cultural backgrounds influence how people view their environment[35,36,65] and, thus, how they view and value ecosystem services.[29] Apartheid has also left South African society with deeply divided views on the environment.[37–40] Environmental issues are seen by many as a preoccupation of wealthy whites and anti-development groups. In many cases, these views have been profoundly shaped by the historical lack of access to these services and their benefits.[41]

We conducted a literature search to gain an understanding of the current state of research on ecosystem services in South Africa, what has been researched and by whom. We interrogated the ISI databases for article titles and abstracts with the following keywords: South or southern Africa (or African), and ecosystem or environmental or ecological service. This combination includes, for example, all papers which included the words 'environmental' and 'service'.

Overview of past studies of ecosystem services in South Africa

The search identified 62 papers which have been published in the peer-reviewed literature. Their abstracts were read and articles which did not examine ecosystem services were removed from the list. We also excluded all those that did not provide information specific to South Africa. The final selection of 18 papers is very diverse, covering a wide range of topics, disciplinary interests and points of view (Table 2). We review the objectives reported, areas studied, the services covered and the estimated values where applicable.

Some important studies on ecosystem services were not identified by our literature search. They examined the impacts and benefits of the harvesting of goods from natural ecosystems, focusing mainly on woodland and forest environments (e.g. refs 59 and 60). These goods fall mainly under production services (Table 1) and include harvestable products such as fuelwood, fibre, foodstuffs, medicinal products and the regulatory service of carbon sequestration. The objectives of these studies generally are to show that rural and urban communities, especially the poorest households, derive substantial benefits from these goods. These investigations did not show up in the literature review because the authors did not use the term 'ecosystem services' when referring to these goods, possibly because they were not familiar with the terminology and also because their studies were couched in the language associated with the concept of 'natural capital'. We are sure there are studies in fields such as anthropology which address production and cultural services that do not use the terminology of ecosystem services. Relevant examples of ecosystem service research which have not used these keywords, or were not included in the ISI databases, have been included in our discussion.

Objectives of the research

The papers that were identified in our literature search were written with various objectives in mind, and only a few focus specifically on ecosystem services (Table 2). Most of the studies deal, at some level, with the effects of different policies and water management approaches on the delivery of water-related services and the

Table 1. A summary of the different types of ecosystem services derived from the classification developed by Daily.[14]

