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Abstract

While the concept of ecosystem services which links biodiversity to human wellbeing, is by now well-known, its translation into actual management decisions is still uneven. African Biosphere Reserves, which are to be living labs for sustainable development, embody the idea of synergies between people and nature. Gaining knowledge about the provision, the use and the trends of ecosystem services in these reserves is essential to ensure their global change-proof management. The diversity of rapidly evolving ecosystem services assessment tools requires a systematic and informed selection process, in order to ensure that prospective tool users select the most adequate tool. Based on a Delphi survey of future tool users, we propose a tool selection process and we review a range of ecosystem services assessment tools, highlighting their requirements regarding data input, necessary skills, outputs and types of ecosystem services addressed. The existing range of tools can provide key ecosystem services-related information to decision-makers, yet not all the tools are as well-suited to the specific context of African Biosphere Reserve, which makes a systematic, user-informed selection process essential.

Keywords	ecosystem services; assessment tools; Biosphere reserves; Africa; Delphi.
Taxonomy	Ecosystem Services Accounting, Ecosystem Services Literature Reviews

Corresponding Author	Jean Hugé
Corresponding Author's Institution	Université Libre de Bruxelles (ULB)
Order of Authors	Jean Hugé, Anne-Julie Rochette, Stef de Béthune, Claudia Parra Paitan, Koen Vanderhaegen, Thibaut Vandervelden, Steven Van Passel, Maarten Vanhove, Bruno Verbist, Dorien Verheyen, Luc Janssens de Bisthoven
Suggested reviewers	Tom Waas, Francisco Benitez-Capistros, Rodrigue Idohou, Cosmas Munga

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Data will be made available on request

Brussels, March 15, 2019

Dear editors of 'Ecosystem Services',

The importance of the sustainable management of ecosystem services is now well-established, as is the urgency to act based on co-produced scientific and societal knowledge. Translating this into action requires adapted tools and methods, and this topic has received quite some attention in Ecosystem Services, a journal we know well and often cite.

With our manuscript, entitled 'Ecosystem services assessment tools for African Man & Biosphere Reserves: a review and user-informed categorization', we aim to provide an overview of the characteristics of a set of ecosystem services assessment tools from the perspective of a particular category of potential tool users: the actual managers of African Man & Biosphere Reserves.

The specificity of our approach lies not only in the scoping of the areas in which the ecosystem services assessment tools are to be used (in our case: African MAB Reserves); it is also embedded in the method we used.

Using the iterative Delphi method, which is gaining ground in natural resource management *s.l.,* we surveyed potential tool users (all people involved with the AfriMAB African network of Man & Biosphere Reserves) in order to feed the selection of criteria that need to be taken into account when selecting which tool to use.

The manuscript has been conceived and written by interdisciplinary team of authors who all have extensive research and capacity-building experience in the global South, and particularly in Africa. We believe the manuscript has benefited from our first-hand experience the African context.

We look forward to your reaction on our manuscript.

We confirm that the manuscript nor any parts of its content are currently under consideration or published in another journal.

Please do not hesitate to contact us should you need any additional information.

Best regards,

Dr. Jean Hugé and co-authors

Ecosystem services assessment tools for African Biosphere Reserves: a review and user-informed categorization

Hugé, J., Rochette, A.J*., de Béthune, S., Parra Paitan C.C., Vanderhaegen, K., Vandervelden, T., Van Passel, S., Vanhove M.P.M., Verbist, B., Verheyen, D., Janssens de Bisthoven, L.*

**equal contribution*

Abstract

While the concept of ecosystem services which links biodiversity to human wellbeing, is by now well-known, its translation into actual management decisions is still uneven. African Biosphere Reserves, which are to be living labs for sustainable development, embody the idea of synergies between people and nature. Gaining knowledge about the provision, the use and the trends of ecosystem services in these reserves is essential to ensure their global change-proof management. The diversity of rapidly evolving ecosystem services assessment tools requires a systematic and informed selection process, in order to ensure that prospective tool users select the most adequate tool. Based on a Delphi survey of future tool users, we propose a tool selection process and we review a range of ecosystem services assessment tools, highlighting their requirements regarding data input, necessary skills, outputs and types of ecosystem services addressed. The existing range of tools can provide key ecosystem services-related information to decision-makers, yet not all the tools are as well-suited to the specific context of African Biosphere Reserve, which makes a systematic, user-informed selection process essential.

Keywords: ecosystem services, assessment tools, Biosphere reserves, Africa, Delphi;

1 Introduction

Biodiversity is under threat at global and local level. Its continuous decline threatens human wellbeing directly and indirectly, as human systems and biodiversity-based natural systems are closely intertwined. The loss of biodiversity alters the functioning of ecosystems and decreases their ability to provide society with essential goods and services (Cardinale *et al.*, 2012; Costanza *et al.*, 2017). The diversity of services provided by ecosystems includes provisioning services such as freshwater and food provision, regulating services such as air and water purification and climate regulation, and cultural and aesthetic services reflecting the deeply embedded relations between human beings and nature (Mukherjee *et al.*, 2014; Chan *et al.*, 2016). While ecosystem services are by now well-known and well analysed (Costanza *et al.*, 2017) thanks to milestone publications as the 2005 Millennium Ecosystem Assessment and the recent work of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). these services are under threat by ongoing unsustainable human development crossing the systemic boundaries representing the so-called 'safe operating space for humanity' (Steffen *et al.,* 2015). The recent emergence of the 'nature's contributions to people'-idea in the constantly evolving concept of ecosystem services, fosters a more inclusive definition in which indigenous knowledge is explicitly considered (Diaz *et al.*, 2018). The boom of ecosystem services research, applications and policies has led to high expectations among scientists, policy-makers and natural resources managers regarding possible quick wins that could start turning the tide of biodiversity loss, while simultaneously enhancing *e.g.* carbon sequestration and delivery of watershed functions. However, moving from scientific knowledge and societal awareness about ecosystem services to effective real-world decision-making and impact remains challenging. Notwithstanding some success stories, ecosystem services are currently still inadequately acknowledged in decision-making processes (Ruckelshaus *et al.*, 2015).

