A review of studies on ecosystem services in Africa

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Abstract

Assessments of ecosystem services (ES) are vital for Africa’s sustainability. ES supply and demand take place in distinctive patterns in Africa due to the continent’s characteristic spatial heterogeneity, rich biodiversity, demographic developments, resource endowment, resource management conflicts, and fragile political landscapes, along with current industrialization and urbanization processes. Ignorance of the dynamism of these parameters could diminish the capacity of the different ecosystem service providing units (SPU) to satisfy the demands in the ecosystem service benefiting areas (SBA) in Africa. The main aim of this review article is to assess the extent to which ES studies have been conducted and applied in Africa. This review analyzes those articles accessible online via the ISI Web of Science and open access journals. The online search yielded 52 ES-related studies, which were used for the review. Results indicate that most studies were conducted in South Africa, Kenya and Tanzania, and focused on services provided by watersheds and catchment ecosystems. Crucially, most of the studies focused on more than one ES category. Provisioning ES dominated across all the ES categories. However, ES tradeoffs and synergies were barely addressed. Economic valuation of ES and ES mapping comprised more than three-quarters of all the studies, and a quarter referred to biophysical quantification or qualification of ES. There are emerging alternative, non-monetary valuation methods for ES, which could pave a new way of capturing value of non-monetized ES in Africa. Moreover, there is an urgent need to extend ES studies to the entire continent, in order to capture spatial and socio-economic uniqueness of various countries and focus more on local-scale assessments of multiple ES, as a means for addressing ES tradeoffs, synergies and SPU-SBA relations in Africa.

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Keywords: Ecosystem services; Scale; Quantification; Mapping; Valuation

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1. Introduction

Africa hosts an estimated population of 1.1 billion people, with an annual population growth rate of 2.3% (UNFPA, 2011). This population, like any other, depends on a continuous supply and flow of ecosystem services (ES) from nature to society. However, ES providing units (SPU) and benefitting areas (SBA) are relatively unevenly distributed across Africa (Serna-Chavez et al., 2014). For example, the Africa’s total surface area is deserts and arid lands, and that only 26.9% of the total area is viable arable land (Cotula et al., 2009). However, large parts of Africa are rich in natural resources such as tropical forests, freshwater lakes, rivers, oil, minerals and biodiversity (Elbra, 2013; Holland et al., 2012; Green et al., 2013). These resources are vital SPUs that hold significant amounts of natural capital, or deliver abiotic outputs from natural systems, such as oil and minerals. The spatial mismatch between SPU and SBA is further exacerbated by frequent resource management conflicts, political instability (Miguel and Gugerty, 2005), ecosystem degradation (Masese et al., 2013; Jalloh et al., 2012; Green et al., 2013), droughts, diseases, poverty, and inadequate knowledge on human-environmental system dynamics and interrelations (Basedau and Pierskalla, 2014). The latter is vital for methodological development, assessment and analysis of ES potentials, flows and demands across Africa. As Costanza and Kubiszewski (2012) have shown, there were only eight authors from Africa that have published more than five papers on ES. However, since the turn of the second millennium, ES have increasingly become a topical issue for research and discussion in scientific forums (MA, 2005; TEEB, 2010; Müller and Burkhard, 2012), not only at global level, but also in Africa (Egoh et al., 2012).

1.1. Ecosystem services

The concept of ‘ecosystem services’ is a relatively recent development, tracing back to the middle of 1960s and beginning of 1970s (De Groot et al., 2010; Braat and De Groot, 2012; Hernández-Morcillo et al., 2013). The Millennium Ecosystem Assessment (MA) (2005) defines ecosystem services as “the benefits that humans obtain from ecosystems”. Costanza et al. (1997) postulate that ecosystem services comprise of “flows of materials, energy, and information” from the natural environment to the society. Wu (2014) defines ecosystem services as “benefits that people derive from biodiversity and ecosystem functions”. Other definitions focus on a range of services including: ecosystem benefits to human well-being, ecosystem goods and services to humans, value derivation by humans from ecosystems, direct/indirect positive contribution of ecosystems to human well-being, and utility from ecosystems (Ericksen et al., 2012; Fisher et al., 2009; Müller and Burkhard, 2012; Sagie et al., 2013; Costanza et al., 1997). It is noted that some authors use either an ecological or economic perspective in defining ecosystem services (Jax, 2010). However, distinguishing these two perspectives is not within the focus of this review.

The interest in ecosystem services has greatly increased after the publication of the Millennium Ecosystem Assessment (MA, 2005; Haines-Young and Potschin, 2010). Beyond the MA’s contributions to the conceptual and
theoretical development of the ES framework, the ES community’s focus is now increasingly shifting toward methods and results improvement, application and addressing involved uncertainties (Haines-Young and Potschin, 2010; de Groot et al., 2010; Portman, 2013; Jacobs et al., 2015; Hou et al., 2014). This paper is motivated by the clear need to widen the knowledge base for applications of the ES framework in Africa, meeting human demands, especially in fast-growing urban and peri-urban areas. Furthermore, it is widely accepted that a universal ES categorization is difficult, because ES and the human-environmental systems in which they are embedded, are often based on case-specific abstractions (Costanza, 2008; Burkhard et al., 2012). Nevertheless, all ES definitions acknowledge a link between ecosystem processes and structures, ecosystem functions, ecosystem services, benefits and human well-being (MA, 2005; Haines-Young and Potschin, 2010). Although to date many publications recognize humans as integral part of ecosystems (Müller and Burkhard, 2012; Pagella and Sinclair, 2014), humans mostly exploit, or significantly modify, ecosystem components. Hence, the relationship between ecosystems and human beings can be characterized as being asymmetrical and disharmonious.

1.2. Contextualizing ES in the urbanization debate

Ecosystem degradation currently taking place in Africa (AEO, 2013) is comparable to that which took place during the industrial revolution of the 19th century in Europe (Gafta and Akeroyd, 2006). Economic activities associated with urbanization attract large numbers of people, leading to high population densities at sites where jobs are available. The colonial administration had a strong impact on human mobility, land use and urbanization in Africa. For example, the Maasai community from East Africa lost 60% of their communal grazing land to the British colonial administration between 1904 and 1911 (Fratkin and Mearns, 2003), which is partly the current Nairobi city (Makachia, 2011). Africans were not allowed to grow cash crops and most Africans were confined into small villages. The confiscated lands became administrative and economic centers of the colonial governments (Fratkin and Mearns, 2003). This encouraged urbanization, as people sought employment from the introduced market economy. At the same time environmental degradation occurred, due to the high population densities in tribal villages (Fratkin, 2005). Fratkin (2005) further argues that pastoralism is livelihood that requires extensive land area, and hence in cases of land fragmentation, overgrazing is inevitable. These urbanization and land fragmentation processes eventually led to the emergence of permanent urban societies.