Ecosystem service	Description
Stabilizing and regulatory processes	
Regulation of the hydrological cycle (flood & drought mitigation)	Vegetation stabilizes soils and enhances the infiltration of rainfall, reducing the rate at which storm rains run off into rivers and, thus, the flood peaks; water stored under the surface is critical for supplying water to rivers during the dry season
Partial stabilization of climate	This includes the role of plants in altering the energy balance of the globe by changing the albedo (reflective properties) of the surface and by transpiring water which absorbs energy from the atmosphere
Moderation of weather extremes	This one is linked to the one above and includes the ability of vegetation to moderate climate extremes by, for example, buffering the impact of storm winds
Compensation of one species for another under varying conditions	Ecosystems are generally are characterized by many apparently similar species which play particular roles (e.g. nitrogen fixation) but one is better adapted to one set of environmental conditions and the other under a different set of conditions
Coastal & river channel stability	Vegetation on floodplain and coastal dune systems; vegetation is critical for stabilizing the loose soils
Purification and maintenance of the gas composition of the air	The filtering and cleansing of the air by vegetation including the production of oxygen (O_2) by plants and carbon storage through incorporation into organic matter
Control of the majority of potential pest species	Animals, and some plant species, are very important natural pest controls, a property which is exploited in the production of so-called organic goods
Regenerating processes	
Generation & renewal of soil fertility	The generation of soils through weathering is strongly controlled by interactions with living organisms and soil fertility and productivity is maintained by a range of organisms, notably micro-organisms
Purification of water. Detoxification and decomposition of wastes	Ecosystems play a critical role in, and are generally very efficient at absorbing, processing and detoxifying waste products (solid and liquid)
Pollination	Insects are critical for pollinating a wide range of crops and much of the pollination is done by wild insects, including bees
Dispersal of seeds/spores necessary for revegetation	Wind, water and many animal species are critical for dispersing seeds and spores needed to revegetate areas cleared during development, or disturbed by floods, storms or fires
Production of goods	
Food	The productivity of our farming systems is still totally dependent on the ecosystems which sustain those crops and livestock or the natural environments where they are harvested
Durable materials	Similarly, the natural fibres in much of what we wear and use, and the wood used in construction, all depend on the productivity of ecosystems whether cultivated or not.
Energy	An ever-increasing range of natural products are being used to generate energy whether in firewood or biofuels; water, and gravity, are the source of hydroelectric power
Industrial products	Although many products (waxes, oils, fragrances, latex, rubber, precursors to synthetic products) are now derived from synthetics, they were derived from natural resources; there is also increasing use of natural products
Genetic resources	Genetic diversity enables living organisms to adapt to changing conditions, genetic resources for enhancing commercial crops are found in wild relatives; genetic resources are used to produce intermediate goods that enhance the production of other goods
Pharmaceuticals	Like the industrial products, almost all of our medicinal products and precursors for synthetic drugs are derived from plants and animals
Life-fulfilling functions	
Aesthetic beauty	Appreciation and enjoyment of natural environments is a basic human need
Serenity	The serenity of living environments, whether urban parks or wilderness, meets a basic need
Cultural, intellectual and spiritual inspiration	South Africa has a wealth of cultural diversity which adds immensely to the quality of life
Scientific discovery	Curiosity is a basic human drive which is fulfilled by exploring natural environments, whether as scientists or as amateurs
Preservation of options for the future	Change is inevitable in both human and natural environments; the rich biodiversity of South Africa provides options that will support society as it adapts to the impacts of global (climate) change

Table 2. A summary of the studies of ecological services in South Africa.

Source	Objective(s) of the paper	Area studied (spatial unit)	Category of service & actual service	Value (base year unless otherwise specified)*
Bohensky and Lynam[42]	To present a framework for evaluating the effectiveness of management responses (behavioural, institutional, technical) when dealing with complex, adaptive systems such as water resources	Gariep and Zambezi River basins at multiple scales	• Stabilizing & regulatory – water flows	No values of ecosystem services *per se,* although some costs of human impacts on ecosystem function and services are cited
Bohensky *et al.*[43]	To illustrate the value of scenarios in facilitating stakeholder participation in comparisons of the impacts of alternative socio-economic development options on selected ecosystem services	Gariep River basin (including the Great Fish River)	• Production services: food, minerals, energy	Not estimated
Heydenrych *et al.*[44]	Describe a strategic framework for the conservation of terrestrial biodiversity which addresses biodiversity, institutional and socio-economic aspects	Agulhas plain	• Stabilizing & regulatory – impacts of invading species on water flows • Life-fulfilling – nature-related tourism	Not estimated 1998 – tourism comprised 11% of the GNP of the Western Cape – the fraction that was nature-based is unknown
Higgins *et al.*[45]	To identify the ecosystem services and quantify their benefits & the impacts of different management scenarios on these values, particularly the impacts of invasive species as loss of value	Fynbos biome – hypothetical catchment scale	• Stabilizing & regulatory – water flows • Production – food and other products harvested from fynbos plant species • Production – genetic resources • All	R35–75 ha^{-1} yr^{-1} (1996) R1.3–29.1 ha^{-1} yr^{-1} (1996) R3–3000 ha^{-1} yr^{-1} (1996) Total Net Present Value (over 50 years) equivalent to R39–416 ha^{-1} yr^{-1}
Holmes *et al.*[46]	To report on the recovery of fynbos vegetation (especially ecosystem function) after alien plant control operations	Fynbos – no specific scale	• Regeneration – nutrient cycling • Stabilization and regulation – water storage and flows	Not estimated
Jewitt[47]	To illustrate how Integrated Water Resource Management policy and practice may be used to ensure the sustained yield of the ecosystem services associated with water resources	National – no specific catchment	• All	Not estimated
Lange *et al.*[48] and Hassan (2002 cited in Lange *et al.*[48])	To show how the System of Integrated Environmental and Economic Accounts has been used to influence national government policy on natural resource use, including ecosystem services	Southern Africa – South Africa, Botswana, Namibia	• Production – particularly non-market goods • Regulatory – carbon storage • Stabilizing & regulatory – water flows	South Africa: Forest goods and services (including plantations) in 1998: – market timber R1.8 billion – non-market timber & goods R2.7 billion – livestock grazing R1.2 billion – Carbon storage R0.5 billion – R19 GDP per m^3 of water (1996) – R65 GDP per m^3 of water including agriculture (1996)
Matete and Hassan[49]	To develop an ecological economics framework for water transfer schemes	Southern Africa, Lesotho, Namibia – Gariep River catchment as a case study	• Stabilizing & regulatory – water flows, groundwater recharge • Regulatory – water purification through waste assimilation • Production – food, biomass for energy, pharmaceuticals, durable products	Not estimated Not estimated Loss of R8.99 million to households affected by dams and changes in river flows (1 rand = 1 maloti, 2000)
Richardson and van Wilgen[50]	To review published information on the adverse ecological effects of invasive alien plant species in South Africa	National	• Stabilizing & regulatory – water flows, sediment stabilization, flood regulation; sand supply to beaches • Life-fulfilling – recreational opportunities	Not estimated Not estimated

