International Journal of Sustainable Development & World Ecology

Taylor & Francis
Taylor & Francis Group

Identifying future research directions for biodiversity, ecosystem services and sustainability: perspectives from early-career researchers

Journal:	*International Journal of Sustainable Development & World Ecology*
Manuscript ID	TSDW-2017-0221
Manuscript Type:	Original Article
Keywords:	biodiversity, ecosystem services, early career researchers, future research and interdisciplinary, sustainability

Identifying future research directions for biodiversity, ecosystem services and sustainability: perspectives from early-career researchers

~~Md Sarwar Hossain[1,2*], Sarah J. Pogue[2,3], Liz Trenchard[4], Alexander P.E. Van Oudenhoven[5], Carla-Leanne Washbourne[6], , Evalyne W. Muiruri[7], Aleksandra M. Tomczyk[8,9], Marina García-Llorente[10,11], Rachel Hale[12], Violeta Hevia[11], Tom Adams[13] , Leila Tavallali[14], Siân de Bell[8], Marian Pye[15], Fernando Resende[16]~~

~~[1]Institute of Geography, University of Bern, Switzerland,[2] Geography and Environment, University of Southampton UK [3]Department of Geography, University of Lethbridge/Agriculture and Agri-Food Canada, [4]Centre for Agroecology, Water and Resilience, Coventry University UK,[5]Institute of Environmental Sciences CML, Leiden University The Netherlands, [6]Department of Science, Technology, Engineering and Public Policy, University College London UK,[7]Department of Biosciences, Durham University, UK, UK [8] Environment Department, University of York, UK [9] Faculty of Geographical and Geological Sciences, Adam Mickiewicz University, Poland [10]Department of Applied Research and Agricultural Extension, Madrid Institute for Rural, Agricultural and Food Research and Development (IMIDRA),Spain [11]Social-ecological Systems Laboratory, Department of Ecology, Universidad Autónoma de Madrid, Spain [12]Ocean and Earth Science, National Oceanography Centre Southampton, University of Southampton, Waterfront Campus UK [13] Scottish Association for Marine Science, UK [14]School of Biological Science, University of Essex,UK [15]School of Biological Sciences, Bangor University,UK [16] Department of Ecology, Universidade Federal de Goiás, Brazil~~

Abstract

We aimed to identify priority research questions in the field of biodiversity, ecosystem services and sustainability (BESS), based on a workshop held during the NRG BESS Conference for Early Career Researchers on BESS, and to compare these to existing horizon scanning exercises. This work highlights the need for improved data availability through collaboration and knowledge exchange, which, in turn, can support the integrated valuation and sustainable management of ecosystems in response to global change. In addition, clear connectivity among ~~the~~ different research themes in this field further emphasises the need to consider a wider range of topics simultaneously to ensure the sustainable management of ecosystems for human wellbeing. In contrast to ~~experienced researchers~~other horizon scanning exercises, ~~the early career researchers'~~our focus was more interdisciplinary and more concerned with the limits of sustainability and dynamic relationships between social and ecological systems. The identified questions could provide a framework for researchers, policy makers, funding agencies and the private sector to advance knowledge in biodiversity and ES research and to develop and implement policies to enable sustainable future development.

Key words: biodiversity, ecosystem services, early career researchers, future research and interdisciplinary, sustainability.

* Corresponding author: Sarwar.Sohel@giub.unibe.ch and koushikadd@yahoo.com

1. Introduction

The concepts of biodiversity, ecosystem services, and sustainability (BESS) have received increasing attention in policy, academia and funding worldwide in recent decades (Rillig et al. 2015; Luck et al. 2012). The growing number of published articles on biodiversity (from ~1,000 to ~7,000), ES (from ~100 to ~5,000) and sustainability (from ~1,000 to ~12,000) between the 1990s and 2014, indicates the influential role of these concepts in academia (Chaudhary et al. 2015; Kajikawa et al. 2013; Liu et al. 2011). The growing awareness of the impacts of humans on the natural environment, and the increasing attention and resources focussed on these areas of research, have led to several initiatives aimed at assessing the state of biodiversity and ecosystem services provided to society, such as the Millennium Ecosystem Assessment (MA 2005), and the Ecosystem Services for Poverty Alleviation project (ESPA). Thus, the role of biodiversity and ES assessment in developing strategy (e.g. the European Union Biodiversity Strategy to 2020) and policy instruments (e.g. Reducing Emissions from Deforestation and Forest Degradation (REDD), Payment for Ecosystem Services (PES), greening of national accounting) is becoming more widespread. This explosion of interest also motivated the incorporation of the biodiversity concept into the United Nations Sustainable Development Goals (SDGs) by 2030 and the creation of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) in 2012.

Despite the growing attention to BESS, the aspiration for sustainable development has not been met (Gross 2012), neither at the global (Rockström et al. 2009) nor at the regional scale (Dearing et al. 2014). Moreover, despite increasing responses to BESS and some local success, the state of biodiversity and ES is deteriorating (Pereira et al. 2012; Butchart et al. 2010). Humanity has entered a new phase of sustainability challenges (Rockström and Karlberg 2010) as evidence grows that human activities have adversely influenced the earth's climate (IPCC 2007) and ecosystems (MEA 2005) over the past two centuries.

Therefore, it is of fundamental importance that we pay more attention to BESS (Kajikawa et al. 2014), by engaging researchers and encouraging them to contemplate priority future research directions~~,~~ in participatory ways for interdisciplinary and transdisciplinary work (Steelmam et al. 2015; Miller et al. 2014; Hackmann and Clair 2013; Kates 2011). Exercises to identify research questions by engaging researchers ~~has~~ have previously been used to provide future research direction in the fields of biodiversity (Roy et al. 2014; Sutherland et al., 2008), o~~O~~cean science (Rudd 2014), palaeoecology (Seddon et al. 2013) and water research (Brown et al. 2010). This paper presents important research questions for BESS as identified by early career researchers. In addition, we also compared between our results to those obtained by ~~experienced researchers~~ other relevant horizon scanning exercises (e.g. Oldekop et al. 2016; Fleishman et al. 2011 and ~~Seddon et al. 2013~~; Sutherland et al. 2008) from existing publications relating to biodiversity, post-2015 development agendas (e.g. Environmental sustainability, food security), conservation and management~~to identify whether early career researchers prioritised different research questions to established researchers for biodiversity and ES~~.

2. Materials and methods

We adopted and modified the methodology of Sutherland et al. (2008) and Seddon et al., (2013) to identify priority research questions for future research directions on BESS. Figure 1 depicts the methodological flow diagram which comprises three steps: (1) collecting and screening of the questions before the conference; (2) voting and discussion on the questions during the conference workshop~~ in the conference~~; (3) scoring, revising and writing the paper based on the expertise of the groups and feedbacks from the workshop. In addition, we ~~have~~ compared our identified research questions to existing horizon scanning exercises.

This work is the output of a workshop organized during a two-day international conference on BESS for early career researchers held in September 2014 at the University of Southampton (UoS), United Kingdom. This conference was organized by the NRG BESS (Next Research Generation for Biodiversity, Ecosystem Services and Sustainability) network (http://www.nrgbess.net/), which is made up of early career researchers contributing to interdisciplinary research within a range of disciplines spanning both the natural and social sciences including theoretical ecology, applied ecology, conservation biology, sociology and economics.

Most conference participants were researchers based in the European Union (EU) (73%), but participants from Bangladesh, Indonesia, Pakistan, Malawi, Mexico and Brazil also attended. The ~~P~~participants conducted research across~~' research focused on~~ all continents. All participants were early career researchers, either PhD students or post-doctoral researchers working in BESS ~~research~~fields. Prior to the conference, we asked participants to identify the questions they deemed important (2-3 per person), specifying that they should be not so narrow as to only be relevant to one species or situation, but not so broad that the steps that might be taken to find an answer would be unclear. Overall, 55 participant's submitted approximately 140 questions.

The submitted questions were screened; slightly rephrased where necessary and combined, and similar questions were excluded to avoid repetition. The identified questions were then grouped, first into seven themes and following further discussion into five revised themes. During the conference workshop, participants voted on the importance of these questions and then were divided into smaller groups to participate in discussions to further clarify and refine the questions for specific themes, depending on their expertise and interests. This paper concentrates on the significance of the identified research questions, followed by a consideration of possible approaches (e.g. frameworks, data, models, concepts) to answer the questions and the critical aspects of those questions in the discussion section.

After the conference, the co-authors of this paper (a subset of the participants remaining after self-selection) selected the top three questions for each theme based on the number of votes each question received during the workshop, and merged overlapping themes. Some of the themes therefore contain more than three research questions, such as themes 1 and 3.