Today, the global urban population is already higher than 50% (Wu, 2014) and it is expected to reach more than 67% by 2050 (UNDESA, 2012). Other studies reveal that an approximated 60% of the global human population will be living in cities by 2030 (Radford and James, 2013), with 90% of these projected changes expected to take place in low-income countries (Haregeweyn et al., 2012), such as those in Africa. More rapid urbanization is already taking place in Sub-Saharan Africa and Asia (Bhuang and Urdal, 2013). With the current population projections of two billion people in Africa by 2044 (UNDESA, 2012), it is obvious that human-environmental interactions, and ES supply and demand patterns will change. ES demand will increase with rising population density in urban areas. Therefore, sufficient ES flows need to be created and maintained (UNDESA, 2012). Conversely, whenever ES flows to urban areas diminish, or even stop due to overuse, misuse or mismanagement, ES demands will exceed supply. This could cause environmental degradation, and result in an undersupply in vital ES, such as water shortages/scarcity, lack of food and other products or loss of cultural services such as landscape esthetics. Environmental degradation can also result in ecosystem disservices such as poor drainage/flooding, pest and disease outbreaks, or air and noise pollution (Nedkov and Burkhard, 2012; Gómez-Baggethun and Barton, 2013), increasing the likelihood of human conflicts.

When ecosystem disservices emerge, the affluent class of urban residents tend to move to the exurbs to continue receiving a constant flow of better quality ES (Pickett and Grove, 2009). Similarly the poor urban residents, who can be characterized by insecure and poorly paid jobs, also move from the cities’ Central Business Districts (CBDs) to the cities’ peripheries. In these areas ES flow from adjacent rural landscapes (e.g. public forest for fuel-wood) and are thus often cheaper and easier to access (Archambault et al., 2012). At the periphery of cities, ES are more often exhibiting a ‘public good character’, that is, there is neither rivalry nor excludability of anybody from accessing a certain good or service (Costanza et al., 1997) from an ecosystem, which could lead to environmental degradation. Environmental degradation could be through overexploitation, pollution and mismanagement of ES. In order to understand the spatio-temporal dynamics of social, economic and ecological structures, urban and peri-urban areas are becoming a critical sub-set of the larger ES assessments (Vejre et al., 2010).

1.3. Aims of the review

Generally, the process of ES assessment faces challenges of appropriate ES identification, indicator formulation, data acquisition, quantification, interpretation and inherent uncertainties (Burkhard et al., 2009; Jacobs et al., 2015; Hou et al., 2014; Vrebos et al., 2015). In order to better prepare a comprehensive ES assessment in Africa, this review paper aims at gathering information about ES research in Africa with a focus on spatial distribution, criteria and methodologies used in the studies.

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2 UN Department of Economic and Social Affairs
The review explores two questions:

I. Are ES studies homogenously distributed across local, regional and national scales in Africa?

II. Are the numbers of studies referring to ES quantification/qualification, ES mapping and ES economic valuation studies in Africa similar?

From the two questions, we conceptualize a mind map of distribution homogeneity and proportions of case studies for ES quantification/qualification, mapping and economic valuation studies in Africa similar?

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From the two questions, we conceptualize a mind map of distribution homogeneity and proportions of case studies for ES quantification/qualification, mapping and economic valuation in Africa (see Fig. 1). This review is further contextualized within the population projections for Africa in the next thirty years. Therefore, it is imperative to review the ES research in Africa to date. Moreover, it is useful to assess whether results can address the projected critical concerns of ES supply and demand patterns in the spatially heterogeneous continent (Busch et al., 2012).

2. Africa in context

2.1. Natural conditions of Africa

Africa has an area of 30 million km² and is the second largest continent (UNEP, 2007)\(^3\). Currently, it has 54 sovereign countries recognized by the United Nations. AEO (2013) confirms that 66% of the total land area is characterized by arid and desert conditions. The remaining 44% have conditions favorable for human settlement (covering 123,408 km²) and food production (on 2,292,000 km²; AEO, 2013). These areas also have high potentials for industrial development (availability of raw materials) and conservation activities (Weiβ et al., 2009). The mean annual rainfall ranges between 1500 mm at the coast of West Africa (Eltahir and Gong, 1996) to ~100–200 mm in the north and Sahel regions (Nicholson, 1981). The equatorial region is characterized by relatively high mean annual rainfalls of 400–1600 mm, with some zones receiving mean annual rainfalls of more than 1600 mm (Nicholson, 1981). The desert regions receive less than 100 mm per annum (Nicholson, 1981). The central region is characterized by ever-green tropical forests such as the Congo Basin in the Democratic Republic of Congo (DRC) and the Kakamega forest in Kenya. These areas ‘act as reservoirs of biodiversity, timber, medicinal plants, and play a critical role in watershed protection’ (Fashing et al., 2004: 754). The southern region is mainly characterized by bushlands, woodlands and savanna. The African tropical forests and the savanna grasslands contain hotspots of biodiversity, which have been recognized and mapped by Myers et al. (2000). Africa is popular for its geographical features such as the Great Rift Valley and Mt. Kilimanjaro, the highest mountain in Africa with a height of 5895 m a.s.l (Hemp, 2005), Lake Victoria with a total surface area of 68,800 km² (the second largest freshwater lake in the world; Swallow et al., 2009), Lake Tanganyika with a depth of 1,470 m (the second deepest lake in the world; Cohen et al., 1993), and unparalleled archeological evidence of human evolution in Africa (Semaw, 2000).

2.2. Specific ecosystem services

Adequate and sustainable supplies of multiple ES are required in order to meet human needs, sustain livelihoods and safeguard productivity (Vrebos et al., 2015). However, Africa has a remarkable spatial heterogeneity of SPU. The heterogeneity of ES supply goes along with varying demands for ES across countries and regions in Africa (Busch et al., 2012; Serna-Chavez et al., 2014). The IPCC\(^4\) (1997) predicts that climate change will cause further desertification in Africa, leading to additional changes in ES supply and demand. Besides global change effects, desertification in Africa is further driven by local human-induced actions such as deforestation and unsustainable production systems. Such developments can often be linked to increasing population numbers resulting in higher demands for ES (IPCC, 1997). ES undersupply can result in: (1) resource conflicts emerging specifically in arid- and semi-arid regions, (2) degradation of fragile SPU such as wetlands (Wangai et al., 2013), and (3) failing response mechanisms due to inadequate knowledge of human-environmental systems. Africa has several characteristics that make certain ES unique for human well-being. These characteristics include human and development history, geographical location on the globe, climate and biodiversity, socio-economic mobility and the role in geopolitics, which have all interactively and iteratively influenced the demand and supply patterns of ES.