Source	Objective(s) of the paper	Area studied (spatial unit)	Category of service & actual service	Value (base year unless otherwise specified)
Rockström *et al.*[51]	To outline an approach to Integrated Water Resource Management (IWRM), which includes balancing green (evapotranspiration) and blue (liquid) water flows in agriculture, sustain freshwater ecosystem functions and downstream human use of water	Tanzania and SouthAfrica as examples – IWRM at all scales: local field to the watershed (approx. quaternary catchment) and basin (approx. primary catchment)	• Stabilizing & regulatory – water flows for human use, aquatic ecosystems and plant water use • Production – food, biomass for energy, pharmaceuticals, durable products	Not estimated
Sengo *et al.*[52]	To assess the implications of different water resource planning scenarios for the balance between upstream and downstream benefits, particularly those generated by freshwater inflows into the estuary	Incomati River basin (South Africa, Swaziland, Mozambique) with emphasis on the estuary	• Production – food, fuelwood and charcoal, durable products • Regulatory – water quality and flows • Life-fulfilling – nature-related tourism	Direct value of shrimp catches ~R21 million/yr; fish ~R5.6 million/yr; total ~R63 million/yr and involving ~4 500 households; whole catchment value ~R2.5 billion/yr [converted at 1 US$ = R7, base year for US$ not given in the paper]
Turpie[53]	To provide a critical overview of the role of resource economics in the establishment of the Working for Water Programme and identify ones that have not been studied yet	Not spatially specific	• Range of services, focusing on those affected (positively or negatively) by invasive alien plants	Not estimated
Turpie and Joubert[54]	To develop a methodology for estimating the economic value of rivers and the impacts of a change in river quality, using the indirect measure of tourism value	Savanna biome – southern Kruger National Park	• Life-fulfilling – recreational opportunities	R41 million/yr† – on site [1999/2000] R80 million/yr – economic impact [1999/2000] R300 million/yr – consumers' surplus (1999/2000)
Turpie *et al.*[27]	Estimate of the economic value of the biodiversity of the Cape Floristic Region and how the main agents of biodiversity loss (mainly invading alien plants) affect these values	Fynbos biome – estuaries, coastline and near-shore environments	• Stabilising & regulatory – water flows • Regenerating – pollination • Production – food, pharmaceuticals, durable materials • Production – fish and shellfish • Life-fulfilling – nature-related tourism • Life-fulfilling – existence value	R475 billion (value of water loss due to invasive species [2000] R580 million (40% of deciduous fruit industry turnover), loss due to invasions R194 billion [2000] R7–177 ha^{-1} yr^{-1} or R1.4 billion/yr; loss due to invasions R19 billion [2000] R1.3 billion or R1.12/km of coastline per year [2000] R7.4 billion/yr, 24% estimated to be active nature-based tourism [2000] R181 million/yr [2000]
Van Jaarsveld and Biggs[55]	Present a summary of a workshop on establishing a long-term ecological research and monitoring platform aimed at more effective ecosystem management and maintenance of ecosystem service delivery	National	• All	Not estimated
Van Jaarsveld *et al.*[56]	To assess trends in ecosystem state, service delivery and human well-being at multiple scales and present an approach to monitoring to detect trends	Regional	• Production – food, fuelwood • Stabilizing & regulatory – water flows • Life-fulfilling – spiritual, aesthetic, recreational • Biodiversity (species richness and type and degree of threat)	No values estimated, only quantities and trends versus human needs
Van Wilgen *et al.*[57]	Quantify the impacts of invasive species on the reliability of water supplies	Fynbos biome – hypothetical catchment	• Stabilizing & regulatory – water flows	Sewage re-use would cost 1.8 and desalination 6.7 times as much as a control operation
Van Wilgen *et al.*[58]	Present the Working for Water Programme as a model for protecting ecosystem services and achieving social benefits	National	• Stabilizing & regulatory – water flows	No service value estimated, focuses on control costs