The wellbeing of people is directly dependent on ecosystem services (Suich *et al.*, 2015) and access to the benefits provided by a steady flow of the ecosystem services contributes to poverty alleviation (Fisher *et al.*, 2014). The challenge of biodiversity loss is particularly acute in developing countries, where economies and a large part of their population depends on goods and services provided by local ecosystems (IPBES, 2018). These countries, often rich with and highly dependent on natural resources, would benefit from the inclusion of ecosystem services in their policy-making processes. Although their economies and a large share of their population is directly dependent on goods and services provided by local ecosystems (IPBES, 2018), until now, these are often not managed sustainably. Africa in particular, has a high proportion of Least Developed Countries (UN DESA, 2016), contains multiple biodiversity hotspots (Myers *et al.*, 2000) and shows a particularly high direct dependency on ecosystem services (*e.g.* 62 percent of its rural population depends directly of ecosystem services for its survival (IPBES, 2018)). Moreover, the continent is expected to suffer an ever-increasing decline in biodiversity, in part due to a rapidly expanding population as the continent's population is expected to double by 2050, reaching 1.25 billion people (UN, 2017). The value of Africa's biodiversity for human well-being is still vastly under-researched (IPBES, 2018).

The linkages between the conservation of biodiversity which forms the basis of the generation of ecosystem services and human development, lies at the roots of UNESCO's Man and Biosphere (MAB) programme (Cuong *et al.*, 2017),The programme finds it spatial expression in a a global network of Biosphere reserves (or MAB reserves). These reserves must meet a minimal set of criteria in order to be proposed by national authorities and subsequently be designated by UNESCO. The sites are widely recognized as being locations where the sustainable development idea, which gained new momentum following the adoption of the Sustainable Development Goals (SDGs), can be implemented (Pool-Stanvliet *et al.*, 2018). This network of protected areas also provides an opportunity to realize and fine-tune the 'ecosystems approach' to natural resource management, which fosters a strategy "*for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way*" (CBD, 2017).

Biosphere Reserves entail a mosaic of ecological (sub-)systems that typically provide a diverse set of ecosystem services and exhibit different degrees of vulnerability, and hence require a differential and adaptable management. They are typically divided into a protected core area, a buffer zone and a transition area (Pool-Stanvliet *et al.*, 2018). This zonation allows for differential use of ecosystem services and for a range of management regimes within each Biosphere Reserve. Managers hence need to identify the ecosystem services delivered by the Biosphere Reserve and need to ensure the long-term provision of these services. Together with the additional income generated by carefully designed Payments for Ecosystem Services (PES)-schemes, Biosphere reserves can continue to improve the livelihoods of the millions of people living in their transition zones and beyond (UNESCO, 2016).

A better knowledge and a better integration of ecosystem services is a key priority for African Biosphere Reserves, as these reserves are facing high anthropogenic pressures. Common causes are the rapid population growth, its strong dependence on natural resources for its livelihoods, weak institutions and competing stakeholder interests in challenging governance conditions (German Federal Agency of Nature Conservation, 2011). Insight in the state and flux of ecosystem services and their use, and in the risk's ecosystem services are facing, is key for sustainable management (Maron *et al.*, 2017). An assessment of the social and economic value of ecosystem services can provide important leverage to safeguard and manage Biosphere reserves and their ecosystem services in a plural way, acknowledging the interests of a wide range of stakeholders. As an example of current threats to well-known and globally recognized biodiversity hotspots in Africa, the recent threats emanating from oil exploration in the Virunga National Park (Democratic Republic of the Congo) and the adjacent Queen Elizabeth Biosphere Reserve (Uganda) should be kept in mind. The economic value of the ecosystem services provided by the intact, un-exploited Virunga National Park, as compiled by WWF & Dalberg (2013) fed the international pressure which ultimately convinced the Congolese government to opt for long-term conservation benefits instead of short-term oil profits.

To ensure that ecosystem services contribute to improved decision-making, the assessment of these services -and their contributions to human wellbeing needs to become systematic, quantifiable, robust and credible (Bagstad *et al.*, 2013). Solid methods to assess and map ecosystem services exist, but remain insufficiently known, used and communicated (Maes *et al.,* 2013; Martinez-Harms *et al.*, 2016; Ruckelshaus *et al.*, 2015). Many decision-support tools have been developed in recent years, yet their applicability and user-friendliness are often context-, site- and user-specific. Moreover, their application is often limited due to high demands of data, skills, time and resources. In order to structure and understand the diversity of these tools, some authors performed reviews attempting to classify these methods and analyse their trade-offs. Bagstad *et al.* (2013) evaluated ecosystem services assessment tools based on their suitability to be mainstreamed in environmental decision-making processes in the most resource-efficient way. Pandeya *et al.* (2016) reviewed tools that contribute to better policy making and are locally applicable in data-scarce areas. Grêt-Regamey *et al.* (2017) reviewed tools that have been operationalized into decision-support for a range of sectors such as water, soil, forest, agriculture and transport; while IUCN (2018) reviewed tools to model and value ecosystem services in among others World Heritage Sites and Key Biodiversity Areas. Despite these valuable efforts, a review of widely applicable, rapid and affordable tools to assess multiple ecosystem services in the specific context of African Biosphere Reserves, building on the expectations of the prospective users of such tools, was still lacking. In this study, we will identify the expectations of prospective tool users, review existing rapid ecosystem services assessment tools based on an integration of these user-generated criteria and criteria from the literature, and subsequently provide users with guidance on ecosystem services assessment tool selection.