3. Future research questions for BESS

3.1. Theme 1: Exploring the relationships between the components of social-ecological systems components

1. How do the main drivers of global change (e.g. climate change, land use change) impact biodiversity, ecosystem functioning and the provision of ES?
2. What mechanisms underpin the relationships between biodiversity, ecosystem functions and ES and how can we better utilise integrative approaches to understand these relationships?
3. What are the relationships between ES and different dimensions of individual and collective human wellbeing (HWB), and how can we develop suitable indicators for decision-makers?
4. What role can ecologists and conservationists play in ensuring long-term HWB and sustainable development?
5. How can we examine and demonstrate in real-world situations some of the theories of social-ecological systems such as tipping points, critical transitions or resilience?

And how do different social, economic and political institutions drive and respond to such shifts?

The link between ecological function and HWB is extremely complex and multi-dimensional, and remains subject to much uncertainty. While considerable research has been devoted to the effects of biodiversity loss on ecosystems (Balvanera et al. 2006, Cardinale et al. 2006), many studies marginalise the role of global environmental change and its consequences for HWB (Cardinale et al. 2012). Similarly, although it is well understood that HWB strongly relies on ES (MEA 2005), explicit causal relationships between biodiversity, ecosystem functioning ~~and~~ ES and~~,~~ HWB, are rarely explored (Mace and Bateman 2011).

Understanding the responses of biodiversity to drivers of change and the effects of biodiversity on ecosystem functions (Q1-3) is critical for developing predictions about the effect of global environmental change (Lavorel and Garnier 2002). However, to date, most studies have focused on taxonomic diversity (Queiroz et al. 2014; Vilà et al. 2011), conservation and species richness, while functional traits, system dynamics and ecosystem functions have received much less attention (Hevia et al. 2017; Liu et al. 2011; Devictor et al. 2010). Many recent studies have indicated that functional diversity is the key determinant of ecosystem functioning (Cardinale et al. 2012; Cadotte et al. 2011).

The questions in this theme reflect that importance and highlight the urgent need for greater interaction between natural and social scientists (Milner-Gulland 2012), as well as other sectors such as public health, landscape planners, etc., in order to adopt a multi-stakeholder participatory approach. Ecologists need to work more closely with policy-makers who can help define research priorities, and ensure that research is conducted at spatial and temporal scales that are relevant to decision-making. For instance, Robinson (2004) illustrated how a combination of ecological and conservation knowledge integrated with local knowledge and policy maker considerations can lead to greater sustainable development in industrialised countries. Further progress in this area will be facilitated by improved collaboration across disciplines to analyse the social, economic and political dimensions of ecological change.

Question 5 highlights the need for better understanding of the character of ecological tipping points and limits to ES provision across a range of scales (Bommarco et al. 2013;

Mason and De Bello 2013; Lenton 2013). These transitions, known as thresholds or tipping points, can significantly affect the provision of ES (Scheffer et al., 2009). Despite increases in HWB at both global and regional scales (Raudsepp-Hearne et al. 2010), there is a significant risk that HWB may experience a tipping point in response to ~~a~~ declines in ES delivery and biodiversity and unfavourable environmental change (Renaud et al. 2013).

Although researchers have empirically demonstrated tipping points (e.g. Hossain et al., 2015), developed frameworks (e.g. Dearing et al. 2014) and proposed empirical methods (Dakos et al. 2012) to operationalize sustainability science concepts such as critical transitions and safe operating spaces, robust methods for operationalizing these concepts that take the social system into account are still in progress. The evaluation of tipping points and transitions in the real world requires three essential components. Firstly, availability of real-world data based on long-term observations, proxies or derived from experiments. Secondly, the availability of appropriate methods to determine whether a regime transition was generated by chance, by sudden changes in external conditions, or due to the crossing of a tipping point. Thirdly, a comprehensive understanding of the system under examination is required, which is the most difficult aspect to address.

3.2. Theme 2: Improving awareness, collaboration and data availability

6. What options and technologies exist to assist primary data collection and increased awareness of data-poor sectors~~,~~ in developing countries and remote field locations?
7. How can the development of more participatory approaches improve communication and collaboration between stakeholders and ensure that relevant data is available to those who need it?
8. What are the challenges of adopting a mixed methods approach (social and ecological) in a research project? Are there any limitations in successfully publishing interdisciplinary research?
9. How can we use small-scale experiments to validate trends in data at large scales?

Although global and national scale data are available at increasingly high spatial and temporal resolutions, data unavailability at the regional scale, in particular in developing countries, is one of the major limitations for conducting research (UN 2014; UNEP 2012). Good (quality) databases are required at the regional scale at which most planetary processes (e.g. land use change, deforestation) take place (Nordhaus et al. 2012; Lewis 2012).

Recent advances in the availability of high-resolution, multispectral satellite imagery (with spatial resolution better than 1 m) is one of the solutions, which can enable us to study some ~~of the~~ ecosystem service~~s~~ indicators (e.g. amount of biomass) or drivers of change (e.g. land-use/land-cover changes) in quantitative and qualitative ways at~~in~~ local and regional scales,~~;~~ and to extrapolate (at least to some extent) the results of field-based studies. ~~Yet~~However, although good quality datasets can give an indication of generic patterns, ~~but~~ they do not directly contribute to our understanding of the processes and drivers giving rise to patterns and disparity at different scales.

Questions 7 and 8 focus essentially on the importance of closer collaboration between stakeholders involved in ES projects, as well as between academic disciplines. The long-term success of ES projects depends very much on the involvement of the local community. However, too often local people's involvement in these types of projects is passive and they have no decision-making powers (Pretty 1995). Informal data available in the local community, such as detailed knowledge of local conditions~~,~~ and of previous successes and failures, can be vital to success (Fish et al. 2011). Therefore, more participatory approaches are needed to improve communication and increase trust and collaboration between stakeholders. Improving collaboration between academics from different fields and overcoming the challenges of publishing interdisciplinary research is also vital for future ES research. Although social~~o~~-ecological systems seem to naturally lend themselves to research approaches that cross traditional disciplinary boundaries, there are a number of challenges in undertaking and ultimately publishing interdisciplinary research (Kareiva and Marvier 2012). Key challenges are the availability of appropriate methods and the willingness of researchers from different disciplines to both overcome and respect the cognitive barriers that exist between them (Hadorn et al. 2006)

3.3. Theme 3: Exchanging knowledge

10. How can we better integrate science with the needs of policy makers and create working relationships between scientists and policy makers?
11. What is the best way to engage and communicate with the public on the importance of biodiversity and ES, and to encourage society to take greater ownership of the impacts?
12. What are the best tools for communicating scientific results to decision makers, stakeholders and (multi) disciplinary scientists? Can they be improved/developed?

Understanding effective processes of knowledge exchange on technical topics is of primary importance in addressing the questions in this theme. Question 10 reflects directly the need to create a collective understanding of how contemporary technical research agendas fit with the 'questions' that are being asked by decision-making communities on different spatial and temporal governance scales (Likens 2010).

Question 11 acknowledges the contemporary importance of, (and increasing opportunities for), the integration of public voices and views into local, national and international decision-making, for example through open policy making instruments (UK Government 2015). This question also references the potential for action through 'bottom-up' grassroots societal movements, which have been significant in mobilising ownership of issues and community action in other areas of environmental science and sustainability (Seyfang & Smith 2007).

Question 12 emphasises a general challenge, present in all cases where technical knowledge is communicated in decision-making settings: the need for participants to share an understanding of the language and ideas in which the conversations are conducted (Fisher et al. 2009). This has implications for creating and maintaining a shared understanding of terms such as 'sustainability' and 'ecosystem services' (discussed further in section 3.5) across different communities. This question also highlights the challenge of determining which methods of communication (written, oral or graphic, digital, analogue, static or dynamic) are effective for diverse stakeholder groups. In the context of BESS research, this provides scope to consider the efficacy of existing and proposed toolkits for the practical application of biodiversity and ES concepts (Peh et al. 2013) and consider the impact of the strong disciplinary interest in ES mapping and geospatial analysis.

3.4. Theme 4: Valuing ES, including market and non-market valuation

13. How can the value of non-monetary ES be integrated into the assessment of socialo-ecological systems?
14. How can ecological and biophysical research support socio-economic valuation research, and vice versa?
15. Is there a market for ES and how would it be regulated?

The first question in this theme addresses the core problem that valuation studies aim to solve: how can meaningful estimates of ES values, especially those not traded in any (formal) markets, be provided so that these services can be accounted for in social-ecological systems? The underlying assumption is that if we can put some value on ES, they are more likely to be considered in decision-making processes, alongside other financial/economic, ecological and social interests, rather than ignored. De Groot et al. (2012) highlight the importance of expressing the value of ES in monetary units to raise awareness and convey the importance of ecosystems and biodiversity to policy makers. Watts et al. (2015) placed a high priority on pricing carbon to address the interlinked challengesd of health and climate change. However, multiple papers from within and beyond the ES literature emphasise the need for non-monetary valuation of ES to better integrate the socio-cultural dimension of ES (Quintas-Soriano et al. 2016; Chan et al. 2012). The suitability of these different valuation methods depends on the complexity of the problem, the stakeholders involved, and the dynamics of the social-ecological system that are addressed, including the type of ES.

