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Do ecosystem service maps and models meet stakeholders' needs? A preliminary survey across sub-Saharan Africa

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ABSTRACT

To achieve sustainability goals, it is important to incorporate ecosystem service (ES) information into decision-making processes. However, little is known about the correspondence between the needs of ES information users and the data provided by the researcher community. We surveyed stakeholders within sub-Saharan Africa, determining their ES data requirements using a targeted sampling strategy. Of those respondents utilising ES information (>90%; n=60), 27% report having sufficient data; with the remainder requiring additional data – particularly at higher spatial resolutions and at multiple points in time. The majority of respondents focus on provisioning and regulating services, particularly food and fresh water supply (both 58%) and climate regulation (49%). Their focus is generally at national scales or below and in accordance with data availability. Among the stakeholders surveyed, we performed a follow-up assessment for a sub-sample of 17 technical experts. The technical experts are unanimous that ES models must be able to incorporate scenarios, and most agree that ES models should be at least 90% accurate. However, relatively coarse-resolution (1–10 km^2) models are sufficient for many services. To maximise the impact of future research, dynamic, multi-scale datasets on ES must be delivered alongside capacity-building efforts.

1. Introduction

An understanding of ecosystem services (the benefits humans get from nature; ES) is critical for decision-making if multi-functional landscapes are to be successfully managed to maximise long-term benefits for society (Carpenter et al., 2009; Millennium Ecosystem Assessment, 2005). Decisions and policy regarding land and water management can be improved through the provision of quantitative ES information (defined here as data that assists with decision-making, including reports, maps, models, lists, websites, biophysical surveys and social surveys) derived through robust and repeatable methods, based on spatially-explicit data (Bastian et al., 2012; Fisher et al., 2009; McKenzie et al., 2011). This could be especially so in developing countries, where the rural poor are often highly dependent on ES for their livelihoods, especially as a safety net during crises (Enfors and Gordon, 2008; Shackleton et al., 2008).

Globally, ES science has had relatively broad uptake into policies and management plans by a range of stakeholders. For example, some governments (e.g. China), development agencies (e.g. the World Bank), non-governmental organisations (NGOs; e.g. Conservation International) and businesses (e.g. Unilever) have made substantial efforts to incorporate ES into their missions and practices (Ruckelshaus et al., 2013; Wong et al., 2014). This relatively rapid uptake into policies and management may indicate that ES science has a high potential to alter decision-making practices, leading to more ecologically sound decisions. However, the realisation of the concept appears to be limited, with few documented examples demonstrating how ES concepts have

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changed decision-making outcomes (Laurans et al., 2013; Ruckelshaus et al., 2013). For example, a number of recent papers have critically analysed the scientific literature to evaluate the production and utilisation of ES information, focussing on methodological frameworks and data availability (Crossman et al., 2013; Egoh et al., 2012; Laurans et al., 2013; Martínez-Harms and Balvanera, 2012; McKenzie et al., 2014; Ruckelshaus et al., 2013; Wong et al., 2014). However, other than isolated local-scale studies (e.g. Sitas et al., 2013, 2014), the implementation gap between the potential impact of ES research and its utilisation in practice remains and has yet to be investigated through engagement with stakeholders (Laurans et al., 2013). Such engagement is vital if ES science is to move towards demand-driven research (Honey-Rosés and Pendleton, 2013).

Our goal in this study was to provide a first-order evaluation of potential reasons for the implementation gap by systematically surveying stakeholders about both their current use of ES information and of their future requirements and needs, in a region where quantitative data are scarce. Stakeholders are defined here as individuals capable of directly or indirectly influencing the long-term development of policy (e.g. impacting the visibility of particular issues, or being involved in discussions and what technical knowledge is emphasised), following Ruckelshaus et al. (2013). Specifically, we investigate: 1) *if stakeholders lack sufficient knowledge and training to utilise ES information* (Laurans et al., 2013); and 2) *whether existing ES information is fundamentally inadequate*. For the latter, we ask whether those surveyed can get access to information for their desired ES at the appropriate temporal or spatial scales, or whether they perceive the available ES information as too uncertain or too inaccurate to support changes in policy or practices (Bingham et al., 1995; Toman, 1998; Turner, 2007). We focus on sub-Saharan Africa as this is one of the world's poorest regions, so any changes in practice or policy could have substantial impact on human well-being (Enfors and Gordon, 2008; Shackleton et al., 2008). This region is, however, perhaps the most data-poor in the world, with little proof of evidence-based ES decision-making (Crossman et al., 2013; Egoh et al., 2012; Martínez-Harms and Balvanera, 2012; Ruckelshaus et al., 2013; Wong et al., 2014).