In order to ensure that managers of African Biosphere Reserves and other stakeholders gain rapid and reliable access to the ecosystem services assessment tools that are best suited to their demands, their capacities and the available data and resources, this study aims to:

- Provide insight into the evolving landscape of ecosystem services assessment tools and their applicability in the context of African Biosphere Reserves;
- Identify the perspective of prospective users of ecosystem services assessment tools (*e.g.* Biosphere Reserves managers) on management challenges and preferences regarding tool format and objectives;
- Evaluate the characteristics of ecosystem services assessment tools to facilitate an informed selection process when choosing which tool to apply;
- Critically reflect on the design and the use of current and future ecosystem services assessment tools in African Biosphere Reserves.

2 Methodology

2.1 Selecting ecosystem services assessment tools for African Biosphere Reserves: a stepwise approach

The diversity of ecosystem services assessment tools (see *e.g.* Bagstad *et al.*, 2013; Grêt-Regamey *et al.*, 2017; IUCN, 2018) can make it difficult for prospective tool users to see the wood for the trees. We opted for a three-step approach to identify the tools that may be suitable for African Biosphere Reserves.

Step 1: Selection of ecosystem services assessment tools based on a review of existing tools, on evaluation criteria in the scientific literature and on the specific context of African Biosphere Reserves;

Step 2: Identification of user-generated criteria to evaluate ecosystem services assessment tools;

Step 3: Evaluation of selected tools (Step 1) using the user-generated criteria (identified in Step 2); and provision of guidance for tool selection;

2.2 Step 1: Selection of a range of ecosystem services assessment tools

A qualitative screening of ecosystem services assessment tools, frameworks, guidelines and methods (from now on referred as 'tools') was carried out based on the review of the literature in specialized scientific journals (including: *Ecosystem Services, Ecological Economics, Ecological Indicators, Ecological Modelling,* and the *Journal of Environmental Management*) and in the scientific search engines *Web of Science* and *Google Scholar* for the following keywords: ecosystem services assessment, ecosystem services tool, ecosystem services toolkit, ecosystem services framework, ecosystem services guideline(s) and ecosystem services assessment method. Additional tools were identified from specialized databases built by the *Ecosystem Knowledge Network* (https://ecosystemsknowledge.net/), the *Ecosystem Services Partnership* (https://www.es-partnership.org/) and the *ValuES* method navigator (http://www.aboutvalues.net/method_navigator/). Key sources for this step include: Bagstad *et al.* (2013), Grêt-Regamey *et al.* (2017), Oosterbroek *et al.* (2013), Pandeya *et al.* (2016), Peh *et al.* (2013).

The specificities of the African Biosphere Reserves-context were also taken into account. African Biosphere Reserves are characterized by a high diversity of ecosystems, a high diversity of users of ecosystem services, an increasing pressure for access to all areas of- Biosphere Reserves, pervasive governance challenges throughout most African countries, pervasive lack of financial resources, lack of awareness of National MAB Committees, implementation challenges due to lack of resources and uneven capacities, and the excessive workload and/or lack of availability of ecosystem services experts in Africa (German Federal Agency of Nature Conservation, 2011).

Based on the descriptions of the existing tools, and on the context-specific requirements associated with the context of African Biosphere Reserves, we propose the following set of criteria to make a first selection of tools to be evaluated. The ecosystem services assessment tools that will be considered should at least be:

- Generalizable (*i.e.* applicable across a variety of social-ecological settings, while allowing to take into account different local specificities);
- Applicable at the landscape scale (*i.e.* going beyond application on small patches only, allowing to include large zones with different management regimes and/or intensity);
- Applicable independently (*i.e.* without *a priori* requiring external expertise);
- Affordable (*i.e.* without requiring a priori financial investment);
- Able to assess multiple ecosystem services (*i.e.* not focusing on only one category of ecosystem services (*e.g.* not only carbon sequestration, or only water));
- Rapid (*i.e.* requiring less than a year to apply the tool);

The criteria were then confronted to the opinion of potential users, by way of the Delphi technique (see Section 2.3). This resulted in a final list of criteria, that were used to evaluate each tool.

2.3 Step 2: Identification of user-generated criteria to evaluate ecosystem services assessment tools

Despite the increasing awareness of the importance to include the information, views and preferences of stakeholders into decision-making, until now, reviews focusing on ecosystem services assessment tools have typically failed to systematically acknowledge the perspective of prospective tool users. In order to gather the perspectives and expectations of the prospective users of ecosystem services assessment tools in African Biosphere reserves, we used the Delphi technique. The Delphi technique is a structured, anonymous and iterative survey, and typically aims to address complex issues that require inputs from different disciplines and backgrounds (Mukherjee *et al.*, 2015). The Delphi participants remain mutually anonymous (no participant knows what any other participant is responding), which contributes to address a range of social pressures that can negatively affect group-based approaches (biases such as groupthink, halo effects, egocentrism, and dominance are reduced – as there is no face-to-face interaction among participants) (Mukherjee *et al.*, 2015). During the successive rounds of the iterative Delphi survey, participants tend to move towards consensus on some issues, as they are progressively exposed to the opinions of their peers (Mukherjee *et al.*, 2015). In our study, we set the level of consensus at >50%, meaning that a tool's characteristic is accepted (deemed relevant for an ecosystem services assessment tool) if at least 50% of the respondents selected the characteristic after round 2 (which is in line with von der Gracht (2012) and Mukherjee *et al.*, (2015)).

For this study, all Delphi participants were members of the African Network of Biosphere Reserves (AfriMAB), who are all involved with the strategic and/or day-to-day management of African Biosphere Reserves. All attendants of the 5th General Assembly of AfriMAB, held in Ibadan, Nigeria, in September 2017, were given the opportunity to participate in the Delphi survey. We conducted a two-round Delphi survey, that could be answered online using Google Forms, or completed on paper forms. Each Delphi round consisted of two main sections, with regard respectively to: *i.* the management challenges faced by African Biosphere Reserve managers; *ii.* the desired characteristics of ecosystem services assessment tools. The two rounds of the online survey were completed individually and anonymously by the respondents in September 2017. Twenty-four respondents participated in the first Delphi round, and twenty-two participants took part in the second round, which is in line with the average number of respondents in Delphi studies as reported by Mukherjee *et al.* (2015) and Hugé *et al.* (2018). The profile of the respondents is described in the Results section.