In relation to question 14, it is important to consider that any assessment of the consequences of activities to manage ES requires an estimate of the supply of these services from the system in biophysical terms; it is impossible to carry out a valuation without this knowledge. Where knowledge is incomplete, an important improvement would be to explore ways to address uncertainty. Mechanisms to regulate ES provision and use include market and non-market options: direct payments, regulation and penalty, cap and trade (e.g. tradable permits), and self-regulation such as voluntary agreements motivated by social norms (Kinzig et al. 2011). The suitability of these mechanisms depends on the scale (in time and space) of the supply and demand (e.g. local vs global stakeholders), the type of ES, and political and socio-economic considerations such as equity, and conditions including institutional arrangements, transaction costs, and property rights structures. However, there is a need for better understanding of what works where and when.

3.5. Theme 5: Sustainable management

16. How can we manage biodiversity and ES sustainably in the context of climate change?
17. Is the ES approach suitable for providing an evidence base for sustainable management of the environment?
18. What decision-making processes should be put in place to manage trade-offs between different ES?

Climate change and land-use change are the main drivers of environmental degradation and the subsequent loss of ES and biodiversity (Ellis et al. 2010; Schröter et al. 2005). Yet, as a driver of changing ES provision, climate change has been relatively understudied (Mooney et al. 2009). Moreover, our understanding of the general response of landscapes to ongoing climate change and human impact is insufficient for a more accurate prediction of future threats. Hence, policy makers are unable to develop and implement appropriate initiatives that will allow society to adapt to future environmental conditions (Knight and Harrison 2014).

Question 16 highlights not only the need for sustainable management of biodiversity and ES (Geijzendorffer et al. 2015), but also emphasises that sustainability is subject to, and intimately connected with, on-going climate change. Questions 17 and 18 highlight the need for an evidence base to inform decision makers and managers about the consequences of unsustainable land-use and management. Environmental management must be evidence based, particularly if it is to be supported by policy. The ES approach has led to an increase in research and the provision of a growing evidence base that can potentially support environmental management. However, the concept of ES is but one of many concepts that have been or can be used to inform decision-making and is not undisputed. The usefulness of the concept depends on, for instance, a) how well ecosystem assessments quantify and communicate policy- and management-relevant information for sustainable management, and b) whether trade-offs resulting from management decisions can be communicated convincingly to decision makers, using ES as a narrative (Carpenter et al. 2009; Daily et al. 2009).

4. Possible future approaches for BESS

4.1. Tools and frameworks for decision-support

There are a range of tools and frameworks to support decision-making for sustainable management. Mixed methods approaches and the integration of different perspectives in pluralistic frameworks (Wegner and Pascual 2011) provide important opportunities for future research. For example, the 'balance sheets approach' advocated in Turner et al. (2015) brings together complementary, context-dependent types of ES assessment, arguing for the use of a range of findings from different methods. It also demonstrates the importance of tools to support BESS trade-offs, including cost-benefit analysis, multi-~~Criteria~~ criteria ~~Analysis~~analysis, and citizen's juries~~,~~ that enable the use of various evaluation criteria: efficiency, equity (distribution of gains and losses), social effects (e.g. employment, socio-cultural values), and ecological sustainability.

4.2. Methods for data collection

The growing concern for the effects of global environmental change on ecosystems demands a shift in the focus of ecological research towards whole communities and landscapes (Mace 2013). Our understanding of the relationships between global change, biodiversity and ecosystems might benefit from experimental studies manipulating both producer diversity (Tobner et al. 2014) and environmental conditions (Beier et al. 2004). Additional insight can be provided by retrospective analysis of past environmental responses to global and regional changes, which were not directly influenced by human impact.

Paleoenvironmental techniques (i.e., geomorphological, lithological and biological proxies and lines of evidence to reconstruct historic landscapes and environmental conditions) (Verburg et al. 2015) represent a range of approaches for the development of databases of long-term, high quality data. For example, the application of dendrochronological techniques in challenging environments such as in tropical countries (Wils et al. 2010) or polar areas (e.g. Myers-Smith et al. 2015) can help to understand micro-scale ecological responses to environmental change. This requires enhanced collaboration between these countries and funding opportunities to allow the creation of high quality databases. In addition, recent advances in remote sensing of the environment also creates a unique opportunity to collect data (e.g. land-use change~~s~~) at a range of spatial and temporal scales (from locally-derived UAV-based imagery, through sub-meter coverage at the regional scale, to global datasets with a resolution of tens of metres) and facilitate comparison between scales, and extrapolation based on point data-, sample-based results. Social science research methods, such as household surveys and focus group discussions, can be combined with technology (e.g. GPS, mobile technology, remote sensing, social media) to support research on long-term societal change in response to ecosystem change.

Mobile technology and smart phones have become ubiquitous in all corners of the globe and the development of simple applications (e.g. ESM-Apps) (Priess et al. 2014) allows researchers to reach wide audiences in what may be geographically or politically sensitive areas. In the United Kingdom, the smart phone application Leafwatch used citizen science to document cases of the leaf-mining moth across the country (Pocock and Evans 2014). Recently, the mini Stream Assessment Scoring System (miniSASS) used a reduced checklist of aquatic invertebrates that can be easily identified with a smartphone application to allow South Africans to assess their local river catchment quality and upload results to an interactive Google Earth map and database, ~~giving~~ providing invaluable tools to governmental advisors to ensure the provision of clean and safe drinking water (Water Research Commission 2015).

4.3.Statistical approaches

Statistical tools hold promise for identifying the missing links between the origins and societal consequences of environmental problems.~~:~~ For example, Bayesian Belief Networks have proven useful in the construction of models that intersect several disciplines (Marcot et al. 2006). They have not only been used to set out causal relationships linking habitat and environmental variables to ecological factors, but they can also help to communicate insights across knowledge cultures and support participatory approaches to ecosystem assessment (Haines-Young 2011). Statistical analysis such as generalized additive models (GAM) can be used for analysing non-linearity in social-ecological systems (e.g. Hossain et al. 2016), while structural equation models (Santos-Martın et al. 2013) and vector auto regressive models can be used for analysing links between HWB and ecosystems. In addition, econometric methods such as the nonlinear granger causality test (Chen et al. 2013) and feedback models (Granger 1969) can provide insight on dynamic interrelationships (e.g. causality and feedbacks) between ES and HWB.

Statistical meta-analyses of existing data may also help to determine the generality of identified mechanisms and identify knowledge gaps where research efforts might be targeted. However, environmental change is likely to alter the combination of genes, species, functional traits and trophic interactions in a given ecosystem (Duffy et al. 2007). Therefore, general mechanistic explanations for whole communities are unlikely to emerge from empirical studies in the midst of such complex interactions.

4.4. Modelling

Modelling approaches have historically been critical tools for predicting and mitigating the effects of anthropogenic change (Fox and Kerr 2012; Alkemade et al. 2009). System dynamics and agent-based modelling approaches can provide insight on how systems and human behaviour will respond to environmental change and human development. Both of these approaches are able to capture the dynamic and complex relationships between ES and HWB. Multi-agent models can be useful in modelling and exploring the dynamic behaviour of HWB in response to environmental change (Hossain et al. 2017).

Models such as IMAGE-GLOBIO (also downscaled) provide crucial information on the potential influence of climate change on ES (Alkemade et al. 2009). Modelling platforms such as ARIES (ARtificial Intelligence for Ecosystem Services) can be useful for mapping ES flows and critical transitions in ecosystem processes (Villa et al. 2014). However, to increase the usefulness of modelling in relation to our priority research questions, models should rely less on correlations between observational data, and more on the mechanisms underlying ecosystem responses. For example, the Madingley Model, developed by Harfoot et al. (2014) highlights the value of models that not only predict but also illuminate the mechanisms underlying ecosystem responses under novel conditions. Local evidence needs to be collected and compared to support the modelling approach. Participatory methods can be used in the co-construction of models intersecting different disciplines as seen in the companion modelling approach, which can also solve the challenges of data unavailability across different scales (Hossain et al. 2016; Etienne, 2014).

4.5. Linking science to policy

Possible approaches to answering these research questions include drawing upon diverse cases in which engagement between scientists, decision-makers and the general public has been central in communicating knowledge and enacting decisions (Ishii 2014). A proactive approach to integrating science with the needs of policy makers involves researchers working closely with and within decision-making bodies through formal or informal knowledge exchange partnerships and/or collaboratively determined research programmes (Mitlin 2008). The on-going collaboration between Birmingham City Council and Birmingham City University in applying ecosystems thinking to the urban planning of Birmingham, UK is one example of such a collaboration (Development Directorate

Birmingham City Council 2013). The most intimately engaged level of co-production (collaborative, highly engaged co-working arrangements between different knowledge communities) of research is an increasingly popular approach for researchers working on socially and politically relevant research (Pohl et al. 2010; Lemos & Morehouse 2005). In understanding the communication of scientific knowledge to non-technical non-specialist audiences, it is of benefit to recognise and engage with the large body of qualitative and quantitative work on 'science and society'. Investigating the way in which terminology and figurative language (Raymond et al. 2013) and delivery formats play a part in knowledge exchange is also critical, with a sensitivity to the fact that personal preferences may vary significantly with audience and setting (Mitton et al. 2007). Public consultations, events and other methods for direct engagement that circumvent traditional decision-making settings may be experimented with. A detailed analysis of the efficacy of various methods for knowledge exchange would be appropriate and timely in understanding and evaluating the use of existing communication methods (including proposed frameworks, toolkits and data visualisations) for biodiversity and ES research.