*The cited values should be treated as indicative only because they were estimated using different approaches and have different base years, discount rates and other factors and often represent the total economic value generated as a result of the service, only part of which may be due to inputs from the service itself.

#These assessments did not explicitly include thicket vegetation but they may be representative of the moist and grassy forms of thicket vegetation.

†Values shown are 30% of total values for the park based on river systems accounting for about 30% of the tourism value.[54]

benefits derived from them. Some propose that an ecosystem service-based approach which balances benefits arising from rain-fed (green water) and from irrigated agriculture and direct human use (blue water) offers the best framework for policy implementation, e.g. refs 47 and 51 (Table 2). The second main group of papers deals with the value and benefits of production services, primarily goods harvested from natural ecosystems (e.g. refs 27 and 45), and with the ways in which decisions about resource allocation affect benefit flows.[52] The third group of articles focus on quantifying the effects of invading alien plant species on the regulatory and production service of water flows (e.g. refs 27 and 57).

Scope of the research

The papers identified by the literature search focus mainly on case studies of specific areas, which are used to illustrate general principles, although a few use hypothetical examples (Table 2). Matete and Hassan[49] cover the Gariep (Orange) River basin (which includes Lesotho and part of Namibia) and Lange *et al.*[48] present comparisons between natural resource management policies and approaches in Botswana, Namibia and South Africa. The analysis by Rockstrom *et al.*,[51] which compared water resource management in South Africa and Tanzania, was not conducted at a country scale. Sengo *et al.*[52] analysed the role of flow patterns in the Incomati River—which runs through South Africa, Swaziland and Mozambique—in the production services delivered in its estuary and Maputo Bay. Within South Africa, the main focus has been on the fynbos biome, with a few papers on limited areas and restricted aspects of the savanna and thicket biomes; also on estuarine and coastal fisheries and the links between them (Table 2). Papers on the harvesting of goods from natural ecosystems have emphasized mainly woodland and forest vegetation types and particular areas or communities, although the results have sometimes been extrapolated to wider areas.

The Southern African Millennium Ecosystem Assessment (SAfMA)[61,62] and the Gariep Basin Assessment reports[63] are in the grey literature and were not identified by our literature search. These are the only studies that have attempted to provide a consistent approach in describing selected ecosystem services in the countries south of the equator and the Gariep Basin, respectively. One paper summarized the principal approaches and findings of the SAfMA study[56] (Table 2), whereas two analysed and interpreted aspects of the Gariep Basin study[42,43] (Table 2).