3. Results

3.1 User expectations regarding ecosystem services assessment tools

3.1.1 Profile of the Delphi respondents

We present the profiles of the respondents of the second round (n = 22), as these respondents completed the full Delphi process (in line with Mukherjee *et al.*, 2014). Figure 1 gives the profile of the actual Delphi respondents and the profile of all the participants to the 2017 AfriMAB General Assembly (which hence represents the population from which the Delphi respondents originate).

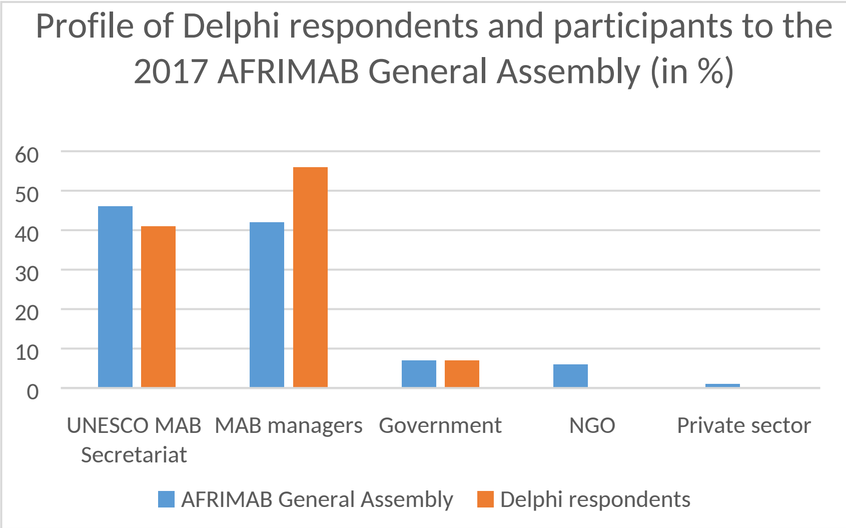

Figure 1: Profile of the Delphi respondents and the participants to the 2017 AfriMAB General Assembly (in %)

3.1.2 Main management challenges faced in African Biosphere Reserves

Table 1 presents the main management challenges according to the Delphi respondents.

Table 1: Main management challenges in African Biosphere Reserves according to the respondents. Only challenges scoring over >50% consensus are mentioned with the percentage indicating the share of respondents that selected this challenge. The trends in scores between round 1 and round 2 are indicated.

	Consensus level	Score variance	Trends in scores between rounds
Inadequate financial resources	90%	15%	↑
Pressure from human activities	70%	20%	↓
Limited capacity (*e.g.* human resources)	55%	15%	↑
Unavailability of data to support management	55%	20%	↑

3.1.3 Desired characteristics of ideal-typical ecosystem services assessment tools

Table 2 outlines the desired characteristics of an ideal-typical ecosystem services assessment tool, according to the Delphi respondents. Criteria to evaluate ecosystem services assessment tools can be drawn from this set of user-generated desirable characteristics. These criteria are synthesized in Section 3.3.

Table 2: Results of the Delphi (after 2 rounds) regarding the desired characteristics of ecosystem services assessment tools. Only characteristics with scores showing >50% consensus are presented. (*ES stands for ecosystem services*)

Tool descriptors		Consensus level	Score variance	Trend in scores between rounds
Purpose	Environmental awareness raising & education	70%	10%	↓
	Scoping & description of provided ES	65%	10%	↑
	Supporting ES monitoring & evaluation	65%	25%	↑
	Identifying livelihood, development & investment opportunities	55%	25%	↓
Characteristics	Ability to assess multiple types of ES	60%	10%	↓
	Low expertise requirements to be applied	55%	20%	↑
	Provide results that are easy to communicate	55%	5%	↑
Outputs	Quantitative output	53%	15%	↑
	Economic valuation	58%	5%	↑
Inputs	Maps	78%	15%	↓
	Quantitative input	83%	5%	=
	Qualitative input	61%	5%	↓
Hiring someone to apply ES assessment tools	Yes	84%		↑
Most restrictive criterion for fieldwork	Technically demanding	56%	20%	↑
	Expensive	67%	10%	↑

3.2 Criteria to evaluate ecosystem services assessment tools: synthesis

These criteria are synthesized based on the results of the Delphi (Section 3.1.3) and on the existing literature (incl. Peh *et al.,* 2013; Grêt-Regamey *et al.,* 2017; Pagella & Sinclair, 2014; Turner *et al.*, 2016; Villa *et al.*, 2014).

Table 3: Synthesis table outlining criteria to evaluate ecosystem services assessment tools, based on a combination of user-generated preferences and literature sources.

Criteria	Categories (multiple answers possible)
Input data needed	• Spatial data (maps, GIS data) • Stakeholder-based input • Data from field sampling (own site-specific data) – primary sources • Available data – secondary sources
Skills required to apply the tool	• GIS software & skills • Skills in field ecology • Skills in stakeholder's involvement/ participatory processes
Output data generated	• Spatial data • Qualitative outputs • Quantitative outputs • Economic valuation
Ecosystem services addressed	• Provisioning • Regulating • Cultural • Supporting
Time requirements	• Days-week • Weeks-month • Months-year

3.3 Evaluation of the selected ecosystem services assessment tools

Table 4 describes all ecosystem services assessment tools that meet the pre-selection criteria outlined in Step 1 (Section 2.2), and describes these tools using the synthesis criteria outlined in Table 3 (Section 3.2).

Table 4: Description of ecosystem services assessment tools. (⏱ indicates that applying the tool typically takes days-weeks, ⏱⏱ weeks-months and ⏱⏱⏱ months-year).