4.6. Enhancing interdisciplinary research

Addressing critical questions concerning BESS and HWB requires the development of new research approaches, a broader outlook and a fundamental shift towards a culture of interdisciplinary collaboration. The provision of interdisciplinary training for socio-ecologists, and support for long-term social-ecological monitoring and research projects, can serve to strengthen inter-disciplinary links and secure the future of healthy ecosystems and sustainable societies in a changing world. Active collaboration between fields (ecology, economics and social sciences) may also provide novel insight into ecosystem and social processes.

5. Challenges for researchers and interlinkages across the themes

We describe four challenges in interdisciplinary research for BESS. Firstly, researchers involved in this field must recognize that a more comprehensive approach is necessary, and should be willing to consider additional components. Secondly, researchers from distinct fields need to be able to work together to both overcome and respect the cognitive barriers that exist between them (Hadorn et al. 2006). Thirdly, appropriate methods are needed that better integrate the different components of social-ecological systems in a reliable way and at a time scale compatible to the research project. Lastly, publishing research that spans multiple scientific disciplines can also be a challenge for a number of reasons, including the need for the work to be evaluated by researchers from different backgrounds, and the difficulty in finding a common language amongst researchers from different disciplines. Another key challenge would be to improve the collaboration not only between researchers from different disciplines, but between researchers with policy makers, managers and local communities to achieve the development of research with potential to be apply to real-word situations. ~~publishing interdisciplinary research is currently more challenging than mono-disciplinary research, and while the creation of new interdisciplinary journals in recent years may change this, their impact factors are still relatively low. A move away from publication and impact factor-based incentives for research may encourage the wider adoption of interdisciplinary approaches.~~

The five themes that emerged from our workshop are connected to each other. For example, sustainable management depends on the data availability, exploration of linkages, exchange of knowledge and collaboration. Further examples of connectivity between the different themes are: 1. The collection of high quality data through knowledge exchange and collaboration could support the exploration of linkages between social and ecological systems, incorporating both the monetary and non-monetary valuation of ecosystems, and contributing to sustainable ecosystem management; ~~,~~ 2. Incorporating long-term biophysical and societal processes in valuing ES also requires the availability of long-term data; ~~,~~ 3. Understanding the linkages between ecology and society is a pre-requisite for recognizing the early warning signals of an approaching tipping point in a social-ecological system. A paucity of high quality data could also be a reason for the lack of systematic analysis of the resilience of social systems and how HWB will respond to ecosystem changes (Raworth 2012).

6. Commonalities and ~~Difference~~ differences with ~~between the perceptions of early career and established researchers~~other horizon scanning exercises

In addition to identifying future research questions and the various methodologies that can be used to answer these questions, we also aimed to ~~answer~~ identify (Table 1) commonalities and differences between our study and other horizon scanning exercises from existing publications relating to biodiversity (Sutherland et al. 2008), post-2015 development agendas

Comment [SS1]: C1 Reviewer #1:

Thank you for the opportunity to review this paper. I found it interesting and well written. Based on a Conference on Early Career Research, the authors set out to identify key research questions in the fields of BESS. I believe this paper is valuable for identifying critical research questions and providing direction to researchers and policy makers for more effective interdisciplinary and policy relevant research. In this regard, I feel the paper makes a useful contribution. In addition, the paper serves as a very informative literature review that will be of value to researchers and students alike. I do however have some concerns.
The authors suggest that academia needs to "move away from publications – and impact factor based incentives for research and encourage the wider adoption of interdisciplinary approaches." First, it isn't clear to me why interdisciplinary research cannot result in high impact publications. That issue aside I question the reality of this recommendation. Our job as researchers is to disseminate the results of our research through high quality peer reviewed publications. We all hope our papers can be published in high impact journals in order to reach a wider audience and, hopefully, result in positive impact in our respective fields and public policy. Admittedly there are professional and even financial incentives to so. To suggest that this should no longer occur seems rather naïve. I would suggest that authors reconsider or rephrase this recommendation. I do not think it would be difficult to do so.

R1 **Authors:** Thanks for your time, nice words that you find our work useful.

We agree with your comments and we have reconsidered the text and revised it as what we stated before was not actually the aim of the paper. You can find the revised text at line 489-497. So thanks for your comments.

(e.g. Environmental sustainability, food security) (Olderkop et al. 2016), conservation and management (Fleishman et al. 2011).

Each of the existing horizon scanning exercises identified research questions using a participatory approach which involved engaging a wider range of stakeholders from academia, government and non-governmental organizations. Furthermore, strategies in response to climate change are a core focus of all of these exercises. Commonalities are identified between our study and Fleishman et al. (2011), in terms of covering the social and ecological dimensions, bringing interdisciplinary perspectives, spatial-temporal dynamics and recognizing the sustainability science (e.g. interaction, resilience, thresholds) whilst identifying the research questions. Furthermore, similarly to our study, Sutherland et al. (2008) highlighted the collaboration and data availability issues, and recognized the monetary value of ecosystems into their future research direction.

~~the question: 'Do early career researchers identify different BESS research questions than established researchers?' We identified priority research questions identified by established researchers from existing publications relating to biodiversity (Sutherland et al., 2008), post-2015 development agendas (e.g. environmental sustainability, food security) (Olderko et al. 2016), and conservation and management (Fleishman et al. 2011), which often involved a wider range of stakeholders from academia, government and non-governmental organizations.~~

The differences identified related mainly to the linkages between social-ecological systems, long-term sustainability aspects and interdisciplinary approaches. Issues such as the valuation of ecosystems or biodiversity, science-policy interfaces, linkages between social and ecological systems, the challenges relating to and the plausible approaches for answering the research questions did not seem to be as prominent among ~~experienced researchers~~existing horizon scanning exercises as among ~~early career~~the researchers ~~of~~ involved in this study. In addition, ~~long-term sustainability aspects and~~ interdisciplinary approaches did not come to the fore as clearly in existing papers.

Both examples (~~Olderko~~Oldekop et al. 2016 and Sutherland et al. 2008) from existing horizon scanning exercises ~~from the experienced researchers~~ did not link social systems with ecological systems explicitly, beyond some questions related to social and economic components. The dynamic relationships between biodiversity, ecosystem and sustainability were not addressed simultaneously. Although Fleishman et al. (2011) were more focused on

Comment [SS2]: C2 Reviewer #1:
My major concern with the paper is that I feel he authors failed to achieve, or at least explain, one of its major objectives– that being the attitudinal, methodological or theoretical differences that exists between early career and more senior researchers in these fields. While the methods used to assess the different research priorities/questions among early career scientists was well articulated, the same attention was lacking in assessing the priories/questions of more senior researchers. After reading this paper I am not convinced that early career and senior researchers do not share many of these same priorities or would not identify the same research questions. I am more inclined to think there is considerable commonality. For example, I feel both groups recognize the need for integrating science in more informed policy-making. However, there are considerable challenges in doing, which senior researchers have learned through their own experience. This does not mean this group of researchers is any less committed to do so nor discount the need. The need to integrate of science and policy should not be presented as something new that only early career researchers have recognized. I believe that in order for this paper to make a more substantive contribution these differences need to be made more clear (if they do in fact exist), including how those differences were determined.

R2 **Authors:**
Thanks for your very useful comments. We agree with your comments and that is why we have added a large table, which includes the commonalities and differences with other researcher's works. Please see at line 914
This major revision also includes two additional paragraph at line 519-523 and 525-534 and some minor edit all through the paper to integrate your comments and revise accordingly. Furthermore, we have also deleted the term-experienced researchers, as we revealed that many of the researchers of these exercises are early career researchers. Therefore, instead of using differences between experienced researchers and early career researcher, we are using commonalities and differences between our work and other horizon scanning exercises.

interdisciplinary questions and dealt with thresholds and ecosystem resilience, the issues of dynamic relationships between social and ecological systems, the value of ecosystems and biodiversity, the science-policy interface and limits of sustainability were not emphasised to the same extent as they were by ~~the early career researchers~~this study. Failure to consider both the social and ecological sub-systems and the dynamic and complex relationships between them~~,~~ may impede the creation and implementation of sustainable development policies and strategies.