2.2.1. Provisioning ES

A critical provision ES is water. The continent’s per capita annual water availability is 4008 m³, which is below the global annual per capita of 6498 m³ (TEEB, 2010). Fresh

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water scarcity is also projected to rise from 47% in the year 2000 to 65% in 2025 (Bates et al., 2008). The scarcity is understood in the context of the competing freshwater demand for agriculture, industrial and domestic uses (Elisa et al., 2011). This means that water supply and the main SPUs such as rivers, wetlands, lakes or groundwater reservoirs and related ecosystem functions such as groundwater recharge (Kandziora et al., 2013) are priorities for Africa. Food provision is urgently needed to improve nutrition in most countries in Africa, especially in cities (Smart et al., 2015). This urgency is caused by high food prices that are rising beyond the affordability of many families in Africa, especially the urban-poor households (Smart et al., 2015). The African Food Security Urban Network (AFSUN) confirmed that 80% of poor urban households in Africa were chronically food-insecure (Frayne and McCordic, 2015). Although the IFPRI\(^5\) reported that by 2013, Africa generally reduced hunger by 23% as referenced from the 1990 Hunger Index, 20 countries in Africa did not achieve the target of reducing undernourishment below 5% between 1992 and 2015, stipulated in the Millennium Development Goal 1c (MDG)\(^6\) on eradicating hunger (FAO\(^7\), 2015). Cases of malnutrition, poor food production, non-functioning food storage systems, and the overarching goal of food security, are key challenges for the continent (FAO, 2015). Food insecurity in North Africa is partly caused by food losses and wastage between production and distribution stages. The food losses and wastage in North Africa stand at 68% of total food production, whereby losses and wastage in urban areas are mainly at the consumption stage (FAO, 2015). It is expected that the losses and wastage may be even higher in sub-Saharan Africa. Efforts to improve food production through cost-effective biological pest control, agroforestry projects, land management\(^8\) and climate-adaptive crop varieties are urgently needed (Mbow et al., 2014). Climatic change effects are already causing hunger and loss of livelihoods for many people in Africa (AEO, 2013). For example, during a severe drought in 2009, 84% of cattle and 77.8% of goats died in the arid and semi-arid lands of Kenya (Wangai et al., 2013). This affected food security because livestock products such as beef, milk and blood form a major proportion of daily diet for the pastoralistic and nomadic communities (Galvin et al., 2001).

2.2.2. Regulating ES

Africa’s vulnerability to climate change and desertification is expected to escalate due to human-malpractices such as deforestation and general land degradation (IPCC, 1997). Between 1900 and 2010, the frequency of drought events has increased (AEO, 2013). Barrios et al. (2008) reported that 60% of all African countries are vulnerable to drought, with 30% classified as ‘extremely vulnerable’. Desertification (Hulme et al., 2001), soil erosion, loss of biodiversity (Beniston, 2003) and vector-borne\(^9\) diseases (Tanser et al., 2003) are being accelerated by local and regional climate changes. For example, Tanser et al. (2003) asserted that 90% of all global Malaria cases occur in Africa and that altitudinal Malaria zones shall increase by 5–7% by 2100. Africa’s trade and economy depend mainly on primary commodity exports (e.g. wood, cotton, cocoa, coffee, tea, pyrethrum, beef and leather) (Deaton, 2010). The efforts to maximize economic gains from primary commodities have resulted in over-cultivation, overstocking, over-harvesting and deforestation. These activities have led to regional climatic changes (Hulme et al., 2001). Floods have frequently devastated Africa, with the El Nin˜o floods of 1998 killing over 4000 people (Galvin et al., 2001). An upsurge of cholera and typhoid was also recorded and food crops perished, due to prolonged rains beyond crops harvesting time (Galvin et al., 2001). A plausible climate regulating ES program would be vital for socioeconomic and ecological stability in many regions (Velarde et al., 2005). Urban and peri-urban air pollution due to vehicular traffic and industrial processes poses threats to millions of residents (Gatari and Boman, 2003). This can be related to an undersupply of air quality regulating ES and poor air quality control policies. As a consequence, over 14 million Kenyans suffered from respiratory diseases in 2013 (DN\(^10\)). This requires concerted efforts through air quality and emission standards, law and regulations, and ecological practices, such as increasing green spaces (Ngo et al., 2015).


\(^6\)http://www.africa.undp.org/content/rba/en/home/mdgoverview/overview/mdg1/.

\(^7\)http://www.fao.org/documents/card/en/c/e9589c20-5507-4cee-a965-22fc5a08f42f/.

\(^8\)www.thelancet.com.

\(^9\)Malaria causing female Anopheles mosquito genus is a major vector of concern in Africa. It’s breeding and distribution largely depends on temperature variation. Increase in temperature attracts infestation by the vector and this increases transmissions.

\(^10\)Daily Nation, 12th March 2015. Air you breathe in Nairobi may kill you, says research. A publication of Daily Nation, a Newspaper from Nation Company based in Nairobi, Kenya.
across the continent (Barrios et al., 2008). For example, a severe drought in 2009 caused death of 53.9% of zebra (Equus burchelli) and 26.5% of wildebeest (Connochaetes taurinus) in the arid and semi-arid lands of Kenya (Wangai et al., 2013). This led to a decline in tourism revenues and loses of livelihoods, with reduced economic benefits to the Maasai community and tour companies alike (Wangai et al., 2013).

3. Methodology

3.1. Data collection

The open search for scientific articles from the ISI Web of Knowledge was based on the terms “ecosystem services Africa”, “peri-urban ecosystem services Africa”, “urban ecosystem services Africa”, “ecosystem services quantification Africa”, “ecosystem services mapping Africa” and “ecosystem services valuation Africa”. These terms included words from the titles and from the keywords. The open search resulted in a total of 709 scientific articles. These articles were further classified as “General” and “Specific”. It was the interest of this review to adopt the “Specific” class of the articles for further analysis. “Specific” articles were characterized by: (i) use of the ecosystem services framework, (ii) a mode of ES assessment of either ‘ES quantifying/qualifying’, ‘ES mapping’, ‘economic valuation of ES’, or ‘multiple mode of ES assessment’, and (iii) a spatial basis either on the local, regional or national scale in Africa (as elaborated in Section 3.2). Although urban and peri-urban ecosystem services were not the main focus of this review, they were evaluated as an important sub-set of terrestrial ecosystems and in the debate on relationships between Service Providing Units (SPU) and Service Benefiting Areas (SBA) as supported by the literature (Fisher et al., 2009; Syrbe & Walz, 2012). The SPU-SBA concept is further elaborated in Section 3.2.