Tool	Input	Skills	Output	Ecosystem services	Purpose	Sources
A Geographic Information Systems-based LUC change model (GEOMOD) ⏱⏱	Spatial data; Available data	GIS	Spatial data; Quantitative data;	A-Supporting: biodiversity, water purification, soil formation; B- Regulating: climate and water regulation, erosion control, moderation of extreme events; C-Provisioning: food & fibre, raw materials; D-Cultural: recreation, cultural diversity.	Modelling land use/cover changes between two time periods	Estoque & Murayama, 2012
ARIES Artificial Intelligence for Ecosystem Services ⏱ / ⏱⏱	Spatial data; Available data	GIS	Spatial data; Quantitative data; Qualitative data: Economic valuation	A-Supporting: water supply; B-Regulating: carbon sequestration and storage, flood regulation, nutrient regulation, sediment regulation; C-Provisioning: subsistence fisheries; D-Cultural: open space proximity, aesthetic viewsheds, recreation	Modelling and mapping ES flows and distribution of beneficiaries; Comparison between different scenarios (*e.g.* climate, land use...)	Bagstad *et al.*, 2011; Villa *et al.*, 2009
CLIMSAVE Integrated Assessment (IA) Platform ⏱⏱	Available data		Spatial data; Quantitative data; Qualitative data	A-Supporting: /; B-Regulating: climate regulation, flood regulation, water flow regulation, pollination; C-Provisioning: food, fresh water, raw materials; D-Cultural: /	Impact prediction of climate change and vulnerability; Identifying adaptation strategies and their cost-effectiveness	Harrison *et al.* 2015
Co$ting Nature ⏱	Available data	GIS, Field ecology	Spatial data; Quantitative data; Qualitative data	A-Supporting: biodiversity, total carbon; B-Regulating: water quantity and quality, hazard mitigation; D-Cultural: recreation	Mapping ES; Assessing impact of policy interventions or future scenarios on ES; Prioritizing areas for conservation	Co$ting Nature, 2018

Tool	Input	Skills	Output	Ecosystem services	Purpose	Sources
Ecosystem Services Review ⏱⏱⏱	Stakeholder-based input; Available data	Stakeholder involvement	Qualitative data	All	Identifying business dependencies, risks, and opportunities related to ES	Hanson *et al.* 2012.
Ecosystem Services Review for Impact Assessment ⏱⏱	Stakeholder-based input	Stakeholder involvement; Field ecology	Qualitative data	All	Identifying dependencies and impacts of a project on priority ES; Identifying options to mitigate negative project impacts;	Landsberg *et al.* 2014; Landsberg *et al.* 2011
ESP-VT Ecosystem Services Partnership Visualization Tool ⏱	/ (visualization tool)	GIS	Spatial data; Quantitative data; Economic valuation	All	Visualizing existing information about ES in an area	Drakou *et al.* 2015
Green Infrastructure Valuation Toolkit ⏱⏱	Spatial data; Stakeholder-based input; Field sampling; Available data		Quantitative data; Quantitative data; Economic valuation	A-Supporting: biodiversity, land management; B-Regulating: climate change adaptation and mitigation, water and flow management; C-Provisioning: investment, labour productivity	Preparation, assessment and reporting of the value of a 'green' asset or investment; Comparison of project options; Support and mainstream green infrastructure	Natural Economy Northwest *et al.* 2010
Interdisciplinary Decision Support Dashboard (IDSD) ⏱⏱	Spatial data, Stakeholder-based input; Available data; Field sampling		Spatial data; Quantitative data; Qualitative data	A-Supporting: landscape structure and composition, soil nutrient balance, soil organic matter, carbon stocks, climate; B-Regulating: water availability; C-provisioning: fuel wood availability, variability in livelihood	Visualize state and dynamics of natural resource and agricultural metrics and indicators; Decision support	Fegraus *et al.* 2012.

Tool	Input	Skills	Output	Ecosystem services	Purpose	Sources
InVEST Integrated Valuation of Ecosystem Services and Tradeoffs ⏱⏱⏱	Spatial data; Stakeholder-based input; Available data	GIS, Stakeholder involvement	Spatial data; Quantitative data; Economic valuation	A-Supporting: habitat quality, water purification; B-Regulating: crop pollination, climate regulation, coastal protection, marine water quality, habitat risk assessment; C-Provisioning: timber production, energy production, aquaculture production; D-Cultural: scenic quality, nature-based recreation and tourism	Mapping ES; Supporting spatial planning and conservation strategies; Comparing scenarios; Impact assessment	Tallis *et al.,* 2013
i-Tree Eco. Tools for assessing and managing forests & community trees ⏱⏱	Available data; Field sampling	GIS, Field ecology	Quantitative data; Spatial data	All	Provision of baseline data to influence decision-making; Capacity building for small stakeholders; Improve forest management	USDA 2015
MARXAN and MARXAN with zones ⏱⏱⏱	Spatial data; Field sampling; Available data; Stakeholder-based input	GIS, Field ecology	Spatial data; Quantitative data; Qualitative data	Any ES that can be modelled spatially	Identification of areas suitable for conservation; Provision of information about cost effective conservation alternatives; Evaluation of the performance of existing reserves; Identification of alternative management options	Ball *et al* 2009.
PA-BAT The Protected Areas Benefits Assessment Tool ⏱ ➔ ⏱⏱	Stakeholder-based input	Stakeholder involvement	Qualitative data; Economic valuation	All	Identification of benefits provided by Protected Areas;	Dudley & Stolton, 2009
Simulation of Terrestrial Environments (SITE)	Spatial data; Stakeholder-based input; Field	Stakeholder involvement	Spatial data; Quantitative data; Qualitative data	Potentially all	Scenario analysis;	Helmholtz Centre for Environmental Research-UF, Leipzig

