Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Environmental Sustainability

Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability☆

Elena M Bennett[1], Wolfgang Cramer[2], Alpina Begossi[3,4], Georgina Cundill[5], Sandra Díaz[6], Benis N Egoh[7,36], Ilse R Geijzendorffer[2], Cornelia B Krug[8], Sandra Lavorel[10], Elena Lazos[11], Louis Lebel[12], Berta Martín-López[13,14], Patrick Meyfroidt[15,16], Harold A Mooney[17], Jeanne L Nel[18], Unai Pascual[19,20,21], Karine Payet[2,22], Natalia Pérez Harguindeguy[6], Garry D Peterson[23], Anne-Hélène Prieur-Richard[9], Belinda Reyers[18], Peter Roebeling[24], Ralf Seppelt[25,26,27], Martin Solan[28], Petra Tschakert[29], Teja Tscharntke[30], BL Turner II[31], Peter H Verburg[32], Ernesto F Viglizzo[33], Piran CL White[34] and Guy Woodward[35]

Ecosystem services have become a mainstream concept for the expression of values assigned by people to various functions of ecosystems. Even though the introduction of the concept has initiated a vast amount of research, progress in using this knowledge for sustainable resource use remains insufficient. We see a need to broaden the scope of research to answer three key questions that we believe will improve incorporation of ecosystem service research into decision-making for the sustainable use of natural resources to improve human well-being: (i) how are ecosystem services co-produced by social–ecological systems, (ii) who benefits from the provision of ecosystem services, and (iii) what are the best practices for the governance of ecosystem services? Here, we present these key questions, the rationale behind them, and their related scientific challenges in a globally coordinated research programme aimed towards improving sustainable ecosystem management. These questions will frame the activities of ecoSERVICES, formerly a DIVERSITAS project and now a project of Future Earth, in its role as a platform to foster global coordination of multidisciplinary sustainability science through the lens of ecosystem services.

Addresses
[1] Department of Natural Resource Sciences and McGill School of Environment, McGill University - Macdonald Campus, 21,111 Lakeshore Road, St. Anne-de-Bellevue, Quebec, Canada H9X 3V9
[2] Institut Méditerranéen de Biodiversité et d'Ecologie marine et continentale (IMBE), Aix Marseille Université, CNRS, IRD, Avignon Université, Technopôle Arbois-Méditerranée Bât. Villemin – BP 80, F-13545 Aix-en-Provence cedex 04, France
[3] UNICAMP (CAPESCA/NEPA), Campinas 13083-852, SP, Brazil
[4] Fisheries and Food Institute (FIFO), and Programa de Pós Graduação em Ecossistemas Costeiros e Marinhos (ECOMAR), Universidade Santa Cecília (UNISANTA), Santos 11045-040, SP, Brazil
[5] Department of Environmental Science, Rhodes University, Grahamstown 6140, South Africa
[6] Instituto Multidisciplinario de Biología Vegetal, (IMBIV-CONICET) and FCEFyN, Universidad Nacional de Córdoba, Casilla 24 de Correo 495, 5000 Córdoba, Argentina
[7] European Commission – Joint Research Centre, Via E. Fermi, 2749, I-21027 Ispra (VA), Italy
[8] bioDISCOVERY office, Laboratoire d'Ecologie, Systématique et Evolution (ESE), Bâtiment 362, Université Paris-Sud 11, 91405 Orsay Cedex, France
[9] DIVERSITAS, c/o Muséum National d'Histoire Naturelle (MNHN), 57 Rue Cuvier – CP 41, F-75231 Paris Cedex 05, France
[10] Laboratoire d'Écologie Alpine (LECA), CNRS – Université Grenoble Alpes, BP 53, 38041 Grenoble Cedex 9, France
[11] Instituto de Investigaciones Sociales, Universidad Nacional Autónoma de México, Cd. Universitaria, 04510 Coyoacán, México, D.F., Mexico
[12] Unit for Social and Environmental Research, Faculty of Social Science, Chiang Mai University, Chiang Mai 50200, Thailand
[13] Department of Geosciences and Natural Resource Management, University of Copenhagen, Rolighedsvej 23, 1958 Frederiksberg C, Denmark
[14] Social-ecological Systems Laboratory, Autonomous University of Madrid, Madrid 28049, Spain
[15] Georges Lemaitre Earth and Climate Research Centre, Earth and Life Institute, Université Catholique de Louvain, 1348 Louvain-La-Neuve, Belgium
[16] Fonds de la Recherche Scientifique F.R.S. – FNRS, 1000 Brussels, Belgium
[17] Department of Biology, Stanford University, Stanford, CA 94305, USA
[18] Council for Scientific and Industrial Research (CSIR), PO Box 320, Stellenbosch 7599, South Africa
[19] Basque Centre for Climate Change (BC3), Alameda Urquijo 4–4a, 48008 Bilbao, Spain