The review focuses on assessments based on ES quantification/qualification, ES mapping, economic valuation of ES and multiple mode of ES assessment. ‘ES quantification’ means that the presentation of ES is conducted in clearly defined figures such as kilograms of corn, fruits or barley from a given ecosystem in a given time period. ‘ES qualification’ refers to studies focusing on quality status of unquantifiable ES such as the pollution levels of air or the preference rating of a recreation site. ‘ES mapping’ refers to a spatial representation (a map) of ES supply or demand resulting for example from a technical application of Geographic Information Systems (GIS) to reveal the spatial distribution of given ES in a landscape or seascape. ‘Economic valuation of ES’ is concerned with the monetary and non-monetary assessments of various ES, as well as any other method that aimed at placing ES in the economic realm. These three selection criteria resulted in 52 scientific articles (see Appendix A). The three ES assessment criteria were also used for the main classifications. That means each publication was assigned either to quantification/qualification, mapping or the economic valuation category (see Appendix A).

3.2. Terms used in the data collection

The analyzed 52 ES studies in Africa are presented in a table (in Appendix A) with information in 13 columns:

- Column 1: numbering of studies;
- Column 2: author(s) of each study;
- Column 3: country of affiliation for the first author;
- Column 4: research institute, to which the first author is affiliated;
- Column 5: year when the study was officially published;
- Column 6 refers to the country/countries, in which the study was conducted;
- Column 7: type of ecosystem (see details in section 4);
- Column 8: category of investigated ES. (supporting, provisioning, regulating and cultural ES);
- Column 9: number of ES assessed in the category(ies) investigated in a study;
- Column 10: Service Providing Unit (SPU) and Service Benefiting Area (SBA; see explanation below);
- Column 11: types of scales of the study (explained below);
- Column 12: mode of ES assessment (explained below); and
- Column 13: methodologies, frameworks and tools applied in the study.

Service Providing Unit (SPU) refers to the spatial extent of an ecosystem or a sub-set of an ecosystem that generates ES. Service Benefiting Area (SBA) refers to spatial areas hosting beneficiaries of generated ES. Whenever SPU and SBA are well-defined and analyzed, their spatial relationships (connections and feedbacks) are derived and presented. However, whenever SPU and SBA are not defined and analyzed, it is only the SPU-SBA physical direction that could be assigned in the review. There are three possible physical directions (in situ, omni-directional and directional) according to Fisher et al. (2009). In situ refers to a class of ES that are produced and consumed at the same spatial area. Omni-directional refers to a class of ES that are produced in one spatial area but flow to beneficiaries in all direction. Directional refers to a class of ES that are produced in one spatial area but flow only in a specified direction, which dictates the beneficiaries.

The types of scales used in this study are following the modified definition by Pagella and Sinclair (2014). They defined spatial scales as local (10–1000 km²), regional (over 1000 km² but sub-nation), and national (area of varying spatial extent where strategic decisions about ES are made). Since the aim of ES research is to influence decision-making at either local, regional or national level, our modification suggests that in studies where information about spatial scale was not provided, the targeted administrative decision-making level was used in categorizing the
study. For example, if a selected number of cities were used to conduct ES research with the aim of making a ‘strategic decision’, then the ES study is categorized as national scale. Likewise, whenever both the spatial scale and target level of administrative decision-making are provided and that they tend to conflict each other, the target level of administrative decision-making prevails in categorizing the study. Local, regional and national scales are abbreviated as Lo, Re, and Na respectively in Appendix A. However, a fourth scale herein referred to as ‘global’ is used only when comparing criteria of ES assessment for this review and other reviews that cover all continents.

Mode of ES assessment refers to quantification/qualification, mapping and economic valuation, which are the three commonly used approaches in ES assessments for most of the studies reviewed in this paper.

In the discussion (Section 6), the terms ‘stakeholders’ and ‘actors’ are used interchangeably to refer to individuals, groups and/or institutions (social, economic, political, research) that influence given resource policies or get influenced by the same resource policies.

3.3. Data analysis and presentation

Data gathered in this review were analyzed using descriptive statistics. The resulting information about the author(s), authors’ country of affiliation, authors’ institution of affiliation, date of publication, country of study, category of ES, number of ES, scale of the study, mode of ES assessment and the methodologies and tools used for each publication are provided in Appendix A. Percentage shares of the modes of ES assessment were analyzed. Within each mode of ES assessment, statistics of the four ES categories were calculated and displayed.

4. Results

The review found that the total number of selected ES studies in Africa was 52. One study was conducted in the year 2005, increasing to thirteen studies in 2013 (Fig. 2a). The number of studies conducted until July 2014 was six (6). These figures are also compared to other reviews in order to establish the trend in the rate of ES publications (Table 1). The (updated) criteria for comparisons among the reviews are thus detailed in Table 1. Other recent reviews include those conducted by Vihervaara et al. (2010), Seppelt et al. (2011), Martı́nez-Harms and Balvanera (2012) and Crossman et al. (2013). Vihervaara et al. (2010) presented seventeen (17) ES studies in Africa, and this number has been increasing to date.

Appendix A presents the details of the 52 reviewed studies, which indicate an increase of studies conducted in Africa. 67.3% of studies investigated ES under two or more ES categories. The results show that the ‘country of first author’s main affiliation’ for 31 (59.6%) studies was outside of Africa (Europe and North America). This complements findings by Vihervaara et al. (2010) that for all the nine out of the most cited ten articles on ES studies, the main author(s) were affiliated to North America and the main author for the remaining study was affiliated to Europe.

Considering the mode of ES assessment (Appendix A), the scores were as follows: 12 publications (23%) for ES quantification/qualification, 17 publications (33%) for ES mapping and 23 publications (44%) for economic valuation of ES. Although the review also recognizes combined modes of ES assessment as applied in recent global reviews (Plieninger et al., 2013), there was no study that fairly combined two or more modes of assessments. It was noted that a study could mention ‘quantification/qualification’, ‘mapping’ and ‘valuation’ of ES in the literature, but ended up investigating one of them in detail. Therefore, this review is prompted to categorize studies based on any of the three distinct ES assessment methodologies depending on the most striking focus of studies.