Table 1
A summary of the survey structure and questions.

Start of survey			
Organisation At what scale do you carry out most of your work? In which fields do you carry out most of your work? Do you work with ecosystem services as part of your job?			
If yes, Which ecosystem services do you work with? In what way(s) do you use information on ecosystem services? What information of tools on ecosystem services do you find useful in your job? Do you make use of ES maps in your work?		If no, Why not?	
If yes, Please give a specific example of how you have used them in your work Do you make use of ES models in your work?	If no, Why not?		
If yes, Please give a specific example of how you have used them in your work Do you currently have adequate information or tools on ecosystem services to carry out your work?	If no, Why not?		
If yes, Do you required additional information/tools on ES at a difference spatial scale?		If no, Does the inadequacy of information/tools on ES relate to spatial scale?	
If yes, At what spatial scale? Do you require additional ES information/tools on ES at different time points?	If no,	If yes, At what spatial scale? Does the inadequacy of information/tools on ES relate to different time points?	If no,
If yes, At what time point? At what temporal scale? Do you require additional information/tools on different ecosystem services?	If no,	If yes, At what time point? At what temporal scale? Does the inadequacy of information/tools on ES relate to the type of ecosystem services?	If no,
If yes, Which ES? Do you require additional information/tools on ES that are linked to specific policy/policies?	If no,	If yes, Which ES? Does the inadequacy of information/tools on ES relate to policy applicability	If no,
If yes, Which policy/policies?	If no,	If yes, Which policy/policies should the information relate to/inform?	If no,
Is there any other information related to ES, not mentioned above, that you would find useful to carry out your job? Do you consent to being contacted for more information?			
End of survey			

2. Method

2.1. Survey methodology

The survey was designed to elicit perceptions of the adequacy of existing ES information and capacity, alongside qualitative statements whereby respondents could give in-depth responses detailing specific issues related to their work (Table 1; Appendix A). The survey was conducted in two phases. Firstly, we surveyed stakeholders at the Capacity Building for Undertaking Ecosystem Assessment workshop in Pretoria, South Africa (3rd–6th February 2014). Secondly, we developed an online version of the same survey in both English and French using Google Forms. The online survey was circulated by email to other stakeholders from sub-Saharan Africa who are engaged in projects in the Ecosystem Services for Poverty Alleviation research programmme (http://www.espa.ac.uk/). The online-survey was open from 1st April to 30th June 2014.

We employed a targeted sampling strategy, focussing on stakeholders already engaged with general ES concepts, but not actively selecting people working with specific ES types (i.e. provisioning, regulating, supporting, and cultural) nor topics (e.g. food production, forest management etc). For example, the workshop in Pretoria was held to assist engagement with the Intergovernmental Platform on Biodiversity and Ecosystem Services and so attracted stakeholders with a general ES interest. It is also conceivable that, of those invited to partake in this study, stakeholders already using ES in their work were more inclined to invest time in completing the survey. This would result in an over-estimate of the proportion of stakeholders utilising ES information, therefore underestimating the implementation gap. Our aim, however, was not to *quantify* the implementation gap, but to understand *why* it remains. By favouring those stakeholders engaged in using ES

Table 2
A summary of the follow-up survey structure and questions.

Start of survey	
Organisation At what scale do you carry out most of your work? In which fields do you carry out most of your work? Do you work with ecosystem services as part of your job? What features would you consider in selecting which ES model to use? What spatial scale do/would you require outputs from ecosystem service models? What units are most relevant to your needs and what unit precision do/would you require? Do/would you use ranked information to support ecosystem service related decision?	
If yes, What unit of precision of percentage groups do/would you require?	If no,
What is the minimum level of certainty that you require/would require from ES models? Is there any other information related to ES, not mentioned above, that you would find useful to carry out your job? Do you consent to being contacted for more information?	
End of survey	

information, this approach provides insights into the reasons stakeholders are unable to use ES information despite a willingness to do so. Understanding the reasons behind why some potential stakeholders are not engaged in using ES information would benefit ES scientists and society, but is beyond the scope of this investigation. Our findings concerning the priorities, preferences and needs of stakeholders that are utilising ES information are likely transferable to similar stakeholders (i.e. those willing to use ES information to support evidence-based decision-making); however, caution should be applied when extrapolating our results to the wider policy-making community in sub-Saharan Africa.