7. Conclusions

The list of key research questions for future research on Biodiversity, Ecosystem Services and Sustainability may provide guidance for researchers, policy makers and funding agencies to prioritise research questions and frame their activities. We discussed the importance of the selected questions and provided possible avenues for research to answer them. Our aim was neither to provide a complete list of questions nor to develop specific questions for BESS research. We acknowledge that the participants' interests may have biased the initial selection of questions, however we have attempted to address this by engaging with and counting the votes of all researchers to finalise the list of key questions. This study can be extended by including early career researchers working in government and non-governmental organizations and researchers from other countries who could not participate in the conference.

The results identified an urgent need to consider a wider range of topics simultaneously to ensure the sustainability of ecosystem service supply and biodiversity for the maintenance and continued improvement of HWB and the critical importance of interdisciplinary approaches for BESS in response to the challenges of global change and sustainability.

Acknowledgements

We acknowledge BESS (Biodiversity and Ecosystem Services Sustainability), Geography & Environment Department and Sustainability Science at the University of Southampton for supporting the conference and workshops. Both of the events were organized by the NRG BESS (Next Research Generation for Biodiversity, Ecosystem Services and Sustainability) network. NRG BESS network is part of the BESS programme (NERC/PR100027) which is a six-year programme (2011-2017) funded by the UK Natural Environment Research Council (NERC) and the Biotechnology and Biological Sciences Research Council (BBSRC) as part of the UK's Living with Environmental Change (LWEC) programme.

Individual acknowledgement for each authors are as follows; Md Sarwar Hossain: ESRC/NERC interdisciplinary studentship and Geography and Environment, University of Southampton; Sarah Pogue: Natural Environment Research Council (NERC) and a Vice-Chancellor Scholarship from the University of Southampton; Alexander P.E. Van Oudenhoven: STW, project 579 number 12691 "Nature-driven nourishment of coastal systems (NatureCoast); Tom Adams: NERC CBESS (NE/J015644/1); A.M. Tomczyk: Polish Ministry of Science and Higher Education: "Mobility Plus" program (927/MOB/2012/0); Marina García-Llorente: Spanish National Institute for Agriculture and Food Research and Technology (INIA)

We also acknowledge Professor Georgina Mace, Professor Katrina Brown, Professor David Raffaelli, Professor John A Dearing, Dr Sandra Nogue, Dr Marije Schaafsma and Dr Laura Harrison for their valuable comments and discussion. This study was approved (Ethics ID: 12208) by the ethics and research governance committee of the University of Southampton.

References

Alkemade R, van Oorschot M, Miles L, Nellemann C, Bakkenes M, ten Brink B. 2009. GLOBIO3: a framework to investigate options for reducing global terrestrial biodiversity loss .Ecosystems. 12 : 374–390

Balvanera P, Pfisterer A, Buchmann N, He JS, Nakashizuka T, Raffaelli D, Schmid B. 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecology Letters. 9:1146–56.

Beier C, Emmett B, Gundersen P, Tietema A, Peñuelas J, Estiarte M, Gordon C, Gorissen A, Llorens L, Roda F, Williams D. 2004. Novel approaches to study climate change effects on terrestrial ecosystems in the field: Drought and passive nighttime warming. Ecosystems 7:583–597.

Bommarco R, Kleijn D, Potts SG. 2013. Ecological intensification: harnessing ecosystem services for food security. Trends in Ecology & Evolution 28:230–8.

Brown LE, Mitchell G, Holden J, Folkard A, Wright N, Beharry-Borg N, Berry G, Brierley B, Chapman P, Clarke SJ, Cotton L, Dobson M, Dollar E, Fletcher M, Foster J, Hanlon A, Hildon S, Hiley P, Hillis P, Hoseason J, Johnston K, Kay P, McDonald A, Parrott A, Powell A, Slack RJ, Sleigh A, Spray C, Tapley K, Underhill R, Woulds C. 2010. Priority water research questions as determined by UK practitioners and policy makers. Sci Total Environ. 409(2):256-66. doi: 10.1016/j.scitotenv.2010.09.040.

Butchart SHM, Walpole M, Collen B, Van Strien A, Scharlemann JPW, Almond REA, Baillie JEM, Bomhard B, Brown C, Bruno J, Carpenter KE, Carr GM, Chanson J, Chenery AM, Csirke J, Davidson NC, Dentener F, Foster M, Galli A, Galloway JN, Genovesi P, Gregory RD, Hockings M, Kapos V, Lamarque JF, Leverington F, Loh J, McGeoch MA, McRae L, Minasyan A, Morcillo MH, Oldfield TEE, Pauly D, Quader S, Revenga C, Sauer JR, Skolnik B, Spear D, Stanwell-Smith D, Stuart SN, Symes A, Tierney M, Tyrrell TD, Vie JC, Watson R. 2010. Global biodiversity: indicators of recent declines. Science 328 : 1164–1168. http://dx.doi.org/10.1126/science.1187512

648 Cadotte MW, Carscadden K, Mirotchnick N. 2011. Beyond species: Functional diversity and the maintenance of ecological processes and services. Journal of Applied Ecology 48:1079–1087.

650 Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, Narwani A, Mace GM, Tilman D, Wardle DA, Kinzig AP, Daily GC, Loreau GC, Grace JB, Larigauderie A, Srivastava DS, Naeem S. 2012. Biodiversity loss and its impact on humanity. Nature 486:59–67.

653 Cardinale BJ, Srivastava DS, Duffy JE, Wright JP, Downing AL, Sankaran M, Jouseau C. 2006. Effects of biodiversity on the functioning of trophic groups and ecosystems. Nature 443:989–92.

655 Carpenter SR, Mooney HA, Agard J, Capistrano D, DeFries RS, Díaz S, Dietz T, Duraiappah AK, Oteng-Yeboah A, Pereira HM, Perrings C, Reid WV, Sarukhan J, Scholes RJ, Whyte A. 2009. Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. Proceedings of the National Academy of Sciences 106, 1305-1312.

659 Chan KM, Guerry AD, Balvanera P, Klain S, Satterfield T, Basurto X, Bostrom A, Chuenpagdee R, Gould R, Halpern BS, Hannahs N. 2012. Where are cultural and social in ecosystem services? A framework for constructive engagement. BioScience 62(8):744–756. doi:10.1525/bio.2012.62.8.7

662 Chaudhary S, McGregor A, Houston D, Chettri N- 2015. The evolution of ecosystem services: a time series and discourse-centered analysis. Environ. Sci. Policy 54 : 25–34

664 Chen H, Cummins JD, Viswanathan KS, Weiss MA. 2013. Systemic risk and the interconnectedness between banks and insures: An econometric analysis. The Journal of Risk and Insurance 81(3): 623–652. DOI: 10.1111/j.1539-6975.2012.01503.x

667 Daily GC, Polasky S, Goldstein J, Kareiva PM, Mooney HA, Pejchar L, Ricketts TH, Salzman J, Shallenberger R. 2009. Ecosystem services in decision making: time to deliver. Frontiers in Ecology and the Environment 7, 21-28.

670 Dakos V, Carpenter SR, Brock WA, Ellison AM, Guttal V, Ellison AM, Guttal V, Ives AR, Ke´ fi S, Livina V, Seekell DA, van Nes WH, Scheffer M. 2012. Methods for Detecting Early Warnings of Critical Transitions in Time Series Illustrated Using Simulated Ecological Data. PLoS ONE 7(7): e41010. doi:10.1371/journal.pone.0041010

674 de Groot R, Brander L, Costanza R, Bernard F, Braat L, Christie M, Crossman N, Ghermandi A, Hein L, Hussain S, Kumar P, McVittie A, Portela R, Rodriguez LC, ten Brink P, van Beukering P. 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst. Serv., 1 (1) : 51–60

678 Dearing JA, Wang R, Zhang K, Dyke JG, Haberl H, Hossain MS, Langdon PG, Lenton TM, Raworth K, Brown S, Carstensen J, Cole MJ, Cornell SE, Dawson TP, Doncaster CP, Eigenbrod F, Flörken M, Jeffers E, Mackay AS, Nykvist B, PoppyGM. 2014. Safe and just operating spaces for regional social-ecological system. Glob Environ Change 28:227–238. doi:10.1016/j.gloenvcha.2014.06.012

683 Development Directorate Birmingham City Council. 2013. Green Living Spaces Plan

684 Devictor V, Mouillot D, Meynard C, Jiguet F, Thuiller W, Mouquet N. 2010. Spatial mismatch and congruence between taxonomic, phylogenetic and functional diversity: the need for integrative conservation strategies in a changing world. Ecology letters 13:1030–40.

687 Duffy JE, Cardinale BJ, France KE, McIntyre PB, Thébault E, Loreau M. 2007. The functional role of biodiversity in ecosystems: incorporating trophic complexity. Ecology Letters 10:522–38.

689 Ellis EC, Klein GK, Siebert S, Lightman D, Ramankutty N. 2010. Anthropogenic transformation of the biomes, 1700 to 2000. Global Ecology and Biogeography, 19, 589-606.

