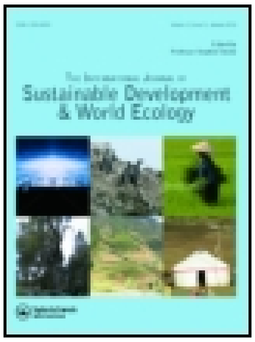

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ABSTRACT
We aimed to identify priority research questions in the field of biodiversity, ecosystem services and sustainability (BESS), based on a workshop held during the NRG BESS Conference for Early Career Researchers on BESS, and to compare these 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 different research themes in this field further emphasizes the need to consider a wider range of topics simultaneously to ensure the sustainable management of ecosystems for human wellbeing. In contrast to other horizon scanning exercises, 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.

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1. Introduction

The concepts of biodiversity, ecosystem services, and sustainability (BESS) have received increasing attention in policy, academia and funding worldwide in recent decades (Luck et al. 2012; Rillig et al. 2015). The growing number of published articles on biodiversity (from ~1000 to ~7000), ES (from ~100 to ~5000) and sustainability (from ~1000 to ~12,000) between the 1990s and 2014, indicates the influential role of these concepts in academia (Liu et al. 2011; Chaudhary et al. 2015; Kajikawa et al. 2014). 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 (Butchart et al. 2010 ; Pereira et al. 2010). Humanity has entered a new phase of sustainability challenges (Rockström and Karlberg 2010) as evidence

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grows that human activities have adversely influenced the earth's climate (IPCC 2007) and ecosystems (MA 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 (Kates 2011; Hackmann and Clair 2013; Miller et al. 2014; Steelman et al. 2015). Exercises to identify research questions by engaging researchers have previously been used to provide future research direction in the fields of biodiversity (Sutherland et al. 2008; Roy et al. 2014), ocean science (Rudd 2014), palaeoecology (Seddon et al. 2014) 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 other relevant horizon scanning exercises (e.g. Oldekop et al. 2016; Fleishman et al. 2011 and; Sutherland et al. 2008) from existing publications relating to biodiversity, post-2015 development agendas (e.g. environmental sustainability, food security), conservation and management.

2. Materials and methods

We adopted and modified the methodology of Sutherland et al. (2008) and Seddon et al. (2014) 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; (3) scoring, revising and writing the paper based on the expertise of the groups and feedback from the workshop. In addition, we 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 participants conducted research across all continents. All participants were early career researchers, either PhD students or