☆ The writing team for this article was co-led by Elena Bennett and Wolfgang Cramer.

[20] Ikerbasque Basque Foundation for Science, Maria Díaz de Haro 3, 48013 Bilbao, Spain
[21] Department of Land Economy, University of Cambridge, Cambridge, United Kingdom
[22] ecoSERVICES office, c/o IMBE, Technopôle Arbois-Méditerranée, F-13545 Aix-en-Provence cedex 04, France
[23] Stockholm Resilience Centre, Stockholm University, Stockholm 106 91, Sweden
[24] CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
[25] Department of Computational Landscape Ecology, UFZ – Helmholtz Centre for Environmental Research, 04318 Leipzig, Germany
[26] German Centre for Integrative Biodiversity Research (iDiv), 04103 Leipzig, Germany
[27] Institute of Geoscience & Geography, Martin-Luther-University Halle-Wittenberg, 06099 Halle (Saale), Germany
[28] Ocean and Earth Science, National Oceanography Centre, University of Southampton, Waterfront Campus, European Way, Southampton SO14 3ZH, United Kingdom
[29] Department of Geography, Earth and Environmental Systems Institute (EESI), 322 Walker Building, Pennsylvania State University, University Park, PA 16802, USA
[30] Georg-August-University, Grisebachstr. 6, D-37077 Göttingen, Germany
[31] School of Geographical Sciences and Urban Planning & School of Sustainability, Arizona State University, Tempe, AZ, USA
[32] Faculty of Earth and Life Sciences, VU University Amsterdam, De Boelelaan 1087, 1081 HV Amsterdam, The Netherlands
[33] INTA Centro Regional La Pampa-CONICET, Environmental Management Program, Av. Spinetto 785, 6300-Santa Rosa, La Pampa, Argentina
[34] Environment Department, University of York, York YO10 5DD, United Kingdom
[35] Department of Life Sciences, Imperial College London, Silwood Park Campus, Buckhurst Road, Ascot, Berkshire SL5 7PY, United Kingdom

Corresponding author: Cramer, Wolfgang (wolfgang.cramer@imbe.fr)

[36] Current address: School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville 3209, South Africa.

Current Opinion in Environmental Sustainability 2015, **14**:76–85

This review comes from a themed issue on **Open issue**

Edited by **Eduardo Brondizio**, **Rik Leemans** and **William Solecki**

For a complete overview see the Issue and the Editorial

Received 22 December 2014; Accepted 27 March 2015

Available online 22nd April 2015

http://dx.doi.org/10.1016/j.cosust.2015.03.007

Introduction

The consequences of anthropogenic environmental change, the fundamental need to improve the well-being of people around the world, and the desire to conserve biodiversity at the planetary scale together require more focused attention on how ecosystems can be managed to sustainably, efficiently, and equitably produce ecosystem services that benefit society [1•]. Several research and assessment approaches have been proposed to better understand the potential of the ecosystem service concept to improve management of ecosystems for human well-being [e.g., 2,3•,4•,5,6]. These frameworks mostly build on the principles of sustainable development and include aspirational goals to enhance both ecosystem functioning and human well-being. Yet, despite extensive work on ecosystem services in recent decades, our understanding of their ecological foundation, their impacts on human well-being, and our knowledge about how to govern their benefits remains insufficient [7–9].