691 Etienne M. 2014. Companion Modelling - A Participatory Approach to Support Sustainable Development. Netherlands, Springer.Fish R, Burgess J, Chilvers J, Footitt A, Haines-Young R,

693 Russel D, Winter DM. 2011. Participatory and Deliberative Techniques to embed an Ecosystems Approach into Decision Making: an introductory Guide. (Defra Project Code: NR0124)

695 Fleishman E, Blockstein DE, Hall JA, Mascia MB, Rudd MA, Scott JM, Sutherland WJ, Bartuska AN, Brown AG, Christen CA, Clement JP, Dellasala D, Duke CS, Eaton M, Fiske SJ, Gosnell H, Haney JC, Hutchins M, Klein ML, Marquesee J, Noon BR, Nordgren JR, Orbuch PM, Powell J, Quarles SP, Saterson KA, Savitt CC, Stein BA, Webster MS, Vedder A. 2011.Top 40 Priorities for Science to Inform US Conservation and Management Policy. BioScience 61 (4): 290-300. doi: 10.1525/bio.2011.61.4.9

701 Fox JW, Kerr B.. 2012. Analyzing the effects of species gain and loss on ecosystem function using the extended Price equation partition. Oikos 121:290–298.

703 Geijzendorffer IR, Martín-López B, Roche PK. 2015. Improving the identification of mismatches in ecosystem services assessments. Ecological Indicators 52, 320-331.

705 Granger CWT. 1969. Investigating causal relations by econometric models and cross spectral methods. Econometrica 37 93 424-438.

707 Gross M. 2012. Will Rio ? 20 find a way to more sustainable development? Curr Biol 22:11

708 Hackmann H, Clair AL. 2013. Transformative cornerstones of social science research for global change. Mundo Amazo´nico 4:117-152. http://www.worldsocialscience.org/documents/transformative-cornerstones.pdf

711 Hadorn GH, Bradley D, Pohl C, Rist S, Wiesmann U. 2006. Implications of transdisciplinarity for sustainability research. Ecological Economics 60: 119-128.

713 Haines-Young R. 2011. Exploring ecosystem service issues across diverse knowledge domains using Bayesian Belief Networks. Progress in Physical Geography 35:681–699.

715 Harfoot MBJ, Newbold T, Tittensor DP, Emmott S, Hutton J, Lyutsarev V, Smith MJ, Scharlemann JPW, Purves DW. 2014. Emergent Global Patterns of Ecosystem Structure and Function from a Mechanistic General Ecosystem Model. PLoS Biology 12.

718 Hevia V, Martín‐López B, Palomo S, García‐Llorente M, Bello F, González J.A. (2017). Trait‐based approaches to analyze links between the drivers of change and ecosystem services: Synthesizing existing evidence and future challenges. Ecology and Evolution DOI: 10.1002/ece3.2692

722 Hossain MS, Dearing JA, Eigenbrod F, Johnson FA (2017) Operationalizing safe operating space for the regional social-ecological systems. Science of The Total Environment. http://www.sciencedirect.com/science/article/pii/S0048969717301067

725 Hossain MS, Dearing JA, Jhonson FA, Eigenbrod F. 2016. Participatory modelling as the basis for a conceptual system dynamic model of the social-ecological system in the Bangladesh delta. The South Asian Network for Development and Environmental Economics (SANDEE), working paper (In press)

729 Hossain MS, Dearing JA, Rahman MM, Salehin M. 2015. Recent changes in ecosystem services and human wellbeing in the coastal zone. Reg Environ Chang. doi:10.1007/s10113-014-0748-z.

731 Hossain MS, Eigenbrod F, Johnson FA, Dearing JA. 2016. Unravelling the interrelationships between ecosystem services and human wellbeing in the Bangladesh delta. International Journal of Sustainable Development & World Ecology. DOI:10.1080/13504509.2016.1182087

734 IPCC. 2007. Climate change 2007: the physical science basis. Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

736 Ishii T. 2014. Potential impact of human mitochondrial replacement on global policy regarding germline gene modification. Reproductive biomedicine online 29(2): 150-155.

Formatted: Highlight

Formatted: German (Switzerland)

Formatted: German (Switzerland)

Kajikawa Y, Tacoa F, Yamaguchi K. 2014. Sustainability science: the changing landscape of sustainability research. Sustain Sci 9: 431. doi:10.1007/s11625-014-0244-x

Kareiva P, Marvier M. 2012. What Is Conservation Science? BioScience, 62 (11), 962-969. doi: 10.1525/bio.2012.62.11.5

Kates RW. 2011. What kind of a science is sustainability science? Proc Natl Acad Sci 108(49):19449–19450

Kinzig AP, Perrings C, Chapin FS, Polasky S, Smith VK, Tilman D, Turner BL. 2011. Paying for ecosystem services—promise and peril. Science 334(6056), 603-604.

Knight J, Harrison S. 2014. Limitations of uniformitarianism in the Anthropocene. Anthropocene 5: 71–75

Lavorel S, Garnier E. 2002. Predicting changes in community composition and ecosystem functioning from plant traits: revisiting the Holy Grail. Functional Ecology 16:545–556.

Lemos MC, Morehouse BJ. 2005. The co-production of science and policy in integrated climate assessments. Global environmental change 15(1): 57-68.

Lenton TM. 2013. Environmental Tipping Points. Annual Review of Environment and Resources 38:1–29.

Lewis SL. 2012. We must set planetary boundaries wisely. Nature 485: 417.

Liu X. Zhang L. Hong, S., 2011. Global biodiversity research during 1900–2009: a bibliometric analysis. Biodivers Conserv 20: 807. doi:10.1007/s10531-010-9981-z

Luck GW, Chan KMA, Eser U, Gómez-Baggethun E, Matzdorf B, Norton B, Potschin MB. 2012. Ethical considerations in on-ground applications of the ecosystem services concept. BioScience 62: 1020–1029. doi: 10.1525/bio.2012.62.12.4

MA 2005. Ecosystems and human well-being: a framework for assessment. Millennium ecosystem assessment. Island Press, Washington.

Mace G. 2013. Ecology must evolve. Nature 503:191–2.

Mace GM, Bateman I. 2011. Conceptual frame work and methodology (ch.2). In:UK National Ecosystem Assessment. The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, Cambridge. Mace GM, Norris K, Fitter AH, 2012. Biodiversity and ecosystem services: a multilayered relationship. TrendsEcol.Evol.27(1).

Marcot BG, Steventon, DJ, Sutherland GD, McCann RK. 2006. Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. Canadian Journal of Forest Research 36.12: 3063-3074.

Mason NWH, De Bello F. 2013. Functional diversity: A tool for answering challenging ecological questions. Journal of Vegetation Science 24:777–780.

Miller TR, Wiek A, Sarewitz D, Robinson J, Olsson L, Kriebel D, Loorbach D. 2014. The future of sustainability science: a solutions-oriented research agenda. Sustain Sci 9:239–246

Milner-Gulland EJ. 2012. Interactions between human behaviour and ecological systems. Philosophical transactions of the Royal Society of London. Series B, Biological sciences 367:270–8.

Mitlin D. 2008. With and beyond the state—co-production as a route to political influence, power and transformation for grassroots organizations. Environment and Urbanization 20(2): 339-360.

Mitton C, Adair CE, McKenzie E, Patten SB, Waye PB. 2007. Knowledge transfer and exchange: review and synthesis of the literature. Milbank Quarterly, 85(4), 729-768.Scheufele DA (2013). Communicating science in social settings. Proceedings of the National Academy of Sciences, 110(Supplement 3), 14040-14047.

Mooney H, Larigauderie A, Cesario M, Elmquist T, Hoegh-Guldberg O, Lavorel S, Mace GM, Palmer M, Scholes R, Yahara T. 2009. Biodiversity, climate change, and ecosystem services. Current Opinion in Environmental Sustainability 1, 46-54.

Myers-Smith IH, Elmendorf SC, Beck PS, Wilmking M, Hallinger M, Blok D, Speed JD. 2015. Climate sensitivity of shrub growth across the tundra biome. Nature Climate Change 5(9), 887-891.

Nordhaus T, Shellenberger, Blomqvist L. 2012. The planetary boundary hypothesis : A review of the evidence. Breakthrough Institute, Oakland, CA.