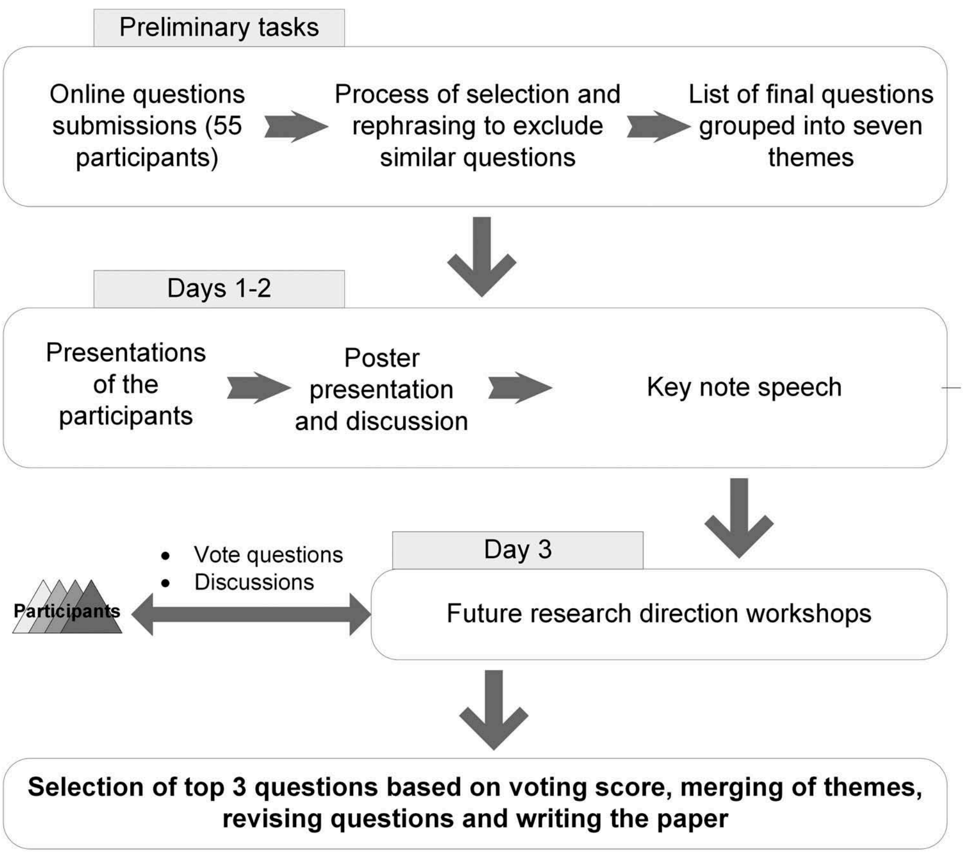

Figure 1. Methodological flow diagram of identification of future research direction for BESS by early career researchers.

post-doctoral researchers working in BESS 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 participants submitted approximately 140 questions.

The submitted questions were screened; 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

(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 utilize 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 marginalize 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 (MA 2005), explicit causal relationships between biodiversity, ecosystem functioning 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 (Vilà et al. 2011; Queiroz et al. 2014), conservation and species richness, while functional traits, system dynamics and ecosystem functions have received much less attention (Devictor et al. 2010; Liu et al. 2011; Hevia et al. 2017). Many recent studies have indicated that functional diversity is the key determinant of ecosystem functioning (Cadotte et al. 2011; Cardinale et al. 2012).

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 industrialized 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; Lenton 2013; Mason and De Bello 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 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 (UNEP 2012; UN 2014). Good (quality) databases are required at the regional scale at which most planetary processes (e.g. land use change, deforestation) take place (Lewis 2012; Nordhaus et al. 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 ecosystem service indicators (e.g. amount of biomass) or drivers of change (e.g. land-use/land-cover changes) in quantitative and qualitative ways at local and regional scales, and to extrapolate (at least to some extent) the results of field-based studies. However, although good quality datasets can give an indication of generic patterns, 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 et al. 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-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 mobilizing ownership of issues and community action in other areas of environmental science and sustainability (Seyfang and Smith 2007).

Question 12 emphasizes 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 social-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 challenges of health and climate change. However, multiple papers from within and beyond the ES literature emphasize the need for non-monetary valuation of ES to better integrate the socio-cultural dimension of ES (Chan et al. 2012; Quintas-Soriano et al. 2016). 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 (Schröter et al. 2005; Ellis et al. 2010). 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 emphasizes 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 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. 2011) 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) 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) 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, 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. 2016b), 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 (Alkemade et al. 2009; Fox and Kerr 2012). 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 artificial intelligence for ecosystem services (ARIES) 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. Forthcoming 2016a ; 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 (Lemos and Morehouse 2005; Pohl et al. 2010). In understanding the communication of scientific knowledge to non-technical non-specialist audiences, it is of benefit to recognize 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 visualizations) 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.

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 differences with 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 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 (e.g. Environmental sustainability, food security) (Oldekop 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 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 existing horizon scanning exercises as among the researchers involved in this study. In addition, interdisciplinary approaches did not come to the fore as clearly in existing papers.

Both examples (Oldekop et al. 2016; Sutherland et al. 2008) from existing horizon scanning exercises 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 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 emphasized to the same extent as they were by this study. Failure to consider both the social and

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 Research question identification process: Consultation with government and non-government organizations academics and decision makers Multidisciplinary approach Multi-stage consultation	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 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,	Participatory approach Covers both natural and social science dimensions Brings interdisciplinary perspective in many cases despite the multidisciplinary approach in identifying 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	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 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 the recent past Research question identification process: Consultation with government and non-governmental organizations, academics and scientific journalists One stage consultation	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 availability	Identifies opportunities and threats Focused on specific issues (e.g. pathogens, biofuels, freshwater, wild life) Plausible approaches are not highlighted Less interdisciplinary Excludes complex dynamics relationships (interaction, feedbacks, thresholds)

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 finalize 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.

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