There are several explanations for these gaps. First, the vast amount of knowledge about ecosystem services is fragmented into many disciplinary studies, mostly in the natural sciences and economics, making it difficult to synthesize it [10]. Also, most publications about ecosystem services are conceptual (i.e., not including empirical measurements of ecosystem services [11]) or cover only one aspect of the interaction between ecosystems and people [12]. To advance, we need to strengthen the science behind the production, distribution, and governance of ecosystem services and the benefits they provide [13]. In this paper, we describe three key gaps in our understanding of ecosystem services, and present a research strategy to jointly address these gaps.

Although we know that the production of ecosystem services is a result of the interplay between social and ecological systems [14•], the precise combinations of social and ecological contributions required to produce services, and how these combinations affect the resilience and sustainability of the provision of services, remains unclear. For example, agricultural production derives from properties and functions of the ecological system, such as soil quality and nutrient cycling, as well as from human interventions, such as ploughing and harvesting. However, the extent to which human manipulation of ecosystems alters ecological functions in ways that change the sustainable supply of services remains uncertain [10,15•]. Differences in the role and balance of ecological and social components in the supply of services are likely to lead to contrasting emergent system properties or unexpected effects on long-term sustainability of service supply [16]. For example, a system in which water is cleaned through ecological processes, such as those occurring in retention ponds, is likely to have different properties from one in which water is cleaned through the use of filtering technology. Each of these systems might be more or less resilient to different perturbations or more or less sustainable over the long run under different conditions. Understanding how altering the mix of ecological and social contributions to services affects long-term sustainability, is a key step in improving management of ecosystems and their services.

Second, we do not yet understand enough about the drivers of ecosystem service distribution, preferences or access across stakeholders, nor the specifics of how services impact human well-being [17]. We have too little empirical understanding about the diversity of stakeholders, their motivations and preferences for various ecosystem services, and furthermore, understand relatively little about the potential social conflicts and inequities arising from the access to specific ecosystem services by different individuals and groups. Without this knowledge, even if we understood how social and ecological systems interact to produce ecosystem services, we would not understand how varying the amount of services provided is likely to affect the well-being of various stakeholder groups.

Finally, knowledge about how governance influences the sustainability, efficiency and equitability of ecosystem service supply remains scant [18•]; and there are very few investigations of the effectiveness of ecosystem service-based policies relative to other interventions [19]. Issues such as how and when existing governance structures prevent or enhance sustainable, equitable, and efficient flows of benefits, and how we transform out of deeply entrenched systems of inequity and non-sustainable use to fundamentally new systems of governance, remain inadequately addressed [20•].

These gaps in our understanding limit the capacity of ecosystem service research to inform policy and management [3•,21–23]. The authors, part of the ecoSERVICES community (which is itself a project of the DIVERSITAS and Future Earth global change programmes) aim to help guide the agenda of natural and social science in a policy context to address crucial knowledge gaps and implementation of ecosystem service science in practice (see Box 1). To respond to this objective, the ecoSERVICES community has identified three key research challenges, illustrated and conceptualized in Figure 1. Here, we explain these challenges in sequence and then present a strategy to address the major research gaps. The goal of this paper is to outline these challenges for the ecosystem service research community, and, at the same time, to highlight how the ecoSERVICES project aims to address them.

Box 1 Box on ecoSERVICES

In 2004, DIVERSITAS — the international programme of biodiversity science (www.diversitas-international.org) — established its ecoSERVICES project to bridge the broadly recognized difficulties of communication and engagement on the environment and to address key challenges by fostering international collaborative research on biodiversity, ecosystem functioning and ecosystem services [81]. Between 2005 and 2011, ecoSERVICES brought together multidisciplinary groups in ecology and economics to research the ecological processes underlying the supply of ecosystem services and to place an economic value on these services. The group made a number of widely recognized key contributions in science [e.g., 82–84]. Active involvement of DIVERSITAS scientists in science-policy activities led to the development of crucial policy related to the impacts of biodiversity change on ecosystem functioning and services (most notably the tenth meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD-COP10) [85] and policy briefs for the United Nations Environment Programme (UNEP) [e.g., 86,87] and for the Earth Summit Rio+20 [88].