Oldekop JA, Fontana LB, Grugel J, Roughton N, Adu-Ampong EA, Bird GK, Dorgan A, Vera Espinoza MA, Wallin S, Hammett D, Agbarakwe E, Agrawal A, Asylbekova N, Azkoul C, Bardsley C, Bebbington AJ, Carvalho S, Chopra D, Christopoulos S, Crewe E, Dop MC, Fischer J, Gerretsen D, Glennie J, Gois W, Gondwe M, Harrison LA, Hujo K, Keen M, Laserna R, Miggiano L, Mistry S, Morgan RJ, Raftree LL, Rhind D, Rodrigues T, Roschnik S, Senkubuge F, Thornton I. Trace S, Ore T, Valdés RM, Vira B, Yeates N, Sutherland WJ. 2016. 100 key research questions for the post-2015 development agenda. Dev Policy Rev, 34: 55–82. doi:10.1111/dpr.12147

Peh KSH, Balmford A, Bradbury RB, Brown C, Butchart SH, Hughes FM, Stattersfield A, Thomas DHL, Walpole M, Bayliss J, Gowing D, Jones JPG, Lewis SL, Mulligan M, Pandeya B, Stratford C, Thompson JR, Turner K, Vira B, Willcock S, Birch JC. 2013. TESSA: A toolkit for rapid assessment of ecosystem services at sites of biodiversity conservation importance. Ecosystem Services 5: 51–57. doi: 10.1016/j.ecoser.2013.06.003

Pereira HM, Belnap J, Brummitt N, Collen B, Ding H, Gonzalez-Espinosa M, Gregory RD, Honrado J, Jongman RH, Julliard R, McRae L, Proença V, Rodrigues P, Opige M, Rodriguez JP, Schmeller DS, van Swaay C, Vieira C. 2010. Global biodiversity monitoring. Frontiers in Ecology and the Environment 8, 459–460

Pocock MJO, Evans DM. 2014. The Success of the Horse-Chestnut Leaf-Miner, Cameraria ohridella, in the UK Revealed with Hypothesis-Led Citizen Science. PLoS ONE 9(1), e86226. doi:10.1371/journal.pone.0086226

Pohl C, Rist S, Zimmermann A, Fry P, Gurung GS, Schneider F, Speranza CI, Kiteme B, Boillat S, Serrano E, Hadorn GH, Wiesmann U. 2010. Researchers' roles in knowledge co-production: experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal. Science and Public Policy 37(4): 267-281.

Pretty JN, Guijt I, Thompson J, Scoones I. 1995. Participatory Learning and Action: A Trainer's Guide. IIED Participatory Methodology Series, International Institute for Environment and Development. London

Queiroz C, Beilin R, Folke C, Lindborg R. 2014. Farmland abandonment: threat or opportunity for biodiversity conservation? A global review. Frontiers in Ecology and the Environment 12:288–296.

Quintas-Soriano C, Castro AJ, Castro H, García-Llorente M. 2016. Impacts of land use change on ecosystem services and implications for human well-being in Spanish drylands. Land use policy 54: 534-548

Raudsepp-Hearne C, Peterson GD, Tengö M, Bennett EM, Holland T, Benessaiah K, MacDonald GK, Pfeifer L. 2010. Untangling the environmentalist's paradox: why is human well-being increasing as ecosystem services degrade? BioScience. 60:576–589.

Raworth K. 2012. A Safe and Just Space for Humanity: Can We Live Within the Doughnut? Oxfam Discussion Paper. Oxfam, Oxford, UK.

Raymond CM, Singh GG, Benessaiah K, Bernhardt JR, Levine J, Nelson H, Turner NJ, Norton B, Tam J, Chan KM. 2013. Ecosystem services and beyond: Using multiple metaphors to understand human–environment relationships. BioScience 63(7): 536-546.

Formatted: Highlight

Renaud FG, Syvitski JPM, Sebesvari Z, Werners SE, Kremer H, Kuenzer C, Ramesh R, Jeuken A, Friedrich J. 2013. Tipping from the Holocene to the Anthropocene: how threatened are major world deltas? Curr Opin Environ Sustain 5:644–654. doi:10.1016/j.cosust.2013.11.007

Rillig MC, Kiessling W, Borsch T, Gessler,A, Greenwood AD, Hofer H, Joshi J, Schröder B, Thonicke K, Tockner K, Weisshuhn K, Jeltsch F. 2015. Biodiversity research: data without theory—theory without data. Front. Ecol. Evol. 3:20. doi: 10.3389/fevo.2015.00020

Robinson J. 2004. Squaring the circle? Some thoughts on the idea of sustainable development. Ecological Economics 48.4: 369-384

Rockström J, Karlberg L. 2010. The Quadruple Squeeze: Defining the safe operating space for freshwater use to achieve a triply green revolution in the Anthropocene. AMBIO 39:257–265.

Rockström J, Steffen W, Noone K, Persson A, Chapin FS, Lambin E, Lenton TM. Scheffer M, Folke C, Schellnhuber H, Nykvist B, De Wit CA, Hughes T, van der Leeuw S, Rodhe H, So¨rlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J. 2009. Planetary boundaries: exploring the safe operating space for humanity. Ecol Soc 14(2):32

Roy HE, Peyto J, Aldridge DC, Bantock T, Blackburn TM, Britton R, Clark P, Cook, E, Dehnen-Schmutz K, Dines T, Dobson M, Edwards F, Harrower C, Harvey MC, Minchin D, Noble DG, Parrott D, Pocock MJO, Preston CD, Roy S, Salisbury A, Schönrogge K, Sewell J, Shaw RH, Stebbing P, Stewart AJA, Walker KJ. 2014. Horizon scanning for invasive alien species with the potential to threaten biodiversity in Great Britain. Glob Change Biol 20: 3859–3871. doi:10.1111/gcb.12603

Rudd MA. 2014. Scientists' perspectives on global ocean research priorities. Forntiers in Marine Research 1:36.

Santos-Martın F, Martı´n-Lo´pez B, Garcı´a-Llorente M, Aguado M, Benayas J, Montes C. 2013. Unraveling the relationships between ecosystems and human wellbeing in Spain. PLoS One. 8:1–12

Scheffer M, Bascompte J, Brock W, Brovkin V, Carpenter SR, Dakos V, Held H, van Nes EH, Rietkerk M, Sugihara G. 2009. Early-warning signals for critical transitions. Nature 461:53–59.

Schröter D, Cramer W, Leemans R, Prentice IC, Araújo MB, Arnell NW, Bondeau A, Bugmann H, Carter TR, Gracia CA, de la Vega-Leinert AC, Erhard M, Ewert F, Glendining M House JI, Kankaanpää S, Klein RJT, Lavorel S, Lindner M, Metzger MJ, Meyer J, Mitchell TD, Reginster I, Rounsevell M, Sabaté S, Sitch S, Smith B, Smith J, Smith P, Sykes MT, Thonicke K, Thuiller W, Tuck G, Zaehle S, Zier B. 2005. Ecosystem Service Supply and Vulnerability to Global Change in Europe. Science 310, 1333-1337.

Seddon AWR, Mackay AW, Baker AG, Birks HJB, Breman E, Buck CE, Ellis EC, Froyd CA, Gill J, Gillson L, Johnso EA, Jones VJ, Juggins S, Macias-Fauria M, Mills K, Morris JL, Nogués-Bravo D, Punyasena SW, RolandTP, Tanentzap AJ, Willis KJ, Aberhan M, van Asperen EN, Austin WEN, Battarbee RW, Bhagwat S, Belanger CL, Bennett KD, Birks HH, Bronk RC, Brooks SJ, de Bruyn M, Butler PG, Chambers FM, Clarke SJ, Davies AL, Dearing JA, Ezard THG, Feurdean A, Flower RJ, Gell P, Hausmann S, Hogan EJ, Hopkins MJ, Jeffers ES, Korhola AA, Marchant R, Kiefer T, Lamentowicz M, Larocque-Tobler I, López-Merino L, Liow LH, McGowan S, Miller JH, Montoya E, Morton O, Nogué S, Onoufriou C, Boush LP, Rodriguez-Sanchez F, Rose NL, Sayer CD, Shaw HE, Payne R, Simpson G, Sohar K, Whitehouse NJ, Williams JW, Witkowski A. 2014. Looking forward through the past: identification of 50 priority research questions in palaeoecology. J Ecol 102: 256–267. doi:10.1111/1365-2745.12195

Seyfang G, Smith A. 2007. Grassroots innovations for sustainable development: Towards a new research and policy agenda. Environmental politics 16(4): 584-603.

Steelman T, Nichols EG, James A, Bradford L, Ebersöhn L, Scherman V, Omidire F, Bunn ND, Twine W, McHale MR. 2015. Practicing the science of sustainability: the challenges of transdisciplinarity in a developing world context. Sustain Sci 10(4):581–599. doi:10.1007/s11625-015-0334-4

Sutherland WJ, Bailey MJ, Bainbridge IP, Brereton T, Dick JTA, Drewitt J, Dulvy NK, Dusic NR, Freckleton RP, Gaston KJ, Gilder PM, Green RE, Heathwaite AL, Johnson SM, Macdonald DW, Mitchell R, Osborn D, Owen RP, Pretty J, Prior SV, Prosser H, Pullin AS, Rose P, Stott A, Tew T, Thomas CD, Thompson DBA, Vickery JA, Walker M, Walmsley C, Warrington S, Watkinson AR, Williams RJ, Woodroffe R, Woodroof HJ. 2008. Future novel threats and opportunities facing UK biodiversity identified by horizon scanning. Journal of Applied Ecology, 45: 821–833. doi:10.1111/j.1365-2664.2008.01474.x

Tobner CM, Paquette A, Reich PB, Gravel D, Messier C. 2014. Advancing biodiversity-ecosystem functioning science using high-density tree-based experiments over functional diversity gradients. Oecologia 174:609–21

Turner RK, Schaafsma M, Mee L, Elliott M, Burdon D, Atkins JP, Jickells T. 2015. Conceptual Framework. In Coastal Zones Ecosystem Services 11-40. Springer International Publishing.