Fig. 2b demonstrates that South Africa, Kenya and Tanzania are the countries with most ES assessment publications. The three countries have a total of 32 publications (61.5%; see also the Google map link for the distribution of ES studies11). The 52 studies were conducted in less than half of the 54 countries in Africa. Ten (19.2%) studies were conducted at local scales, thirty (57.7%) studies were conducted at regional scales and eleven (21.2%) studies were

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11 https://www.google.de/maps/@-2.9024537,-13.9125947,3z/data=!4m2!6m1!1szXtVQ4jNjoS8.k8oTk4THgek?hl=en.
carried out at national scales. One study (1.9%) by van Jaarsveld et al. (2005) covered the three defined scales; local, regional and national. Moreover, there is an emerging spatial trend of ES studies’ distribution such that high numbers are recorded in Southern Africa, followed by East Africa, and the remaining studies are latitudinally distributed south of, but parallel to, the Sahara desert, from Mauritania to Ethiopia. There were no case studies from the countries at the northern part of Sahara desert. The heterogeneity of Africa was also noted in the review and represented by seven (7) different types of ecosystems that emerged in the reviewed studies and defined in this review as; forest ecosystem (FE), grassland and semi-arid ecosystems (GE), agro-ecosystems (AE), wetland and catchment ecosystems (WE), urban ecosystems (UE), marine ecosystems (ME) and mixed ecosystems (MaE). Where the ecosystem of study was not provided, it was noted with ‘NP’. It follows that WE were most frequent with a score of 14 studies. ME scored 11, whereas the other studies investigated ES in UE (9), GE (7), AE (6), FE (3) and MaE (1). However, one study did not provide the type of ecosystem used to investigate ES. From these ecosystems, 209 specific ecosystem services were investigated. This translates to approximately two (2) ES per ES category and approximately four (4) ES per study.

Fig. 2c presents both frequency and percentage of each ES category out of the total 109 ES categories as follows: 14 (12.8%) for cultural, 27 (24.8%) for supporting, 28 (25.7%) for regulating and 40 (36.7%) for provisioning. 17 studies were found to investigate only one category of ES, whereas those studies that examined two or three categories had 16 studies each. There were three studies that focused on four categories. This means that it would be impossible to explore synergies and tradeoffs among different ES categories in the 17 studies that were based on one ES category alone. However, several studies such as Swallow et al. (2009), Egoh et al. (2010), Hicks et al. (2013), Crookes et al. (2013), Chisholm (2010), Stringer et al. (2012) and Silvestri et al. (2013) have addressed tradeoffs and synergies. Regardless of the number of ES categories studied per study, the category of provisioning ES scored higher than regulating, supporting and cultural categories on overall.

On average, there are two categories of ES examined in each study. The type of ES assessed depends on the type of ecosystem, and on whether the ecosystem is a protected or a private area. For example, river water flowing into a national park is a supporting ES (led to thriving biodiversity) for tourism and recreation services.

It emerged that the studies rarely addressed the relationships between SPU and SBA. However, the physical direction from SPU (where ES are generated) to SBA (where ES are consumed) is assigned for each study depending on the ES types (s) investigated. For example, Namaalwa et al., 2013 sub-divided Namatala wetland into SPU with unique vegetation type, crop type(s), hydrology and geomorphology. ES associated with their derived SPU had local in situ (I), directional (D) and omni-directional (O) flows. The numbers of flows are as follows; In situ (9), directional (5) and omni-directional (13). Other studies had a combination of two or three of the flows as follows; ID (1), IO (11), DO (1), IDO (12). It was observed that omni-directional flows dominate by appearing exclusively in thirteen (25%) studies. A combination of the three flow directions (IDO)}
comes second with twelve (23%) studies and IO combination flows come third with eleven (21%) studies.

4.1. Quantification/qualification of ecosystem services in Africa

Quantification/qualification of ES is applied in 12 studies, which are mainly on water, food and energy related services. For example, Dessu et al. (2014) quantified the water budget for the Mara river basin in Kenya. They found that despite the sufficient water volume to meet demands, infrastructural challenges hinder the appropriate distribution of water. Giday et al. (2013) showed that 58 ha of an exclosure could sustainably provide wood fuel to 238 small-scale farmers in the Tigray district in Ethiopia. Kenya contributes most (33%) of the ES quantification studies. 41.7% of the studies apply empirical/experimental methods to quantify/qualify ES, 16.6% apply survey methods and 41.7% use multiple (empirical and survey) methods (Appendix A). An example of a multiple method of study is by Liebenow et al. (2012), where ‘metrics of land degradation’ through remote sensing are used as proxies to represent ecosystem services and the use of survey to elicit consumption pattern of households. 25% of ES quantification is done at local scale, 67% at regional scales and 8% at national scales. 50% of the publications quantify multiple ES categories, and provisioning ES is quantified in 11 (92%) studies (Appendix A). Most studies demonstrate the impact of water and soil quality on human well-being. For example, (Otieno et al., 2011) demonstrates how ‘site quality’ could indicate quantity and distribution of pollination services.

4.2. Mapping ecosystem services in Africa

ES mapping is applied to assess ES at local, regional and national spatial scales. Seventeen studies were found to have conducted spatial mapping of ES between 2005 and 2014. This is a higher figure compared to the global review by Egoh et al. (2012), who revealed that 14 out of 67 (~21%) studies of ES mapping were conducted in Africa. ES mapping studies at local scales, which could be directly applicable in local decision-making, are relatively few compared to those done at regional, national and global scales/levels (Burkhard et al., 2009). Van Jaarsveld et al. (2005) used different scales (local, regional and national) to map ES in nineteen Southern African regions. Five of these nineteen studies were carried out at local scales in Gauteng, Great Fish River, Lesotho highlands, Richtersveld and the Gorongosa-Morromeu areas. Proportionally, the review results show that ES mapping comprises approximately 33% of all reviewed ES case studies in Africa (see Appendix A). 35% of ES mapping studies are conducted in South Africa and the remaining 65% were distributed as follows: Tanzania (12%), Ethiopia (12%) and others (41%). The majority of the corresponding authors of the ES mapping studies come from North America and Europe.

Surprisingly, more than half of the ES mapping studies did not provide information on the mapping scale and the mapping resolution (Appendix A). In cases where this information is provided, the resolution is rather coarse, ranging between 30 m (= 900 m² or 0.09 ha per pixel) and 26,000 m (67,600 ha per pixel). The results of the review show that only two (12%) publications by Fagerholm et al. (2012) and Petz et al. (2014) have mapped ES at a local scale. For example, Fagerholm et al. (2012) mapped provisioning and cultural ES in two local rural villages of Zanzibar, Tanzania using Participatory GIS (PGIS) techniques (Appendix A). Studies at regional scale specifically dealing with ES mapping appear in 14 publications. Some examples of ES mapping at regional scales are found in Southern Africa (i.e. South Africa, Namibia; Reyers et al., 2009; Naidoo et al., 2011), East Africa (i.e. Kenya, Tanzania; Otieno et al., 2011; Swetnam et al., 2011), Horn of Africa (i.e. Ethiopia; Haregeweyn et al., 2012), and on islands (Madagascar; Rogers et al., 2010). ES mapping at national scale is conducted in various publications in Africa (Batjes, 2008; Leh et al., 2013; Cavan et al., 2014). Most studies indicate a decline in ecosystem services, few of them recognize uncertainties (Chisholm, 2010) in certain ES measurements and comparisons, and some of them recommend steps to improve accuracy and the results’ application. Mapping of provisioning ES is conducted in over 80% of studies on ES mapping. Regulating ES have been investigated through mapping of carbon stocks in Central Africa by Batjes (2008) and urban temperature regulation (Cavan et al., 2014). Cultural ES have been mapped by Fagerholm et al. (2012). Finally, supporting ecosystem services have been mapped for example in the case of primary production from floral communities at the Little Karoo in South Africa (Reyers et al., 2009), and in the case of phosphorous and nitrogen retention in Ghana and Cote d’Ivoire (Leh et al., 2013).