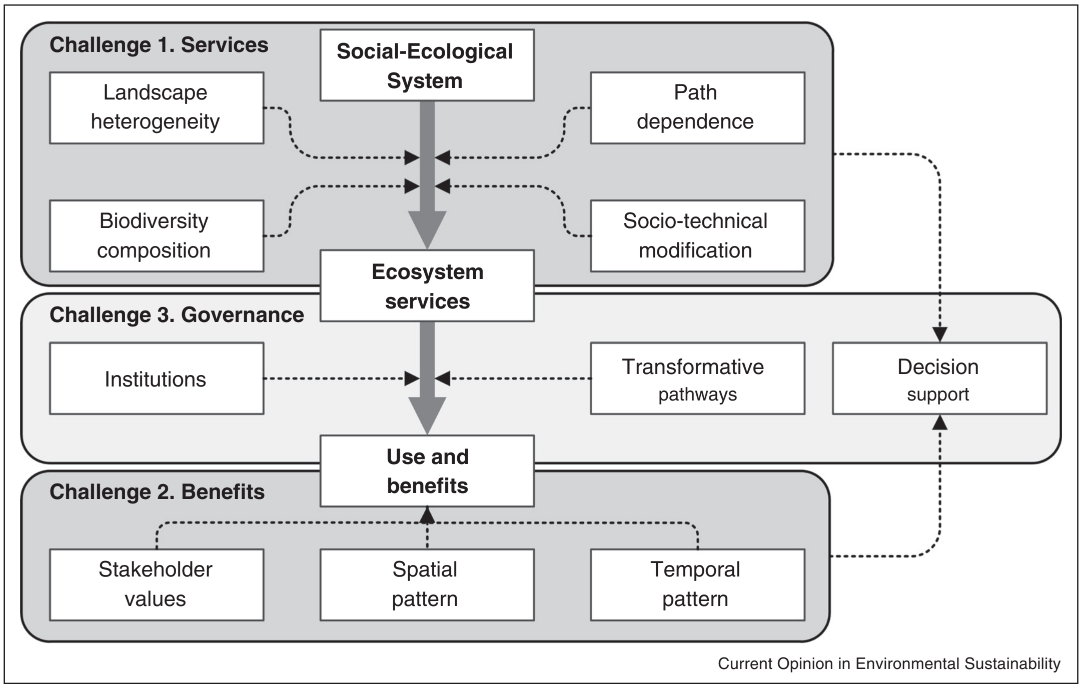
A crucial follow-on to these achievements is the integration of ecoSERVICES within Future Earth, a 10-year international scientific programme on global sustainability (www.futureearth.org). Future Earth emerged in response to calls from the Science and Technology Alliance for Global Sustainability, including the International Council for Science (ICSU), the International Social Science Council (ISSC), research funding agencies, and policy bodies (UNESCO, UNEP, WMO) for a major global scientific initiative that strengthens the engagement between policy, society, and science on the questions posed by the urgent challenges of sustainable development [76]. Future Earth is built on the legacy of the four global environmental change programmes, DIVERSITAS, IGBP, IHDP and WCRP.

Challenge 1: how, when and where are ecosystem services co-produced by social–ecological systems?

The seemingly simple notion that ecosystem services are provided by ecosystems quickly becomes rather complex when we ask how the dynamics of the biological system, and its interaction with the human sphere, translate into the actual stocks and flows of services. The body of ecological research investigating how stocks and flows of specific ecosystem services are moderated tends to be framed with respect to either biophysical processes and context, or the role of human interventions. Considerably less emphasis has been given to understanding the relative importance and interplay of biophysical, ecological, and social components over time and space. Understanding of this interplay can be improved via four key research avenues:

(1a) Identify the role of biodiversity and other forms of heterogeneity in maintaining multiple ecosystem services: Recent reviews have emphasized the pivotal role of biodiversity for ecosystem functions [e.g., 24–27], but only few studies have investigated the linkage between biodiversity, ecosystem function and a broader range of services [27]. In particular, we need to (i) disentangle the effects of the different dimensions of biodiversity (e.g., species richness, functional diversity, phylogenetic diversity) on services at different spatial and temporal scales; and (ii) more comprehensively account for responses of ecosystem function to multi-dimensional anthropogenic environmental forcing. As data on different dimensions of biodiversity and ecosystem services become more readily available, we see high potential to systematically investigate the links between different indicators of biodiversity to various ecosystem functions and ultimately, to different types of ecosystem services themselves. Information linking biodiversity and ecosystem function is required, for example by simultaneously quantifying structural and functional components, or by simultaneously measuring functional trait variation and ecosystem fluxes like carbon