Tool	Input	Skills	Output	Ecosystem services	Purpose	Sources
⏱ → ⏱ ⏱	sampling; Available data				Assessment of impacts of land-use change on socio-environmental aspects;	
Social values for ecosystem services (SolVES) ⏱ ⏱	Spatial data; Stakeholder-based input	GIS; Stakeholder involvement	Spatial data; Quantitative data; Qualitative data	A-Supporting: habitats for species, biodiversity; B-Regulating: /; C-Provisioning: /; D-Cultural: aesthetic inspiration for culture, spiritual experience and identity, tourism, recreation.	Assessment, mapping and quantification of the social values of ecosystem services; Facilitation of discussions among diverse stakeholders about the trade-offs among ES	Sherrouse & Semmens 2015
Soil Water and Assessment Tool (SWAT) ⏱ ⏱ → ⏱ ⏱ ⏱	Spatial data; Available data; Field sampling	GIS	Spatial data; Quantitative data; Qualitative data	A-Supporting: ...; B-Regulating: water quality, soil erosion, carbon stock, flood regulation, etc.; C-Provisioning: water yield, crop yield, vegetation biomass, etc.; D-Cultural:/	Evaluation of the effect of land management on hydrological processes, sediment, nutrients and pesticide yields; Investigation of decade-long impacts	Duku *et al.* 2015.
Toolkit for Ecosystem Service Site-based Assessment (TESSA) ⏱ → ⏱ ⏱	Stakeholder-based input; Available data; Field sampling	Stakeholder involvement	Quantitative data; Qualitative data; Economic valuation	A-Supporting: /; B-Regulating: climate regulation, flood protection, water quality improvement; C-Provisioning: harvested wild and cultivated goods, water provision; D-Cultural: nature-based recreation	Prioritization, quantification and monetary estimation of ES; Comparing current situation with a most likely state of the site	Peh *et al.* 2013

2.4 Visual representation of the ecosystem services assessment tools

While Table 4 provides a detailed schematic description of every ecosystem services assessment tool, Figure 2Figure 3,Figure 4 Figure 5, provide a visualization of the inputs, outputs, required skills and addressed ecosystem services for each tool. The full names of the tools can be found in Table 4. This visual representation allows prospective tool users to quickly select which tool suits their needs and capacities best. Moreover, it allows to select tools based on different perspectives (*e.g.* based on available input data, on desired outputs *etc.*).

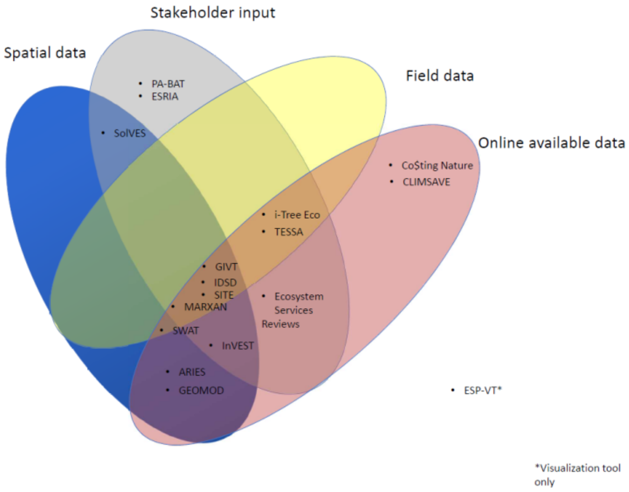

Figure 2: Overview of ecosystem services assessment tools based on required input data

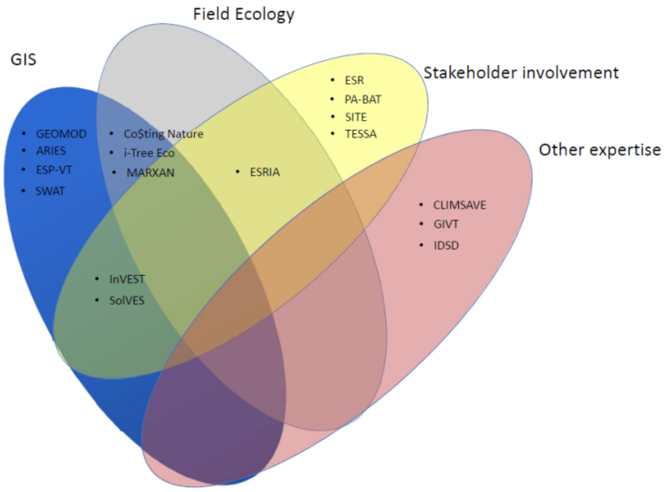

Figure 3: Overview of ecosystem services assessment tools based on required skills

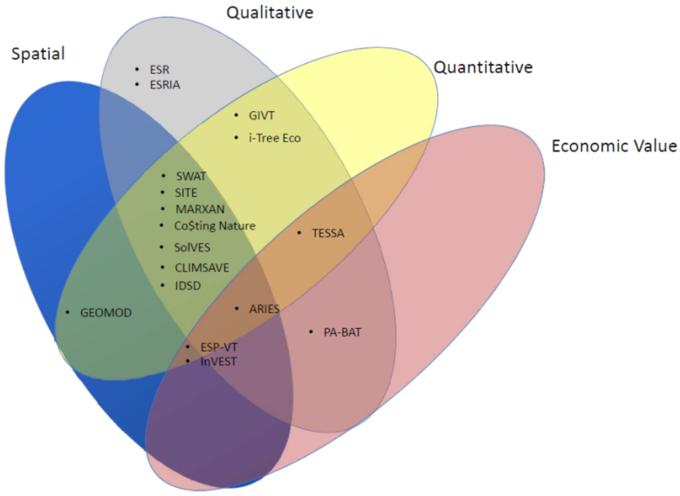

Figure 4: Overview of ecosystem services assessment tools based on generated output data