Services addressed

Most of the studies focused on water as an ecosystem service, mainly in terms of water flows and flow regulation, but also including water quality regulation (Table 2). These range from studies of scenarios for water management and evaluation of management responses[42] to assessments of how water policy and integrated water resource management can contribute to sustained yields of the benefits from ecosystem services (e.g. refs 47, 51, 52). Some of these investigations estimated the reduced flow in rivers due to the high consumption of water by invasive alien plants compared with the natural vegetation they have replaced.[64,65] Almost half of the studies examined production services either on their own or in conjunction with others. The products involved include food (such as fruit and fish) and other goods such as wild flowers and medicinal plants and pharmaceuticals (Table 2) (e.g. refs 27, 52).

A few studies examined regulatory services such as carbon sequestration, soil stability and nutrient cycling, and one included the regeneration service of pollination. Cultural services have been addressed in a few studies, most of which emphasized recreational opportunities and the benefits of tourism. One included an assessment of the existence value[27] and another touched on non-tourism-related cultural values.[56]

Values estimated

Most of the studies listed in Table 2 did not provide estimates of the economic values of the services they addressed. Some of them calculated monetary value and the consequences of changes in ecosystem state or impacts on ecosystem services due to human activities. These estimates were made in various ways and presented in a range of units, so that direct comparisons are not possible.

One economic approach to valuing ecosystem services is to enhance existing national accounting systems by creating Natural Resource Accounts, which demonstrate how the macro-economic benefits derived from natural resources, including ecosystem services, are used in the economy to generate wealth.[48] Thus, one cubic metre of water is used in generating R19 of gross domestic product—when agricultural production (an ecosystem service) is excluded—and R65 when agriculture is included (Table 2). The high value realized when agriculture is accounted for is heavily influenced by water being supplied at a cost which does not reflect the full cost of delivery or the value generated.[48,66] One study assessed the indirect value of the service of water flows in rivers. About 30% of the economic value of the southern part of the Kruger National Park (savanna biome) could be attributed to its healthy river ecosystems and the habitats they provide (Table 2).[54] These economic benefits would be sacrificed if all the river water was diverted, resulting in the loss of recreational value totaling about R380 million a year. The value of estuary-based fish catches would be significantly decreased if dry season flows in the associated river systems, which keep the mouths of the valuable estuaries permanently open, were substantially reduced.[67] Alterations in flow regimes, particularly a decrease in freshwater pulses, would have a significant impact on the services delivered by the mangroves and fisheries in Maputo Bay.[52]

Woody plant invaders have a significant influence on water flow stabilization and regulation by increasing evaporation (interception and transpiration) and reducing the volume of water entering streams and rivers.[68,69] The volume reduction at a national scale may be as much as 6.7% (3 300 million m^3 yr^{-1}), most of this being in the Western Cape, Mpumalanga and KwaZulu-Natal.[68] Subsequent analyses of a sub-set of the high-rainfall catchments suggest that the earlier estimates may be too high but the total reduction remains significant, especially the impacts on yields from storage dams.[70] In the Crocodile River catchment, the flow reductions due to invasive plant species were estimated to be equivalent to a loss of about R690 million a year,[65] based on the mean direct (farm gate) value of R11 per cubic metre for water used for irrigation in this catchment (in 1994 rands).[71] A further study indicated that the value of the irrigation water would be multiplied 2–20 fold through the full value chain,[72] emphasizing the opportunity costs of water losses due to alien plant invasions.