Overall, we received 60 responses; 27 from the workshop and 33 from the online survey (Appendix B). 33 of these respondents indicated they perceived themselves as having enough expertise to take part in a more technical follow-up survey gathering information on the required resolution, precision and accuracy of ES models and their outputs (Table 2; Appendix C). For the purpose of this investigation, an ES model is defined as schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for further study of its characteristics (e.g. computer models such as InVEST, ARIES or GIS based models (Villa et al., 2014)). Whilst models are often required to produce maps, models differ from maps in that they can be run repeatedly, producing multiple outputs that are often customisable; whereas a map is typically a singular output, whose inputs and processes are fixed and non-customisable by the end user (Bagstad et al., 2013). The follow-up survey was developed in English using Google Forms and open from 1st June to 30th July 2015, receiving 17 responses (52% response rate). Whilst our sample is relatively small (n=60 for the initial survey, and n=17 for the follow-up survey), it can provide a first-order estimate of ES information needs in the data-deficient region of sub-Saharan Africa (Brancalion et al., 2014; García-Nieto et al., 2013; Iniesta-Arandia et al., 2014; Mascarenhas et al., 2014; McKenzie et al., 2014; Schomers et al., 2015; Sell et al., 2006; Sitas et al., 2014).

2.2. Analysis of survey results

The analysis involved three methods: descriptive analyses, non-parametric Spearman's rank tests and Chi-square tests. Descriptive statistics were produced by calculating the percentage of respondents, along with 95% confidence intervals (CI), that indicated a specific answer based on the number of respondents asked that particular question; these tests illustrate, for example, the capacity of stakeholders to utilise ES information. Spearman's rank and Chi-square tests were used to evaluate differences between use and demand for ES information in terms of type, spatial scale and temporal scale, highlighting inadequacies in available ES data. Spearman's rank tests were used to compare if the priorities of the stakeholders differed between the ES information they currently use and that they desire to use (Table 1). Chi-square tests were performed on the same responses to quantify differences in the used and desired levels of ES information, which can vary even where the ranking is not significantly different. Since we did not collect information on the temporal scale of ES information that decision-makers currently use and rank-tests for variables with few categories are not sensible, we only performed a Chi-square test to quantify differences between the temporal scales desired and used by decision makers. To ensure equal total sample size, the number of answers given per category for each of the two comparator groups (i.e. used vs. desired) was corrected with the ratio of total answers among the groups. All analyses were repeated, and checked for overarching differences between the two survey methods and for potential distinctions between type of organisation indicated by the respondents (academic, NGO or governmental). All analyses were performed using R version 3.0.1 (R Core Team, 2013).

3. Results

3.1. Respondent descriptive statistics

Our respondents comprised stakeholders from 38 counties, covering all regions of sub-Saharan Africa. Broadly, the types of organisation indicated by the respondents fall into three distinct categories: academic, ranging from PhD students to professors; NGO, including Technical Advisors, Programme Officers and Executive Directors; or governmental, including Coordination Managers, Biodiversity/Natural Resource Officers and Heads of Department. Respondents self-identify their fields of work (individuals gave multiple responses) as environment/nature (80 ± 10%), agriculture (55 ± 13%), and research (53 ± 12%); a full list of respondents' fields of work is provided in Appendix D. Irrespective of their field, most respondents work at national scale or below (Fig. 1), with few working at international (10 ± 8%) or continental scales (3 ± 5%).