Figure 1



This figure depicts the conceptual framework used to structure this paper. It will also serve as the conceptual framework of the ecoSERVICES project. It shows the three challenges to improving our understanding and management of ecosystem services: (1) Understanding how services are produced by social–ecological systems, (2) understanding how benefits are distributed among users, and (3) understanding how governance acts as an interface between the production of services and benefits received by those who use them. Ecosystem services are generated by social–ecological systems, in which four components (landscape heterogeneity, biodiversity, socio-technical modification, and path dependence) play a key role. The services themselves are distributed to people to use, and this use is driven by stakeholder values as well as by the temporal and spatial patterns of both people and services. Governance, through its institutions, is what determines the relationship between services and their use.

sequestration or nutrient cycling [28,29]. Combining empirical survey approaches with modeling and direct experimental manipulations then allows scientists to move from inference to identifying mechanisms.

(1b) Understand the effect of landscape and seascape heterogeneity on ecosystem service supply: Species movement and behavior can change in response to localized resource heterogeneity and small-scale variations in habitat structure and that can, in turn, influence ecosystem functioning and the provision of ecosystem services [30,31]. By the same token, we still lack a comprehensive assessment linking landscape heterogeneity to the supply of multiple ecosystem services across terrestrial, fresh water, and marine systems. Determining how the relationship between biodiversity and ecosystem service supply could best be conserved within and among landscapes, taking into account ecological continua and appropriate spatio-temporal scales [32], will allow us to better predict and mitigate changes to the magnitude and flow of services. Another challenge consists of testing how innovative land systems, spatial planning, and policy can be used to ensure landscape configurations that more optimally sustain desired bundles of ecosystem services over time [33,34].

(1c) Assess the role of path-dependence and legacy effects in the supply of multiple ecosystem services: The interactions of ecosystem services over space and time may be linear or non-linear, and may contain unexpected threshold effects [16,35]. There may also be important cross-scale effects, such that some local or regional changes can cascade up to affect global scale processes and thresholds [36]. Ecosystem services are themselves the manifestation of complex interactions between biophysical context, ecological processes, and human interventions [37]. Such interactions at one point in time can trigger self-reinforcing sequences and influence future trajectories of ecosystem services, potentially constraining options for their supply in the future. For instance, decisions to prioritize food production today may constrain our ability to provide clean water in the future if excess nutrients accumulated in the soil, thereby increasing their availability for potential future runoff that could eutrophy aquatic systems. Approaches to explore path-dependence should be based on long-term monitoring of bundles of ecosystem services across a series of sites around the world with varying mixes of service supply [e.g., 38]. Observations and historical data would allow quantification of service supply and human interventions, and encourage assessment of temporal variations in service supply against key policy changes or transformations in land use and land cover composition and configuration over time.

(1d) Understand the function of social systems in ecosystem service supply: Human intervention in ecosystems has been the fundamental factor driving the supply and distribution of ecosystem services in the Anthropocene [2]. People consciously and unconsciously protect, conserve, use, contest, alter, exploit, destroy, change, and rehabilitate ecosystems, for their own or somebody else's benefit, with implications for ecosystem functions and services. For instance, without ploughing and addition of fertilizers, agricultural production would be far lower than it currently is in most industrialized nations. Although some claim that there are limits to the role of knowledge systems and technology in the supply of services [10], others have argued that these far exceed what we currently imagine [15•,39]. There is little systematic understanding about the particular combinations of different human actions and ecological systems that provide ecosystem services sustainably, efficiently and equitably now and in the future. Our understanding of the implications of such interventions across spatial scales is equally sparse. Research aiming at better understanding the opportunities, limitations and implications of technological interventions in the supply of all kinds of services through time in many different locations and situations will improve our ability to manage ecosystem services sustainably.

Challenge 2: who benefits from the provision of ecosystem services?