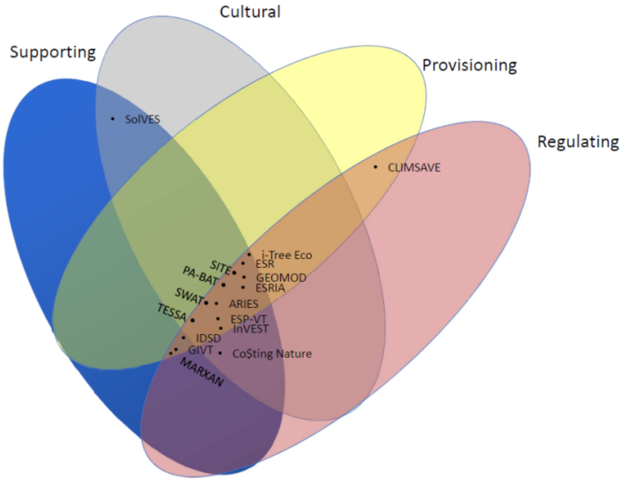

Figure 5: Overview of ecosystem services assessment tools based on ecosystem services addressed

4. Discussion

4.1 The methodological challenge of selecting suitable ecosystem services assessment tools

The potential impact one can have on decision-making by adopting and translating the concept of ecosystem services has triggered high expectations among scientists and managers since the concept was popularized in 2005. This has led to the development of a wide range of tools that have as stated aims the translation, visualization and 'easy' communication of the inherently complex processes that drive the provision, use and management of ecosystem services. Faced with real-world constraints such as limited time, limited financial resources and limited capacity, scientists, reserve managers and decision-makers constantly need to make trade-offs regarding which tool to use to assess and map ecosystem services. While other authors have proposed categorizations and criteria to select the most appropriate ecosystem services assessment tools (*e.g.* Bagstad *et al.*, 2013; Pandeya *et al.,* 2016, Grêt-Regamey *et al.*, 2017; IUCN, 2018), the tool evaluation process and the choice architecture we propose in this current study is based on the systematic identification of user preferences, for which we used the Delphi method. However, while useful to elicit knowledge and preferences, the Delphi method cannot be used as the only source of information to develop criteria for tool selection. The participants' backgrounds introduce some subjectivity, as all were AfriMAB meeting attendants and hence have a stated interest and a deep knowledge of the challenges of managing Biosphere Reserves. The Delphi method allows to collect both the individual and the collective intelligence of the participants, and is suited in situations where there is a lack of established facts and when a consensus needs to be found on complex issues. The number of participants (n=22) that completed the two Delphi rounds is within the range of other Delphi studies (between 8 and 46 participants (Mukherjee *et al.*, 2015)). To obtain a more comprehensive picture of the different stakeholders' expectations regarding ecosystem services assessment tools, ideally a larger number of potential users should be contacted. In order to harness the power of live group discussions while simultaneously ensuring that tool quality criteria can be prioritized, a series of Nominal Group Technique-applications could be useful in the future. Furthermore, given the diversity of direct and indirect beneficiaries of ecosystem services provided by African Biosphere Reserves, the pool of indirect tool users (or at least of people whose lives can be impacted by the uptake of the findings of the proposed tools) should be widened, and they should ideally be included in tool selection processes.

When evaluating a range of tools (n=17), one is unavoidably confronted by the challenges of presenting dense information in a user-friendly yet systematic way. While tables outlining the characteristics of tools are a common presentation format (*e.g.* in Bagstad *et al.*, 2013, Pandeya *et al.*, 2016; IUCN, 2018), arrows depicting successive (ever more in-depth) steps in the process of ecosystem services assessment (as in Bagstad *et al.*, 2013) are also used. Every tool categorization system also emphasizes different aspects of the tools, depending on the scope of the analysis and the preferences of the authors: Pandeya *et al.* (2016) classify tools based on their valuation approaches; Grêt-Regamey *et al.* (2017) classify tools based on their spatial scales, while IUCN classifies tools (among others) based on the underlying reasons to measure ecosystem services (*e.g.* private sector engagement, funding and investment, knowledge generation).

In this study we have avoided the use of a decision-tree to guide users to the most adapted tool (contrary to *e.g.* IUCN (2018)), and instead provide four 'lenses' to select a tool in our visualization (Figure 2,Figure 3,Figure 4 and Figure 5), allowing prospective tool users to base their selection on the required input data, the expected output, the required skills and/or the types of ecosystem services addressed by the tool. In Table 4, the overall purpose of each tool is added, as are the time requirements. In doing so we chose not to pre-empt the selection process of the users.

Inevitably, making choices regarding which criteria are deemed most relevant and useful to select a tool involves a reduction of all possible criteria that are found in the literature. The user expectations guided the selection of criteria, while existing literature provided extra inspiration.

The lack of coordination between tool developers and practitioners is an enduring problem, already identified by Bagstad *et al.* (2013), which is however hard to avoid due to the innovative, open-source character of many tools. A pragmatic approach to ecosystem services assessment tools ideally requires a search for synergies between external and local learning objectives and hence may require the combination of different (part of) tools (van Noordwijk *et al.*, 2013). For example, combining field data with existing environmental datasets improves the quality of ecosystem services maps (Martinez-Harms *et al.*, 2016). A flexible yet informed, cherry-picking approach to tools application can be justified by data requirements, data availabilities and by the urgency to present decision-makers with ecosystem services information in a timely manner.

4.2 The African Biosphere Reserve context

While ecosystem services assessment tools can in theory be used everywhere, many tools come with restrictions that cannot easily be ignored. Some tools require input of existing datasets which may be incomplete, reflecting the geographic bias in ecological research and the comparative neglect of Africa (DiMarco *et al.*, 2017), and/or reflecting the lack of centralized and accessible data repositories, despite the ongoing efforts of among others, the Clearing House Mechanism (CHM) of the Convention of Biological Diversity. Some tools may require skills that are not widely distributed in the rural areasof Africa, where most of the African Biosphere Reserves are located. Especially ground truthing, the economic valuation of biodiversity and the application of modern technologies in biodiversity monitoring are lacking in the global South (Vanhove *et al.*, 2017). Some tools were initially developed with a non-African context in mind (such as CLIMSAVE with its European focus or the i-Tree-Eco set of tools, which have a USA-focus). This does not necessarily mean these tools are not applicable in an African context, however data availability may be an obstacle. The IDSD-tool on the other hand, has been developed with a Tanzanian context in mind.