The fynbos biome is the only one that has been assessed as a complete geographical region for a number of services. Higgins *et al.*[45] estimated the value of water delivered from a hypothetical fynbos catchment to be about R35–75 ha^{-1} yr^{-1}. Turpie *et al.*[27] estimated the total annual value of biodiversity within the Cape Floristic Region and its adjoining marine environment to be about R9.6 billion, most of which is from tourism or consumptive use (Table 2), with the balance coming from indirect use and

existence values. Turpie *et al.*[27] did not include the contribution of the water supplied by the mountain catchments that sustains the economy of the Western Cape—which generated an annual provincial GDP of the order of R119 billion in 2004.[73] Nor did they include the contribution of the water used to irrigate deciduous fruit, citrus and wine and table grapes, which generated most of the gross farming income of about R6 billion for the Western Cape in 2005.[74] Invasions by alien plant species accounted for a loss of water valued at about R684 million a year for the fynbos biome.[27] The commercially harvested marine resources such as fish, crayfish and abalone, off the coastline of the fynbos biome, generated about R1.3 billion annually (or R1.12 km^{-1} yr^{-1}; Table 2).[27]

One study highlighted the value of production services in the forest and moist savanna biomes. Non-market products from forests and woodlands contribute about R2.7 billion annually, considerably more than commercial forestry plantations, which support a timber market worth about R1.8 billion (Table 2).[48] There have been many assessments of the value of particular products from natural ecosystems, which are used by rural communities in the savanna, thicket and forest biomes in the eastern parts of the country,[59,75] including cultural values associated with natural products.[76,77] These studies consistently show that production services in these environments make a significant direct and indirect contribution to the livelihoods and welfare of rural and urban communities, particularly the poorest households.

Although it was not initially seen as being about ecosystem services, the national Working for Water programme combines the benefits of water resource conservation for other uses whilst also achieving a range of social goals by generating employment, training people in basic skills and supporting the development of infrastructure.[58,78] This project resulted in renewed emphasis on the value of protecting mountain catchments for their water generating services[57] and has led to both the Working for Wetlands and Working on Fire programmes.

Important issues identified in these studies

The SAfMA[62] and Gariep Basin studies,[42] together with the global scale Millennium Ecosystem Assessment,[18] found that there has been a marked decline in the state of ecosystems and their biodiversity over the last 50 years.[43,56,62] These changes, largely anthropogenic, have resulted in significant improvements in human well-being, but also in the progressive degradation of ecosystem services. The result is that most ecosystem services are in a poor condition and their status is deteriorating. The continuing decline, together with our knowledge of the links between human wellbeing and ecosystem services, gives rise to concern about our ability to achieve the goals that have been set for human development both globally and nationally. The MA specifically noted that half of the Millennium Development Goals will not be met if these services continue to deteriorate,[18,56] clearly illustrating a situation where objectives for economic and social development are failing to acknowledge that ecological realities may prevent their being realized. This message is reinforced by many of the other studies cited above, which also emphasize the declining benefits from ecosystem services as a result of the progressive loss of ecosystem integrity.

The ecosystems perspective inherent in the concept of ecosystem services acts as an important integrator and identifies connections that might otherwise be overlooked. Good examples are how river flows maintain estuary function and, thus, the services they provide. Assessments of water resources for allocation purposes can overlook the effects of decisions—about how much water should be allocated and where—on downstream ecosystems and the communities they support.[27,52,67] A whole-river ecosystem approach requires an assessment of the requirements of all the ecosystems involved and of their linkages, through estuaries, to the ocean. This, in turn, identifies all the associated services and their beneficiaries.

A key driver for an ecosystem service-based approach to water resources is the National Water Act,[79] with its emphasis on equity, sustainability and maintaining the integrity of the ecosystems that supply South Africa's water resources.[42,80] The principle of the Reserve, which requires water to be set aside for both human and ecological consumption, recognizes the need to balance the maintenance of ecosystem service delivery and human welfare.[80] The process of determining the ecological reserve and setting the desired ecological state has often degenerated into a sterile people-versus-biodiversity argument. We believe that an understanding of the interdependence of biodiversity, ecosystem services and human well-being offers an alternative, and more fruitful, approach which can get beyond this stalemate, to ask what levels of ecosystem functioning are needed for those rivers to provide a full range of regulatory, production and life-enhancing services. This is in line with the intent of the Water Act and with the environmental clause of the Constitution.