Identifying those who benefit from ecosystem services and understanding how benefits are distributed among individuals and stakeholder groups is an acknowledged prerequisite for effective ecosystem services assessments [8,40]; however it remains largely unaddressed in the international research agenda [41•]. Tackling this gap means seeking to understand the diversity of stakeholders, why they use various ecosystem services, and the potential social conflicts that can arise from the use of specific ecosystem services by different individuals and stakeholder groups at different spatial-temporal scales. This can be analyzed through three key research areas:

(2a) Understand the diversity of stakeholders, their benefits from ecosystem services and their preferences for valuing services: Understanding how stakeholders benefit from ecosystem services entails identifying the stakeholders in question and characterizing their knowledge types, capabilities, rights, and value-systems, as well as preferences regarding use of services. Our understanding of benefit distribution must then be integrated with information about stakeholders' relationships with one another and the prevailing entitlement structures that foster or hinder equality in access to, and benefits from, ecosystem services [42]. Together with people's multifaceted reasons for using, valuing, or disregarding ecosystem services, this information helps us understand social constellations that can lead to collaboration or conflict between interest groups with respect to ecosystem service management [43]. Knowledge about benefit distributions and the mechanisms behind these distributions can also help us understand the trade-offs between current versus future needs and rights, and proximate versus geographically distant benefits that are implied by different management strategies [44]. Understanding the social relationships involved in determining the (in)equality of access and benefits of different stakeholder groups to ecosystem services is fundamental to evaluating management options, their implications for livelihoods and wellbeing, and to establishing acceptable trade-offs in the context of equity and access to ecosystem services [8,18•,45•,46].

(2b) Identify spatial patterns of ecosystem services use and benefit: Trade-offs and synergies between the beneficiaries of different ecosystem services help determine winners and losers at different spatial scales [47]. Who wins and who loses generally depends on the location of stakeholders, their access rights and access to decision-making. Additionally, spatial mismatches between areas of ecosystem service supply and demand — e.g., along the rural-urban supply and demand gradient, from mountains to lowlands, or through goods exported from one country to another [48,49•] — mean that human activities and decisions in one area can have a large impact on social–ecological systems in distant locations [50,51]. Indeed, the costs of conservation are often born locally for national, regional, or international gain. Similarly, the disproportionate consumption of certain ecosystem services (e.g., food or freshwater) by rich countries or urban societies in developing countries implies ecosystem depletion in poorer countries [52]. In addition, poor people and poor countries tend to be those most vulnerable to the multiple effects of global environmental change [53]. Understanding how individuals' consumption of a particular ecosystem service in one place can limit the use and enjoyment of this or other services by other people elsewhere, is therefore a major research priority [52]. Understanding these interactions of cost and benefit requires us to understand how the spatial scale of supply and demand differs between services and stakeholders [54], through spatially explicit quantifications of ecosystem service supply and demand using spatial models [55] or public participatory geographic information systems [56]. It also requires the identification of winners and losers at different spatial scales and in different regions [8,57]. Although studies of trade-offs and synergies in provisioning services such as food and water need to be expanded, research should also be undertaken on interactions among non-provisioning services, which are seldom addressed [but see 10].

(2c) Identify temporal dynamics of ecosystem services use and supply: Understanding how past societies adapted to external drivers and perturbations to maintain the flow of ecosystem services without adverse consequences to their well-being, can improve our understanding of how to deal with current drivers of change [1,58]. Historical analysis is one way to understand the mechanisms behind interactions among ecosystem services [59–61]. Additionally, studying history and trends in ecosystem service supply, can help us learn about typical rates of change and time lags between changes in policies or other drivers and resultant changes in ecosystem service supply [62•]. Analysis of historical and current drivers of change is needed to identify key social–ecological features that help cope with perturbations, while maintaining a diverse and desired set of ecosystem service flows for a diversity of beneficiaries. Future scenarios can show possible trends in ecosystem services, the impact of new drivers and increased telecoupling in the global system and the related impacts on the well-being of future generations [51,63].

Challenge 3: what are the best practices for the governance of ecosystem services?

Broadly interpreted, institutions refer to the conventions, norms and formally sanctioned rules of a society that facilitate or hinder governance, both formal and informal [64]. Understanding these institutions and the actors, discourses, and politics generating them, informs assessments of best practices for the management of ecosystem services [65]. Although much attention has been given to institutions regarding resource procurement - especially in common property regimes [67], and to international accords [68] - minimal attention has been given to the full range of ecosystem services and implications for sustainability [69]. Overall improvement in understanding the ways in which different institutional structures influence more equitable, sustainable, and efficient flows of ecosystem services and their benefits, and how socio-political processes promote or hinder the emergence and maintenance of this governance is required, in order to inform best practices for decision making. This goal, in turn, requires improvement in the tools and methods used to address the formation and maintenance of robust mechanisms of governance.