UK Government. 2015. Open policy making toolkit https://www.gov.uk/guidance/open-policy-making-toolkit

UN (2014) The Millennium Development Goals Report 2014. United Nations New York, USA.

UNEP. 2012. Global Environmental Outlook-5. United Nations Environment Programme. New York, USA.

Verburg PH, Dearing JA, Dyke JG, van der Leeuw S, Seitzinger S, Stefan W, Syvitski J. 2015. Methods and approaches to modelling the Anthropocene. Global Environmental Change 1-14

Vilà M, Espinar LJ, Hejda M, Hulme PE, Jarošík V, Maron JL, Pergl J, Schaffner U, Sun Y, Pyšek P. 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecology letters 14:702–8.

Villa F, Bagstad KJ, Voigt B, Johnson GW, Portela R, Honzák M, David B. 2014. A Methodology for Adaptable and Robust Ecosystem Services Assessment. PLoS ONE 9(3): e91001. doi:10.1371/journal.pone.0091001

Villamor GB, Palomo I, López Santiago CA, Oteros-Rozas E, Hill J. 2014. Assessing stakeholders' perceptions and values towards social-ecological systems using participatory methods. Ecological Processes 3:22-34

Water Research Commission. 2015. miniSASS: Acommunity river health monitoring tool. [Online]. [Accessed 29 May 2015]. Available from: http://www.minisass.org/en/

Watts N, Adger WN, Agnolucci P, Blackstock J, Byass P, Cai W, Costello A. 2015. Health and climate change: policy responses to protect public health. The Lancet. doi:10.1016/S0140-6736(15)60854-6

Wegner G, Pascual U. 2011.Cost-benefit analysis in the context of ecosystem services for human well-being: A multidisciplinary critique. Global Environmental Change,21(2), 492-504.

Wils THG, Sass-Klaassen UGW, Eshetu Z, Bräuning A, Gebrekirstos A, CouraletI C, Robertson I, Touchan R, Koprowski M, Conway D, Briffa KR, Beeckman H. 2011. Dendrochronology in the dry tropics: the Ethiopian case 25: 345. doi:10.1007/s00468-010-0521-y

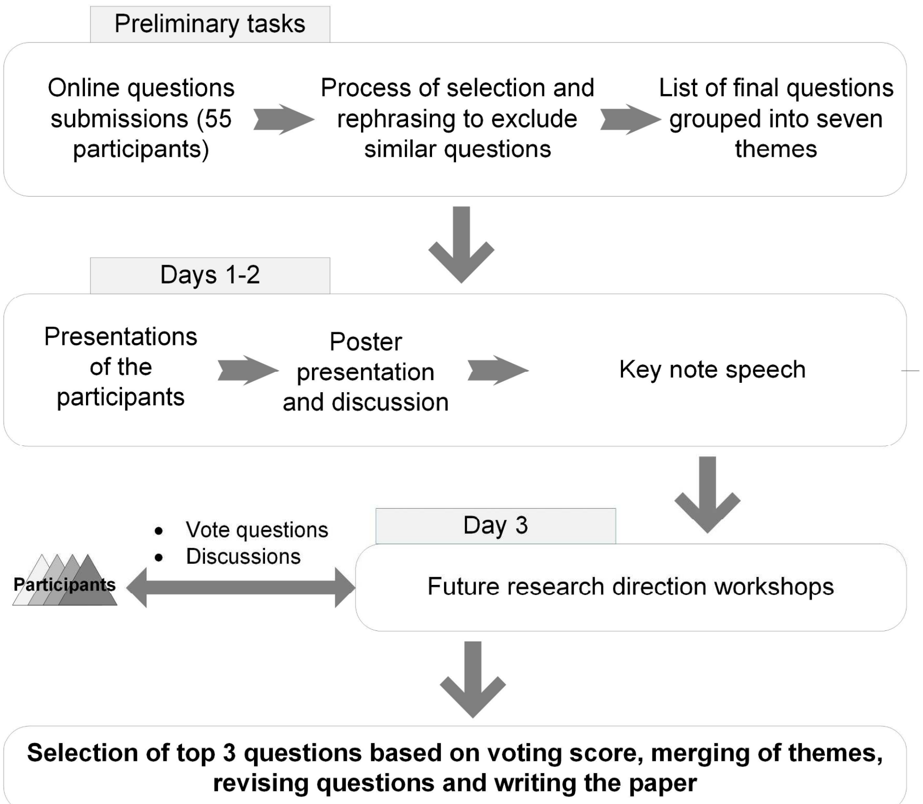

Figure 1. Methodological flow diagram of identification of future research direction for BESS by early career researchers.

923 Table 1. Commonalities and differences between this study and other horizon scanning exercises.

Horizon scanning exercises	Brief methodological description	Focused issues	Commonalities	Differences
Oldekop et al. 2016	Scale: global Purpose: 100 research questions of critical importance for the post-2015 international development agenda. Research question identification process: Two stage stakeholders consultations which includes government and non-government organizations, academics and individuals from global north and south	Post-2015 international development agenda Climate change (cost, institutionalization, impacts, practices, awareness and early warning signals) Land right, trade, gender, governance, agriculture (grassroots problems) Natural resources (distribution, equity, conflicts, sustainable management)	Participatory approach Strategies in response to climate change	Covers wide ranges of development (e.g. health, economic growth, environmental sustainability) agenda North-South perception Grassroots level problems (e.g. conflicts, awareness, equity) Less interdisciplinary Excludes awareness, collaboration ,data availability and knowledge exchange process Excludes the monetary and non-monetary value of ecosystem services Plausible approaches are not highlighted
Fleishman et al. 2011	Scale: United States Purpose: Research questions directed toward informing some of the most important current and future decisions about management of species, communities, and ecological processes in the United States	Ground water, biofuels, renewable and non-renewable energy, soil productivity, interactive and aggregated effects of multiple stressors, agriculture and water availability, socio-economic-ecological effects of human intervention for restoring ecosystem, cultural and demographics, capacity of adaptive management and ecosystem resilience, trade-offs and	Participatory approach Covers both natural and social science dimensions Brings interdisciplinary perspective in many cases despite the multidisciplinary approach in identifying	Multidisciplinary approach Multistage consultation Includes some specific issues such as ground water, biofuels etc. Includes decision makers during the consultation stage Plausible approaches are not highlighted

Horizon scanning exercises	Brief methodological description	Focused issues	Commonalities	Differences
	Research question identification process: Consultation with government and non-government organizations academics and decision makers Multidisciplinary approach Multi-stage consultation	benefits from ecosystem, commodity and market, temporal and spatial cost and benefits of ecosystem services, transition to alternative state of ecosystem, thresholds and abrupt changes, human-nature relationships and response to environmental changes, impacts on human, alternatives of management,	priority research questions Spatial and temporal dynamics Human-nature relationships and human response to environmental changes Recognizes the sustainability sciences such as alternative states, resilience, capacity of ecosystems, complex dynamic relationships (interaction, aggregation), trade-offs of management Strategies in response to climate change	Excludes awareness, collaboration data availability, and knowledge exchange process Excludes the monetary and non-monetary value of ecosystem services Absence of feedback mechanisms
Sutherland et al. 2008	Scale: UK Purpose: Future novel or step changes in threats to, and opportunities for, biodiversity that might arise in the UK up to 2050, but that had not been important in	Pathogens, technology (geo-engineering, Nano and bio technology), climate change, extreme weather events, biofuel, ocean acidification, freshwater, wildlife conservation	Participatory approach-one stage consultation Recognizes the monetary value Collaboration and data	Identifies opportunities and threats Focused on specific issues (e.g. pathogens, biofuels, freshwater, wild life) Plausible approaches are not highlighted

	the recent past Research question identification process: Consultation with government and non-governmental organizations, academics and scientific journalists One stage consultation		availability	Less interdisciplinary Excludes complex dynamics relationships (interaction, feedbacks, thresholds)

Comment [SS3]: R2 **Authors:** Thanks for your very useful comments. We agree with your comments and that is why we have added a large table, which includes the commonalities and differences with other researcher's works. Please see at line 914
This major revision also includes two additional paragraph at line 519-523 and 525-534 and some minor edits all through the paper to integrate your comments and revise accordingly. Furthermore, we have also deleted the term-experienced researchers, as we revealed that many of the researchers of these exercises are early career researchers. Therefore, instead of using differences between experienced researchers and early career researcher, we are using commonalities and differences between our work and other horizon scanning exercises.