Next to the specific data and capacity challenges, the direct dependence of many stakeholders towards ecosystem services provided by Biosphere Reserves highlights the need to explicitly acknowledge the perceptions of ecosystem services' providers and beneficiaries (Pandeya *et al.,* 2016), and to measure and monitor stakeholders' expectations and perceptions about ecosystem services use and trends. A tool like SOLVES focuses specifically on stakeholder perceptions of non-monetary values ascribed to particular ecosystem services, the so-called social values of ecosystems. In total seven of the seventeen tools do require stakeholder engagement skills (see Figure 3) and hence take into account stakeholders' perceptions. The RESPA-tool (which lies outside the scope of this review) assesses stakeholders' familiarity with ecosystem services and their relative importance to them (Rey-Valette *et al.*, 2017). While locals, often have context-specific knowledge of ecosystem services that is easily missed by modelling tools, their input and hence often long-term (informal) managers of ecosystem services is also essential to develop collaborative, socially robust solutions with large buy-in. This is an essential element of inclusive conservation, which encompasses different motivations for conservation, ranging from the intrinsic to the instrumental (Tallis & Lubchenco, 2014; Chan *et al.*, 2016). Given the exemplary function of African Biosphere Reserves as 'living labs' where inclusive sustainable development can be realized, any ecosystem services assessment tool that is used within this context should ideally be able to englobe the diversity of views on nature and its management. This de-polarizing approach to conservation and natural resource management is of utmost importance in the African context, where governance challenges remain pervasive, and where the threat of the militarisation of conservation is real (Duffy *et al.*, 2019).

4.3 From applying tools to influencing decision-making

Applying carefully selected ecosystem services assessment tools based on a user's set of expectations is a first step, yet the ultimate objective is to have an impact on actual decisions, *e.g.* decisions related to the management of a Biosphere Reserve. Bridging the gap between science and policy by linking nature and human wellbeing is the stated aim of the ecosystem services concept (see *e.g.* Mace, 2014). This requires tool outputs that are easily communicated to decision-makers, and a capacity of decision-makers to take up and engage with these outputs. Decision-makers typically prefer a variety of ecosystem services metrics (Ruckelshaus *et al.*, 2015), which may require the use of tools producing multiple outputs, or the combination of complementary tools (see also Section 4.1). In order to be useful to decision-makers, tools must be customizable (Martinez-Lopez *et al.*, 2019) and must foster innovation. Experimentation (*e.g.* using modules originating from different tools) needs to be encouraged, hence the importance of freely available tools and supporting datasets. Training is required both at the data production side (scientists, managers, consultants applying the tools) and at the data uptake & translation side (decision-makers, managers). Transparent communication about the motivations underlying methodological choices is essential. Communicating uncertainty is key in order to ensure the credibility of rapid ecosystem services assessment tools and in order to allow for informed and flexible management trade-offs by decision-makers. However, Grêt-Regamey *et al.* (2016) state that almost half the tools their team reviewed do not quantify these uncertainties. The lack of maintenance and long-term availability of some tools and their online support is a risk, and a consequence of the often time-limited project-based funding of such tools. Uptake and institutionalization of these tools, for example by networks such as AfriMAB (the African Network of Man & Biosphere Reserves) could contribute to solve this issue.

While most tools reviewed in this study have been extensively applied in the field, not all have been applied in Biosphere Reserves, and not all applications have been subject to scientific scrutiny. The INVEST tool applications have been reviewed by Ruckelshaus *et al.* (2015) and have had impact at different decision-making levels. The TESSA tool application for the Shivapuri-Nagarjun National Park in Nepal yielded estimates of avoided monetary loss thanks to conservation (Peh *et al.,* 2016). In order to evaluate the range of impacts ecosystem services assessment tools can have on decision-making on the short- and the long-term, a more comprehensive model of tool effectiveness needs to be kept in mind, focusing on their substantial impact on well-defined decisions, as well as on their less directly measurable normative impact (*e.g.* tools fostering –social- learning and changing mind-sets) (Hugé *et al.,* 2015). An increased awareness of the diversity of existing tools and guidance for prospective tool users will increase the number of applications of such tools and will consequently increase our understanding of their impact.

5. Conclusion

The diverse and dynamic landscape of ecosystem services assessment tools reflects the diversity of representations of the relationship between people and nature. Ecosystem services assessment tools typically start from a range of assumptions about what is important, what is measurable and what is urgent to address – and these assumptions differ between the teams developing the tools. This situation creates a rich landscape of tools in which potential tool users may find it difficult to navigate. The difficult trade-off between simple and complex approaches to ecosystem services assessment should not lead to inaction, as the diversity of tools and their respective strengths and coverage offer opportunities for users with different expectations to find the most suitable tool, while also providing inspiration for users aiming at developing new tools.

In this study, we present a categorization of ecosystem services assessment tools that are adapted to the context of African Biosphere Reserves, based on a combination of literature review and a user survey. We propose a tool selection process and we critically discuss the challenges of developing, selecting and applying such tools. There is no one-size-fits-all approach to ecosystem services assessment tools, and the resource-constrained context of African Biosphere Reserves creates extra challenges that will influence the tool selection process. Tools are not applied in a governance vacuum. Hence the impact of the application of such tools should not only be measured based on their technical quality, but also on their short- and long-term impact on actual decision-making – *i.e.* on the management of Biosphere Reserves. Given the strategic importance of African Biosphere Reserves as key sources of ecosystem services for a directly nature-dependent human population, and given the exemplarity of Biosphere Reserves as living labs for sustainable development, the sound selection and application of ecosystem services assessment tools takes on a particular urgency.

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