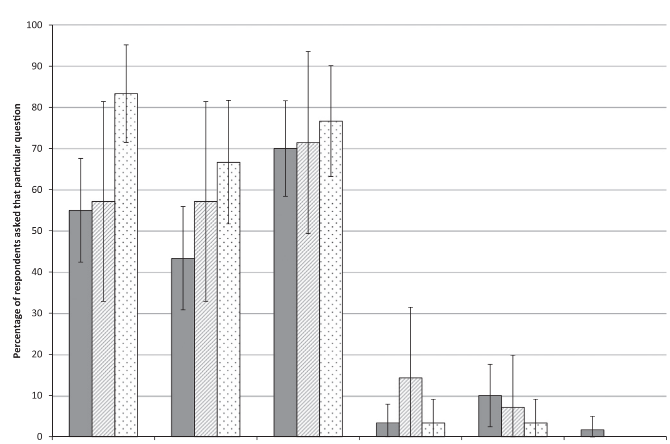

Fig. 1. The spatial scale which respondents indicate they: currently work with (grey; n=60), require additional information for (striped; n=16), and have inadequate information for (dotted; n=38).

Results and patterns are consistent across survey type and respondent organisation type; for example, all respondents show willingness to liaise continually with us (47 ± 25%, 62 ± 18% and 47 ± 25% of academic, NGO or governmental respondents respectively). Thus, below we show the amalgamated results from all respondents.

3.2. Capacity to use available ES information

92 ± 7% (55 of 60) of respondents currently use ES information for a diverse array of goals including policy development (66 ± 12%), to understand links to human well-being (62 ± 13%), ES supply management (60 ± 13%), land-use management (53 ± 13%), and for communication/awareness (53 ± 13%). The ES information derives from a variety of sources including reports (71 ± 12%), biophysical surveys (67 ± 12%), social surveys (66 ± 12%), and maps (62 ± 13%); see Appendix D for a full list. By contrast, only 35 ± 12% of respondents use ES information directly from models. Information from models is not used as it is either unavailable (54 ± 16%) and/or stakeholders do not feel capable of using this information (40 ± 16%).

Our respondents indicate a need for tools *"to represent both economic, social and environmental value and costs of ES … in order to provide information in such a way that it is clear what it means to different stakeholders and inform decision-making"* (Sustainable Land-use Programme Officer, Ethiopia) but highlight that *"poor [infrastructure (e.g. unreliable power and/or internet connections)] hinders access to information"* (Community Radio Editor-in-Chief, Cameroon).

3.3. Adequacy of available ES information

Approximately one-quarter of respondents (27 ± 11%) report having adequate ES information to support their work. However, both the yes-group (adequate information but wanting more information) and no-group (inadequate information and needing more information) show high demand for additional information on the service types that are already in most common use. For example, of those stakeholders using ES information, food and fresh water supply (both 58 ± 13%; Fig. 2) are used most commonly; followed by carbon storage and climate regulation (49 ± 13%). Cultural ES information is less commonly utilised by stakeholders, with the exception of recreation and tourism (31 ± 12%). Needs for additional information reflect current usage patterns (Spearman rank test for equality: $\rho = 0.80$; $P < 0.001$), with further data required for fresh water supply (yes-group: 62 ± 26%; no-group: 55 ± 17%; Fig. 2), food (54 ± 27%; 68 ± 16%), and carbon storage and climate regulation (54 ± 27%, 55 ± 17%) in particular. Comparing additional information requirements to current use for both the yes- and no-groups separately shows high correlation in the ranks (Spearman, $\rho = 0.89$, $P < 0.001$). However, the proportion of answers given for current use and demand varies for both groups (yes-group: $\chi^2 = 48.9$, $P < 0.001$; no-group: $\chi^2 = 35.0$, $P < 0.020$). Demand for ES information tends to be more equally spread across the 22 ES types than the distribution of ES data that is currently used, the latter being dominated by provisioning and regulating ES types. Thus, there are elevated proportions of respondents requiring information about cultural and supporting services (Fig. 2).

Over three-quarters of both the yes- and no-groups require information across spatial scales (88 ± 17% and 79 ± 13% respectively). However, it appears this demand is being met as there is little difference in priority between required spatial scale and currently-used scale (Spearman, $\rho = 0.87$, with $P < 0.070$ and $P = 0.100$ for yes- and no-groups respectively, with 5 categories); with especially high demand for information at the national (yes-group: 71 ± 23%; no-group: 77 ± 14%), regional (57 ± 26%; 67 ± 17%) and local levels (57 ± 26%; 83 ± 13%; Fig. 1). Despite this, respondents citing inadequate ES information (no-group) report higher requirements at local and regional levels than is currently used ($\chi^2 = 13.4$, $P < 0.010$); this difference is not seen for the yes-group ($\chi^2 = 13.4$, $P < 6.31$).