Current research biases and gaps

Our initial search gave us an idea of how few papers have been published on South African ecosystem services. Our analysis shows that the research that has been done is very diverse and that a common basis for, or approach to, studies of ecosystem services is lacking. Although many of the studies have provided estimates of values, these have been calculated and presented in a variety of ways which makes comparisons and syntheses difficult, if not impossible. The overview has also identified research gaps. The interrelationships between biodiversity, ecosystem services, social systems and human well-being are poorly understood and quantified. While economic assessments indicate that ecosystem services are of considerable value, our understanding of these values is incomplete. The impacts of different kinds of land use, land degradation, and biodiversity losses on the generation and delivery of services, especially on the most vulnerable members of society, have hardly been examined. Although there is some information on agricultural and forestry productivity and the state of the land (such as the production of natural pastures), this information must still be reviewed from the perspective of ecosystems services in order to clarify the linkages between biodiversity, ecosystem status, service delivery and human welfare.

Geographical bias

There are marked geographical biases in the research efforts across both the subcontinent and within South Africa. The only biogeographical unit whose ecosystem services have been assessed at a reasonable level of detail is the fynbos biome and, even in this case, key services have been omitted and the estimated values were based on some important assumptions and generalizations.[27] Water-rich and productive regions and ecosystems have received the most attention, and the semi-arid and arid regions the least, although the latter represent more than 50% of South Africa's land area and support some of the most vulnerable human settlements.[63]

Categorical bias

The coverage of the different categories of ecosystem services is clearly full of gaps

and many services still need to be studied (Table 2). Most of the studies have been of production services; water flows or supplies are the only regulatory and stabilizing services that have been investigated. Despite the emphasis on water resources, only a couple of studies have addressed water quality. None of the South African studies has assessed the value of the stabilizing service of nutrient recycling, which was estimated to be the single most valuable service globally,[25] or of soil generation and fertility. Two have addressed non-consumptive uses including tourism and existence value (Table 2), and others have touched on recreational and other cultural values.

Emphasis on valuation rather than ecology or people

The Millennium Ecosystem Assessment dealt with the ecology of ecosystem services but only very superficially; most of the other studies hardly touch on this issue. For example, although studies of the impacts of invasive alien plant species on water resources have some basis in catchment experiments, there are no studies that have fully quantified the long-term gains from clearing programmes.[69] The hydrological consequences of land degradation are well understood in general terms, but there do not seem to have been any detailed analyses of the relationships between biodiversity, ecosystem function and status, and the factors that determine hydrological responses and, thus, river flow and quality. There is research that shows that livestock production potential is related to vegetation production, but it is also clear that, in some former homeland areas, many more livestock are being maintained than should be able to survive. It is not clear how this is being done, how resilient these socio-ecological systems really are, or what the downstream consequences are. We also lack insight into the linkages between service benefits and human well-being, particularly the role, benefits and value of the hard-to-quantify cultural services.

Disciplinary bias

The authors of the 18 papers (Table 2) did not specify their disciplines but, from the objectives of their studies and the authors' institutional affiliations, it is clear that there are biases. The strongest representation is of ecologists followed by hydrologists and other natural scientists. With the exception of the macro-economists, there are no scientists who deal with social and institutional systems (such as governance), human livelihoods, health and well-being, or philosophy represented in any of these studies. This is a significant shortcoming, given that ecosystem services are about people and how they benefit or suffer losses. The contribution of economists is crucial, and can provide critical information on monetary values and value generation (which can be used to influence human behaviour), but economics provides only a limited view of how human society benefits from ecosystem services. We do not believe that this is because scientists are not studying and publishing their work on the relationships between human welfare and their interactions with their environment. Instead, we suggest that there could be three related reasons for the apparent absence of published, peer-reviewed papers: (a) the studies appear in journals to which we do not have access, (b) they are not published in ISI-listed journals, or (c) the studies do not use terms like 'ecosystem service'. An example of this is the literature on human livelihoods, particularly in rural settlements, which uses terminology such as 'natural capital', 'natural resource use', 'food security' and 'non-timber forest products' in describing what we would term production services and their benefits. Examples include studies published or reviewed in Lawes *et al.*,[36] the review by Shackleton and Shackleton,[59] and Cocks's[77] paper on biocultural diversity.