4.3. Economic valuation of ecosystem services in Africa

Economic valuation of ES has been conducted in 44% of all studies (Appendix A). This figure is relatively high in comparison with ES quantification/qualification and ES mapping. 74% (17) of the total (23) economic valuation ES studies are done in Eastern and Southern Africa (exclusive of Madagascar). It also follows that the first study on economic valuation of ES was published in 2006 (Appendix A). This review reveals that out of the 45 ES categories studied under economic valuation of ES, 16 (35.6%) studies examine the category of provisioning ES. Likewise, the percentages of studies that examine categories of regulating, supporting and cultural ES were 12 (26.7%), 10 (22.2%) and 7 (15.5%) respectively. The methodologies used in the economic valuation of ES ranged from ‘common’ to ‘emerging’. ‘Common’ methodologies are those frequently applied in monetary economic valuations such as the Contingent Valuation Method (CVM) (Dumenu, 2013),
Hedonic Pricing, Avoidance Cost, Travel Cost Method (TCM) (TEEB, 2010) and the Cost-Benefit Analysis (Silvestri et al., 2013).

‘Emerging’ methodologies are those based on purely or partly nonmonetary value such as emergy\(^\text{12}\), synthesis, asset-based, carbon trading and the ‘six-step valuation’\(^\text{13}\), and were applied by Cohen et al. (2006), Liebenow et al. (2012), Stringer et al. (2012) and De Wit et al. (2012) respectively (Appendix A). The scales of the economically valued ES are as follows; 21.7% (local), 56.6% (regional) and 21.7% (national) (Appendix A). For example, Bayliss et al. (2014) applied the ‘common’ methods of survey and Willingness-to-Pay (WTP) for building scenarios to show that sustainable resource management strategy scenarios could earn revenues of 1.9 US Dollar compared to 1.6 US Dollar under a Business-As-Usual (BAU) scenario in the eastern Arc mountains of Tanzania. Similarly, De Wit et al. (2012) applied an ‘emerging’ (six-step valuation) methodology to show that the highest potential economic value of a healthy ecosystem in Cape Town, South Africa, was based on regulating and cultural ES, and accounted for 5850 Rand\(^\text{14}\) per annum. They furthermore demonstrated how urban authorities could reduce costs of ES delivery by enhancing ecosystem functioning.

5. Discussion

The first ES studies in Africa took place in 2005 in South Africa (van Jaarsveld et al., 2005). In the same year the Millennium Ecosystem Assessment report was published (MA, 2005). This was followed by another publication by Cohen et al. (2006) in Kenya in 2006. One year later, Mwampamba (2007) published on ES in Tanzania. These three publications seem to be the initial “seed” of ES studies in south and east Africa that later flourished to become the three leading countries in ES studies. A concerted effort and interest to publish more on ES studies was confirmed by the increasing number of ES publications thereafter in the neighboring countries. The distribution of ES studies in Africa is highly heterogeneous as shown by the diversity of ecosystems that were studied. This is synonymous to the heterogeneity in spatial, climatic, demographic, socioeconomic and technological characteristics as indicated by the natural conditions of Africa (Section 2.1). Although the number of ES studies in Africa indicates a general increase since the publication by Vihervaara et al. (2010), more studies have been conducted in South Africa than in any other African country.

There are several explanations for the relatively high amount of ES studies in South Africa. Firstly South Africa gained full independence in 1994 (end of apartheid) just after the launch of the Brundtland report on Environment and Development in 1987. Second, in 2002 the Johannesberg World Summit on Sustainable Development (WSSD)\(^\text{15}\) catapulted South Africa as an attractive entry point for the sustainability agenda in Africa, with a growing number of post-apartheid sustainable mega-projects (Hannan and Sutherland, 2015) and environmental movements (Scott and Barnett, 2009). Third, as argued by Chisholm (2010), ES research is strongly established in South Africa, “largely because widespread poverty means that government expenditure on environmental programs must be justified in economic and social terms”. All these facts could explain the competitive edge of South Africa in ES studies. On the other hand, very large economies within the Sahel region, such as Nigeria, Libya and Egypt, were missing in the reviewed studies. Nigeria and Egypt are part of the 13-member countries under the Great Green Wall for the Sahara and Sahel Initiative (GGWSSI)\(^\text{17}\), but neither of them recorded a study on ES, even in the previous review by Seppelt et al. (2011). Moreover, it is pertinent to note that all the GGWSSI countries have negative water budgets. For example, Egypt has a water demand of 72.4 billion cubic meters against a supply of 57.7 billion cubic meters (Barnes, 2014). This remains a concern, since more than half of the African countries, mainly in the north of the Sahara desert, were still missing in the studies.

Our results suggest that ES studies in Africa are not homogenously distributed (question 1). However, the attempts made by this review to showcase the distribution of ES studies are a step forward in better positioning Africa in the science and debate of ecosystem services, as well as ES-based policy and decision making. The heterogeneity of the continent requires multiple criteria to assess ES in order to objectively influence natural resources management. Therefore, the criteria should be country specific, depending on ES demand and priorities placed on different ES. Moreover, this review revealed that the first authors for more than half of the ES studies were affiliated to countries outside of Africa. This indicated that more African researchers needed to engage in ES research. However, their engagement must be supported through funding commitments by governments (Chisholm, 2010) and other institutions in Africa, as well as availability of expertise in ES research. This could ensure a more robust plan, design, and application of ES tool in ES studies, as well

\(^{12}\) Emergy is ‘the energy required directly and indirectly to create a product or service’ (Cohen et al., 2006: 251).

\(^{13}\) Step 1 “assesses the relative importance of different natural assets [...] for generation of ecosystem goods and services (EGS)”; step 2 “estimates the importance of EGS to users/beneficiaries using a matrix”; step 3 “establishes links between EGS and development objectives”; step 4 “assesses the city’s ability to influence the value of EGS through management”; step 5 “assesses the ability of ecosystems to yield sustainable flow of EGS and prioritize them according to risks”; and step 6 “applies valuation techniques to selected case studies”.

\(^{14}\) Rand: it is the South Africa’s currency of exchange (1 Rand = ~0.076 Euro).