Considering the temporal dimension of existing ES data, over four-fifths of both groups require information across time points (yes-group: 81 ± 19%; no-group: 87 ± 11%), with the highest demand being for data in the present (77 ± 23%; 61 ± 16%; Fig. 3a). Proportions of answers given in both groups are not significantly different ($\chi^2 = 0.19$, $P < 0.900$ with 3 time point categories). The temporal scale requirements are generally for annual (yes-group 69 ± 25%; no-group 36 ± 16%) or monthly (62 ± 26%; 27 ± 15%) data, and much less on a daily or decennial scale (Fig. 3b). This skew towards annual and monthly information is most apparent in the no-group compared to the yes-group ($\chi^2 = 5.9$, $P < 0.050$ with 4 temporal scale categories).

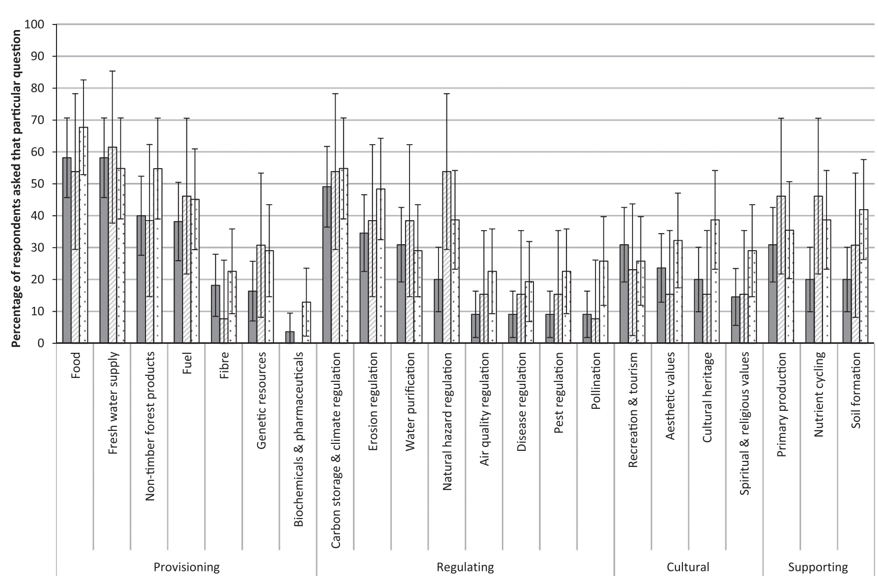

Fig. 2. The ES which respondents indicate they: currently work with (grey; n=60), require additional information (striped; n=16), and have inadequate information (dotted; n=38).

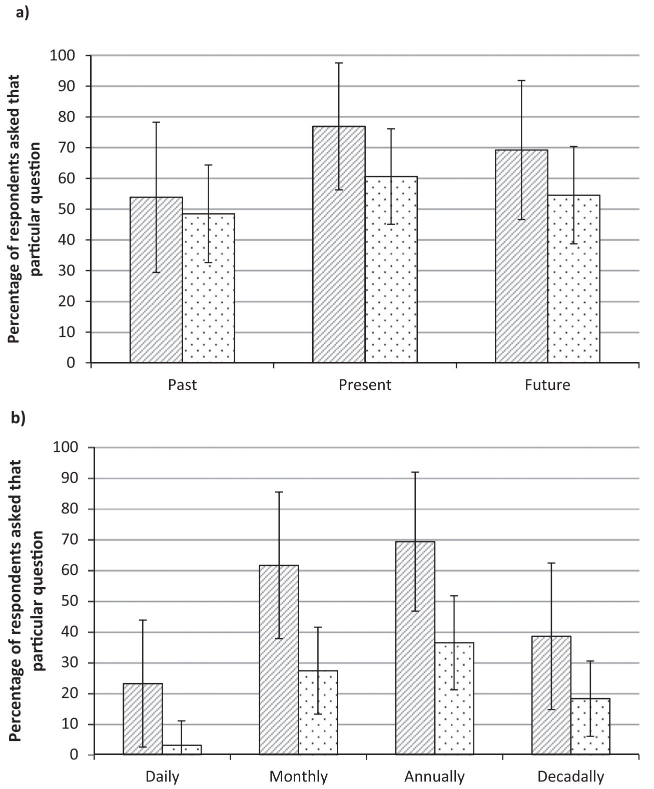

Fig. 3. The a) time point and b) temporal scale for which respondents indicated they: require additional information (stripped; n=16), and have inadequate information (dotted; n=38).