Research on ecosystem services

Ecosystem service research was born out of a need to highlight the interconnectivity between people and their environment and is grounded in the belief that urgent behavioural change is required.[17,18,23,81] It is a multi-faceted research area, incorporating species-, ecosystem-, service- and human-specific research and embracing multiple viewpoints on the valuation of services and changes in service delivery. In many ways ecosystem service research is not a 'new' science. There is a substantial body of knowledge and literature on various aspects of ecosystem processes, interrelations and inter-dependencies between people and their natural environments and the economics of natural services. We expect there to be a large body of knowledge and literature on the human dimensions of ecosystem services, albeit under a variety of synonyms. There is much that can be learnt from simply reviewing this literature from an ecosystem service perspective. But we believe that even more can be gained by establishing a forum or some other means of initiating and sustaining a dialogue on this topic between scientists and decision makers from a range of disciplinary backgrounds, along the lines of the model put forward for sustainability science by Burns *et al.*[5] The recent suggestion that the debate should move from sustainable development to sustainable wellbeing[82] is directly aligned with the aims of ecosystem research as we see them.

The key criterion for ecosystem service research is that it provides a framework for focusing on the interactions (ecosystems ↔ ecosystem services ↔ benefits ↔ people) rather than on specific disciplinary domains. Ecosystem service research will not contribute effectively to sustainable development if it continues to be just a subject for ecological research. It has to expand to embrace at least the inputs and views of economists and social scientists (who study political and management sciences), if it is to deal with this multi-faceted theme. There are major challenges in simply getting the different research domains to acquire the necessary trans-disciplinary understanding.[4,5,83] To get ecologists, economists and sociologists to develop the joint insights and shared understanding, for example, they need to acknowledge the linkages between ecology, society and the benefits of ecosystem services.[84] A further challenge lies in addressing the world views and other factors that will promote dialogue between decision makers in government and the private sector, other stakeholders and scientists.[26,85,86]

Sustainability science has similar goals in seeking to bring the different domains of science together and to build the bridges necessary for effective dialogue between science and society.[5,7–10] To the best of our knowledge, however, no one has yet proposed a theme to use in developing sustainability science. The theme would have to be sufficiently broad to span all the levels of science (see Box 1 on page 367), demanding enough to interest scientists to move beyond their disciplinary comfort zones, and focused on solving the real problems that face society as it addresses the fundamental changes required for sustainable development. We believe that ecosystem services research meets those requirements because there are a number of ways in which the two research fields are closely aligned. All of the characteristics of sustainability science described by Burns *et al.*,[5] and summarized earlier, match completely with the aims and objectives of ecosystem service research as described in this article. This includes full engagement with stake-

holders outside the scientific domain (such as politicians and civil society) from identifying and defining problems through to implementing solutions.[5]

Conclusion

Ecosystem services are not acknowledged by the majority of sectoral programmes, with the exception of biodiversity- and water-related policies, as encompassed in the Biodiversity Act[87] and the Water Act.[79] South Africa's current drive for increased economic growth, and the government's newly launched AsgiSA (for Accelerated and Shared Growth Initiative–South Africa) programme,[88] makes the recognition of the value of ecosystem services in decision making essential if sustainable development goals are to be achieved. We believe that by broadening the dialogue about ecosystem services to scientific disciplines outside of the natural sciences, and to policy makers outside of the biodiversity sector, the likelihood that ecosystem services will be mainstreamed into these strategies and policies will be substantially increased, leading to a better life for all.

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