\(^{16}\) http://www.who.int/trade/glossary/story097/en/.

as ownership of the results from ES research. Literature shows that the demand for ES is driven by human population densities and economic activities. Therefore, this review attempted to showcase the status of ES assessment in high population density areas. It is established that there were more studies focusing on urban and peri-urban ES in comparison to most of the analyzed types of ecosystems. It is argued that based on the population projections in urban and peri-urban areas (UNDESA, 2012), the current momentum of improving resource management decisions and policies, and human well-being in Africa could only be sustained if ES studies on urban and peri-urban ES were accelerated. This is because high human density areas generally have high demographic and land-use change impacts on ES.

However, there was little attempt to explicitly address ES supply, demand, tradeoffs and synergies, hence confirming the findings by Haase et al. (2014) and Balvanera et al. (2012). This recognizes that some ES are consumed at the place of supply, while others in a different location. Demand of ES could be determined by the number of consumers, alternative sources, or even by management options to increase supply. The supply of ES is expected to fluctuate temporally. For example, the volume of water supply may depend on precipitation, which may be influenced by natural weather conditions, droughts or land use change. When interests of various actors toward a given resource differ, tradeoffs occur, but when interests concur, synergies may emerge. Hicks et al. (2013) puts tradeoffs and synergies in perspective by analyzing relationship pathways of different stakeholders to certain ES. In the same way, tradeoffs and synergies among different types of ES could only be possible when their characteristics and relationship pathways are analyzed collectively. However, this type of analysis was missing in those studies based solely on one category of ES. Clear distinction of spatial distribution of SPU was barely addressed in most of the studies. This could lead to incorrect assumptions that the potential of a given ecosystem to provide certain ES is uniform across the ecosystem. This could in return hinder optimal management strategy aimed at documenting hotspots of providing certain ES, and changes of their potential to supply ES over time (Burkhard et al., 2014). Again, the SBA for provisioning ES are de-localized and could be traded far from the supply area. For example, additional information about the spatial distribution of beneficiaries for fish, fuel-wood, charcoal and water (most assessed ES types) could be vital in tracking interactions between SPU and SBA. The results also show that studies at local scale were few compared to studies at regional and national scale at the same period. The results from studies at regional or national scale may not be applicable to the local level. Therefore, more spatially restricted studies are necessary for local policy and decision making, which are often rationalized within the framework of prioritized ES and socio-ecological frameworks (culture, language, diversity of stakeholders, and type of ecosystem).

The modes of assessment (quantification/qualification, mapping and economic valuation) of ES show a clear bias toward economic valuation of ES. As chronologically presented, valuation of ES is the last stage of ES assessment after a comprehensive process of quantifying/qualifying and spatially mapping SPU, SBA and ES (Syrb& Walz, 2012). This should not be a concern for those studies which employ multiple modes of assessment with a ‘finish-start’ relationship among stated objectives. In other words, the first objective in a study must be concluded before objective two begins, because the second objective is dependent upon results of the first (e.g. ES quantification/qualification precedes ES mapping). However, in cases where economic valuation of ES is conducted without acknowledging uncertainties for the quantified/qualified data, researchers could run into a ‘misguided attempt to impose unrealistic order and consistency’ (Costanza, 2008) in ES research.

Further, the concept of SPU-SBA is relevant in drawing a list of activities, rights, obligations and responsibilities for different actors in natural resources management. An Omni-directional flow of ES was the mode for most of the studies. This is probably due to the high number of provisioning ES, most of which have omni-directional flows to SBA. The results shown in Appendix A provide answers to the review questions posed in the beginning of this study, such that the three modes of ES assessments are not given the same weight. Looking at the four ES categories, cultural ES accounted for the least number of studies. Most authors focused on fewer proxies for cultural ES such as tourism, recreation and education as compared to the other categories of ES. The criteria for ES assessment were compared with other reviews, and more unique criteria emerged (Table 1).

5.1. ES quantification/qualification

ES quantification/qualification has been conducted by the least number of studies. It has to be noted that most non-market ES were excluded in the ES quantification studies. Most of the ES quantification studies (>40%) were carried out in Kenya. Empirical methods of study are mainly applied because the majority of quantified ES are provisioning ES, which are measurable and traded in the market, with quantities and values are well documented. In this mode of assessment, results imply that the majority of studies were conducted at regional scale and that the national scale received the least attention from ES researchers. Assessment of biophysical ES is reliable and verifiable because it relies on measurements, models and field experiments. However, such procedures are expensive, and as such less data are available for ES quantification

18 ‘Finish-start’ refers to the logical sequence of working on two tasks, activities or objectives, where one of the two must be finished before the second begins and not the vice versa.
This paucity of data could explain the few studies under the quantification/qualification mode of assessment. However, several studies clearly point to the importance of ES quantity and quality. For example, human well-being, which is mainly defined by the physical, social and psychological needs of people, depends not only on quantity, but also on the quality of ES. Since human well-being depends on the availability of livelihoods, the quantity and quality of ES is strongly intertwined with both the human well-being and livelihoods.

5.2. ES mapping

The term ‘ES mapping’ has been used to denote visualized spatial information of ES (Drakou et al., 2015). However, during the online search, some of the titles and contents of several studies did not meet this criterion. Hence they were considered under the ‘ES quantification/qualification’ mode of assessment or not considered for the review. South Africa is the country with the highest number of ES mapping publications. It was observed that most corresponding authors of the ES mapping publications are affiliated to North America or Europe. Most case studies were undertaken at the regional or national scale and were mainly done with rather coarse spatial resolution. Moreover, some studies emphasize on the importance to consider uncertainties, especially the studies on mapping regulating ES. van Jaarsveld et al. (2005) recognize that due to the differentiated (in space and time) nature of ES mapping, careful local planning and action is required. It is also noted that in cases where many countries are under one study, multiple scales (local, regional, and national) are adopted. More than half of the studies did not provide information on spatial scales (referring to scale used when cartographic maps are used) and map resolutions, which makes it difficult to compare the results’ reliability and uncertainty.

5.3. Economic valuation of ES

A number of economic valuation methods have been criticized in the way they aggregated various economic values of different ES and popularize the substitutability of ES (natural capital) with human-made capital (Ninan and Inoue, 2013). This is a critical issue as most African societies still conduct nonmonetary trade. For example, paying of dowry and gifts during initiation and wedding ceremonies is done in the form of livestock (e.g. cows, sheep, goats, camels) instead of monetary items. The underlying reason is that livestock capital, unlike financial capital, has both value and meaning (Talle, 2007). Therefore, more modern ecological economists have formulated methods that attempt to address the gaps identified in classical methods. Such methods have been applied in economic ES valuations also in Africa. First, De Wit et al. (2012) decided to break from conventional and technocratic methodologies and formulated a six-step methodology to assess economic values of ES provided by the ecosystems of Cape Town, South Africa. The six-step methodology had similarities with the TEEB (2010) methodology, especially in steps 2 and 5. The relatively uncommon energy synthesis methodology was used in Kenya by Cohen et al. (2006). Emergy is anchored in ecology, but its transformity values could, for example, be used to derive economic values of soil erosion loss, crop and biomass yields. Liebenow et al. (2012) applied an asset-based approach and an ES-wellbeing interface, probably after inspiration from Sherraden’s (1991) asset-based theory of development. This new focus emphasizes on asset wealth, which is the household attribute that responds to ES variations whenever they occur. The asset-based approach to assessing linkages between ES and wealth thus requires an understanding of household structures, household sizes and production capacities, cultural practices and access to markets (Liebenow et al., 2012), a necessity for economic valuation of ES in poor and/or developing countries. This wide array of valuation methodologies, in a continent of rich cultural diversity, seems to address Vihervaara et al. (2010) and Seppelt et al. (2011) concern that the only tools for assessing cultural ES are for “ecotourism and recreation” because “they have a market value”. Unlike the case of Latin America (Balvanera et al., 2012), African ES studies have not considered natural capital and ES indicators in estimation of national wealth and gross domestic product.