Approximately half of both groups require additional ES information to address specific policies (yes-group: 56 ± 24%; no-group: 47 ± 16%). The specific policies detailed by our respondents relate to: food security, climate change and risk management, irrigation planning, poverty reduction and development, payment for ecosystem services, and other environmental policies.

3.4. ES model requirements

Our sub-sample of technical experts (hereafter referred to as the technical experts; n=17) show similar descriptive statistics to those of the respondents as a whole (Section 3.1; Table 3). As with the whole sample, the types of organisation indicated by the technical experts fall into three distinct categories: academic, ranging from Researchers to Professors; NGO, including Technical Advisors, Programme Officers and Deputy Division Directors; or governmental, including Researchers, Monitoring and Evaluation Officers, and Senior Forest Officers. The technical experts' self-identified fields of work include environment/nature (88 ± 15%), livelihoods (65 ± 22%), and research (59 ± 23%). All technical experts currently work with ES, predominantly at the national (76 ± 20%), regional (65 ± 22%) and local (65 ± 22%) scales. Furthermore, all our technical experts (100% of the 15 individuals answering this part of the follow-up survey) show willingness to complete further surveys on ES maps and models. Therefore, we can assume the technical experts are good representation of the larger sample (Table 3).

During ES model selection, all of the 17 technical experts consider the ability of the models to perform scenarios to be important. Other important model features considered during model selection include the number of inputs required (65 ± 12%), the effort required to prepare the data and manipulate model outputs (both 59 ± 23%), and the level of support available (53 ± 24%). The complexity of the model and the run-time are of less concern to the technical experts (with only 35 ± 12% and 29 ± 21% considering these features during model selection).

All technical experts (of the 10–14 individuals, depending on the ES, answering this part of the follow-up survey) indicate that ES model outputs at 0.1 km^2 resolution or coarser are adequate for their needs. Many (over 70%) of the experts indicate that 1 km^2 pixel outputs are also adequate for all ES. While a finer spatial resolution (i,e. 0.1 km^2) is preferred for most ES (e.g. carbon storage and fodder production), outputs of 10 km^2 resolution are considered adequate by approximately 70% of the technical experts for certain ES (charcoal and firewood production); indicating that the spatial resolution required is context dependent.

The desired precision (i.e. the required number of significant figures) of model outputs varies across the ES. All our technical experts (100% of the 6 – 8 individuals, depending on the ES, answering these parts of the follow-up survey) indicate that the following levels of precision are adequate: carbon storage – 1 Mg ha^{-1}; crop production – 1 kg ha^{-1}; charcoal production – 1 kg ha^{-1}; firewood production – 10 kg ha^{-1}; fodder production – 1 kg ha^{-1}; and water availability – 10 l. This indicates a desire for high precision in some services. However, the levels of precision required are generally lower if one aims to please just 75% of our technical experts; being 10 Mg ha^{-1}, 1,000 kg ha^{-1}, 10 kg ha^{-1}, 10 kg ha^{-1}, 100 kg ha^{-1}, and 10 l respectively.

88 ± 17% of our technical experts (14 out of 16, depending on the ES, answering this part of the follow-up survey) would use

Table 3
A summary of the key results from the initial and follow-up surveys.

Response category	Initial survey with full sample (± 95% CI; n=60)	Follow-up survey with subsample of technical experts (± 95% CI; n=17)
Most common self-identified fields of work	Environment/nature: 80 ± 10% Agriculture: 55 ± 13% Research 53 ± 12%	Environment/nature: 88 ± 15% Livelihoods: 65 ± 22% Research: 59 ± 23%
Most common spatial scale of work	National: 70 ± 12% Regional: 43 ± 13% Local: 55 ± 13%	National: 76 ± 20% Regional: 65 ± 22% Local: 65 ± 22%
Willingness to complete further surveys	53 ± 13%	100 ± 0%
Currently using ES information	92 ± 7%	100 ± 0%
Most common ES-type of interest	Food supply: 58 ± 13% Freshwater supply: 58 ± 13% Carbon storage and climate regulation: 49 ± 13%	n/a
Have access to adequate ES information	27 ± 11%	n/a
Consider the ability of ES models to perform scenarios during model selection	n/a	100 ± 0%
Would use ranked ES information	n/a	88 ± 17%

ranked information, indicating the relative importance of different ecosystems or sites in terms of ES, to support ES decision-making. Unlike outputs with units (see above), the precision required from ranked outputs is consistent across different ES. All our technical experts (100% of the 10-12 individuals, depending on the ES, answering this part of the follow-up survey) indicate that they would prefer being able to separate ranked data into groups of single percentages (e.g. the top 1% of sites with most ES provision, the 2nd 1% etc.). However, most of our technical experts can manage with lower levels of precision; with 10% groups being adequate for > 80% of our technical experts for all ES except fodder production.

The minimum level of certainty (i.e. the probability of being the true value) model outputs required is relatively consistent across different ES. All our technical experts (100% of the 12-15 individuals, depending on the ES, answering this part of the follow-up survey) indicate that a model output that has 95% certainty is adequate to support decision-making. Most of our technical experts accept lower levels of certainty; with model outputs with 90% certainty being adequate for > 75% of our technical experts for all ES except water availability.

4. Discussion

Our first-order analysis provides insight into some of the barriers which contribute to the implementation gap in a region where quantitative data are scarce, and can be used as a basis for detailed investigations into targeted solutions. Only 27% of those stakeholders surveyed report having adequate ES information to support their work. In particular, data availability limits the assessment of certain ES considered as priorities by the surveyed stakeholders, with additional information required especially for regulating (e.g. natural hazard regulation), cultural (e.g. cultural heritage) and supporting services (e.g. nutrient cycling; Fig. 2). Thus, the stakeholders currently focus, and expect they will continue to focus, predominantly on provisioning and regulating ES, which is reflected in recent reviews summarising the available ES information (Crossman et al., 2013; Egoh et al., 2012; Martínez-Harms and Balvanera, 2012; Wong et al., 2014). For example, from 75 studies published between 1995 and 2011, Martínez-Harms and Balvanera (2012) identified that provisioning and regulating services are the most commonly mapped, and this pattern has continued over recent years (Crossman et al., 2013; Egoh et al., 2012; Wong et al., 2014).

Our results provide evidence that users of ES models concur with the literature that ES assessments need to be conducted at a variety of spatial and temporal scales (de Groot et al., 2010; Perrings et al., 2011; Scholes et al., 2013). Our respondents show a need for information at local, regional and national scales (Fig. 1). The lack of demand from our respondents for information at international scales indicates that cross-border ES supply is hardly on, or perceived to be on, their agenda. This is somewhat surprising considering the high demand for information on fresh water supply and long-standing tension over water resources across Africa (Swain, 2011), a service which is typically not contained within borders. However, the national focus might simply reflect a mandate of respondents to manage natural resources within national boundaries. Our results also show high demand for ES information across different time points, with greatest demand for annual and monthly time scales (Fig. 3); again, this supports previous work (Plummer, 2009). Benefits transfer-based proxy methods are most commonly used (Egoh et al., 2012), and can be applied over a series of land cover maps to indicate changes in ES over time (Jiang et al., 2013). However, benefits transfer-based proxies are known to be error-prone (Eigenbrod et al., 2010; Plummer, 2009). Such high error potential of much ES information is likely one reason why our respondents cite data inadequacies. More accurate proxies have been less readily applied over space and time, potentially resulting in erroneous conclusions about ES trends (Holland et al., 2011). Incorporating the dynamic nature of ecosystems and drivers of change into ES science, e.g. via dynamic, processed-based models, is a remaining challenge which must be addressed (de Groot et al., 2010).

A key finding of our work is complete agreement among the surveyed technical experts about the importance of scenarios within ES models, supporting previous findings (Carpenter et al., 2009; Evans et al., 2009; McKenzie et al., 2012; Swetnam et al., 2011). The reason for this finding is likely that by using scenarios the ES provided by alternative states (or counterfactuals) can be evaluated against the ES currently available, allowing the assessment of specific policies and interventions (Balmford et al., 2011). Most widely used ES modelling frameworks are applicable for this purpose (Bagstad et al., 2013), for example: ARIES (Villa et al., 2014), Co$ting Nature (Policy Support Systems, 2011), and InVEST (Natural Capital Project, 2007). It was beyond the scope of this study to determine if stakeholders require customisable scenarios or if standardised scenarios investigating globally shared issues, such as population growth and climate change, are adequate. Given the importance of scenarios for the utility of ES models, future studies should investigate this.