5.4. Limitations and uncertainties of the review

First, many African countries use three or more languages, as recognized by the United Nations. English is officially used in schools and in transactions of government business in eastern and southern Africa, and a few selected countries such as Nigeria and Ghana in western Africa. Western and central African countries predominantly use French as an official language. Northern Africa is dominated by Arabic cultures and Arabic is the main language for both official and common interactions. The review covers only literature in English. Secondly, all publications that were not freely provided online, and those articles unsubscribed to by the institutions of authors’ affiliation, were unavailable for this review.

Societal rituals and ceremonies have specifics and uniqueness in value and meaning, which are not comparable or substitutable to the global market values.
6. Conclusions

Several ES studies have been conducted in Africa. However, few quantified/qualified ES and studies at local scales are rare, with most being insufficient for applications in environmental management at local levels. As the popular slogan states, “Think Globally Act Locally”, ES studies are expected to have a high number of local scale publications in order to correspond to the UNEP and other scholarly work for local action. There seems to be an over-reliance on monetary valuation of ES, with studies tending to ignore asset-based methods. Asset-based methods would be well-suited for ES assessments in Africa because to date, many communities and tribes in Africa still trade their wealth or value natural capital in nonmonetary currency. Furthermore, studies did not adequately delineate ES demand and supply, and were thus limited in addressing flows, synergies and trade-offs among different types of ES. Most of the reviewed ES studies were assessing provisioning ES such as food crops, fish, water and wood fuel. Regulating ES such as waste water treatment, air filtration, storm and erosion prevention and carbon sequestration were also addressed frequently. Supporting ES/ecosystem functions ranked third and focused mainly on self-organization of ecosystems to enable primary production and biotic engineering of organisms. However, few of the studies dealt with assessments of cultural ES. Examples of cultural ES assessed include recreation (including filming and photography), tourism and education. In the African context, cultural ES are vital for enhancing economic, socio-cultural and spiritual welfare for many countries. Thus the low number of cultural ES studies, and few indicators thereof, lead to an under-representation of this category in ES research.

It is established that there could be a link between the momentum of ES research, funding and available expertise. Therefore, if the momentum of ES research was to be maintained and enhanced by author’s affiliated to African countries, more funding and training of ES experts would be required. ES studies are heterogeneously distributed in Africa and many countries are yet to engage fully with ES research.

There is also high discrepancy of scale used among the ES studies conducted in various countries, with regional scales used in most studies. The results respond to the first review question framed in the introduction section that studies of ES are not homogeneously distributed across Africa. The number of publications on economic valuation of ES is more than twice the number of studies in ES quantification/qualification. Therefore, it is clear that the three modes of ES studies are not equally applied (question 2). Further, our findings are in concurrence with assertions from Egoh et al. (2012) that if the inter-linkages across various ES and involved ES-flows are not sufficiently recognized, neither the provision of ES nor biodiversity could be sustained or optimized. Although, studies at the national scale are useful, especially for awareness raising and problem identification, they may not be relevant for regional and local decision-making. Local decision making needs more detailed and accurate information on ES supply, ES demand, natural conditions, resource management regimes and societal values, which vary significantly across Africa. In order to establish tradeoffs and synergies, interactions among ES at the SPU and feedbacks to and from SBA should be analyzed. In conclusion, we suggest the following recommendations:

(a) In order to achieve a holistic understanding of results and potential applications, ES studies in Africa need to assign equal attention to ES quantification/qualification, ES mapping and economic valuation of ES. (b) ES assessments at regional and local scales are urgently needed to directly contribute to policy making at local levels. (c) There is an urgent need for African scientists to contribute to ES assessment and research in order to couple expertise with long-term environmental and socio-economic experiences, thereby offering responsive solutions. (d) As Africa has a rich diversity of cultural and social capital, a list of proxies for cultural ES is required in order to raise their relevance and enhance application potentials for future cases studies. (e) There is potential to make more precise and relevant value estimations, by utilizing the emerging non-monetary valuation methods of ES in Africa, thereby improving decision-making. (f) More precise assessment and mapping of ES demand and potential ES supply, as well as actual use (flow) of ES, is vital due to the heterogeneity of ES distributions across Africa. This could be useful in assessing tradeoff, synergies and SPU-SBA relationships throughout the continent.

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Appendix A
<table>
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<th>Country/study area</th>
<th>Type of ecosystem(^b) (WE, GE, AE, FE, ME, UE, MAE, NP(^g))</th>
<th>Category of ES studied(^a) (P,R,S,C)</th>
<th>No. of ES assessed</th>
<th>Category of SPU-SBA direction(^b) (I, D, O)</th>
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<th>Mode of ES assessment(^d) (Q/M/V)</th>
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\(^b\) P: Provisioning, R: Regulating, S: Supporting, C: Cultural, P: Provisioning, R: Regulating, S: Supporting, C: Cultural.

\(^c\) Lo: Local, Re: Regional, Na: Nationally.

\(^d\) Q: Quantitative, M: Mixed, V: Verbal.

\(^g\) ME: Mountainous Area, NP: Not provided.
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- P = provisioning services; R = regulating services; S = supporting services; C = cultural services.
- I = in situ; D = directional; O = omni-directional.
- Lo = local; Re = regional; Na = national.
- Q = quantification/qualification; M = mapping; V = economic valuation.
- MS = mapping scale of cartographic maps used in the publication.
- MR = mapping resolution of the raster land use/cover map.
- NA = denotes ‘not available’ and refers to situation where mapping scale or mapping resolution are not provided in the text of the publication.
- Wetland & catchment ecosystems = WE, grassland & semi-arid ecosystems = GE, agro-ecosystems = AE, forest ecosystem = FE, mixed ecosystems = ME, urban ecosystems = UE, marine ecosystems = MaE.
- Not provided = NP.
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