Another interesting finding from our survey of technical experts is the degree to which relatively coarse-resolution (10 km^2) data is deemed sufficient in many instances. This resolution may reflect an awareness by the experts of the technical limitations of current ES models (i.e. they would not believe that higher-resolution models would provide accurate outputs). However, the findings may also reflect a paucity of understanding of the effects of grain size on ES models by our stakeholders – the few results that do exist suggest that grain size can have a major impact on outcomes (Grêt-Regamey et al., 2014).

It is also of interest, and very important for the ES research community, that both outputs quantitatively expressed in SI units and those conveyed in relative terms (e.g. ranked data) are perceived as being useful to support decision-making. Similarly, our technical experts show realistic demands with respect to uncertainty. For example, most of our technical experts (> 75%) indicate that an agricultural production model would be adequate to support decision-making if, 9 times out of 10, it was able to predict correctly yield per hectare, with predictions to the nearest tonne deemed useful. Although environmental management policy can be sensitive to the treatment of uncertainty (Polasky et al., 2011), stakeholders clearly understand that uncertainty is unavoidable and acceptable, and should be expressed transparently (Evans et al., 2009). Our technical experts suggest that modelled scenarios which convey uncertainty to the stakeholder can be used to support environmental decision-making.

Whilst evidence that ES information is used to support decision-making is encouraging, the fact that only 27% of our sample of stakeholders have adequate data should be a call-to-arms for researchers – research needs to be directed to filling those gaps (Honey-Rosés and Pendleton, 2013; Wong et al., 2014). Whilst addressing stakeholders' needs, ES researchers must be mindful of the capacity to utilise information that is produced. Ensuring access and building capacity (e.g. training local experts in the approaches and tools) is essential for the long-term success of ES-related policy (Ruckelshaus et al., 2013). This is particularly apparent for ES models. Two-thirds of respondents do not use models in their decision-making processes due to a lack of, or a perceived lack of, availability or capacity. Training in model usage could eventually provide stakeholders with additional information; for example, runoff is easily extracted from hydrological models and is used as a proxy for surface water availability (Egoh et al., 2012). Thus, ES researchers should engage further in capacity building; establishing and/or participating in training centres and knowledge exchange partnerships to enable stakeholders to *"use models to design program interventions, assess progress toward agreed targets, and incorporate a wide range of inputs into decision-making processes and negotiations"* (Programme Design Manager, East Africa) as well as *"to project future trends and develop future scenarios"* (Senior Programme Officer, Tanzania). An iterative science-policy process, including adequate training, is the most effective method to incorporate ES information into policy (Ruckelshaus et al., 2013) and, as indicated by our results, stakeholders show willingness to engage with such a process. This should encourage ES scientists to continue to incorporate such activities into their research strategies and avoid the possibility of ES science becoming, or being perceived as, *"intellectual masturbation, irrelevant to the users"* (Senior Research Affiliate, Kenya).

5. Conclusions

This study provides evidence that stakeholders within sub-Saharan Africa are actively engaging with ES research and using the information to support policy development, with information on provisioning and regulating services being in greatest demand. However, most stakeholders we surveyed lack adequate information to support their decisions, requiring more reliable information across more ES (including cultural and supporting services). Our results highlight the importance of scenarios and insufficiency of static ES maps to support ES decision-making, with a demand for dynamic ES information across a variety of spatial and temporal scales. Thus, we demonstrate data gaps in current ES research which must be filled to maximise the usefulness of ES science outputs for policy; in particular, the impact of ecosystem dynamics on the supply and demand of ES warrants further study. Future investigations should expand this study targeting specific policy-contexts to provide greater understanding as to the needs of ES stakeholders. Efforts should be made to understand the barriers preventing engagement for stakeholders not currently using ES information. Finally, our results indicate that stakeholders are willing to interact continually with the scientific community, particularly through capacity building. Capacity building should be widely adopted amongst ES researchers, minimising ambiguity at the science-policy interface whilst maximising the ability of research to support sustainable policies and increase human well-being.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.ecoser.2016.02.038.

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