(3a) Characterize how institutions and agents influence the supply and distribution of ecosystem services: Substantial attention has been given to the institutional dimensions of common property regimes and public goods [70], although much of it has been conceptual and game theoretic in kind [71], and almost all case study assessments address one provisioning service only. Synthesis of this work indicates that there are no institutional panaceas for sustainable ecosystem services; rather, multiple institutions may achieve sustainable results, crafted by the social–environmental system in question [67]. These results suggest that attention to the 'institutional and agent landscape' is needed in which different social–ecological systems are examined and compared to identify the conditions in which different governance systems yield robust results. This requires a concrete understanding of the values and social capital of the agents in play, and the benefits they prefer and actually derive from the services [72•]. Addressing this challenge requires novel hybrid methods that can characterize the structural and functional dimensions of institutions (e.g., property rights, formal and informal governance systems), the preferences and capacities of agents, and the integration of both with the biophysical understanding of ecosystem services [73].

(3b) Identify tools, models, and processes to support efficient, equitable, and sustainable decision-making processes that account for feedbacks in complex social–ecological systems: Robust methods for systematic assessments of the effectiveness of international accords (one form of governance) are under development, demonstrating that output, outcome, and impact must be treated as three distinct steps in a causal chain [68]. Other work demonstrates that balancing tradeoffs among information credibility, salience, and legitimacy is essential for the development of governance structures among diverse stakeholders [74]. Building from these and other works, attention to enhancing the applicability of tools and methods to address knowledge generation (e.g., assessments and scenario development), collaborative and transformative learning, and robust institution formation is required to improve the management and governance of ecosystem services [43,75]. A promising research area involves the adaption of cost–benefit analyses and participatory multi-criteria approaches to account for different preferences and values among stakeholders [43]. Adequately capturing and representing the diversity of knowledge systems, institutional structures, governance systems and individual stakeholder's priorities is fundamental to understanding these trade-offs, and how they might best be governed.

(3c) Understand the socio-political processes that create, support or constrain transformative pathways towards equitable, efficient and sustainable governance of ecosystem services: Institutions and governance structures aimed at sustainability emerge from complex political–economic structures and processes. Improving our ability to transform ecosystem service governance — and to know under what conditions such transformation is needed — demands an understanding of how insights from institutional and actor analyses (3a), and best practices with various technical tools and participatory processes (3b), function to lead to transformation in various socio-political settings. Given that these linkages cross spatio-temporal scales, research is needed at multiple levels of analysis; from international governance and prevailing economic conditions to local institutions and social conditions, with attention to scale interactions, including how possible changes in ecosystem services governance may feedback on other institutions and levels of governance [73]. Understanding these dynamics will require approaches that combine empirical tools and modeling that focus on identifying social and environmental values, experiences, expectations, and responsibilities of different actors. Understanding how to draw lessons from the processes of transformative changes in one specific context, to apply to ecosystem management in other contexts, presents a particular challenge [76,77].

A science strategy and beyond

We have laid out a broad, and necessarily transdisciplinary, research agenda for ecosystem service science in the coming decade. Beyond continuing to advance our science, what will it take to respond to the three challenges? Although we presented each challenge separately, they are interconnected. That is, we cannot address issues of governance without a thorough understanding of how social and ecological systems interact to produce services. Similarly, we cannot fully grasp questions about benefits distributions without a clear picture of institutions and how they impact service provision, social relationships, and benefits distribution.

With this in mind, at least two key improvements in the way we do science are needed to make progress here. First, more integrative collaboration across social sciences, natural sciences, and the humanities is required to address the challenges implied by the fact that ecosystem services are supplied and distributed by complex social–ecological systems. This goes well beyond multidisciplinary perspectives on the ecosystem services concept, and recognizes the need for truly integrated, transdisciplinary approaches to studying interactions between socio-economic and ecological systems. Second, the scientific community working on ecosystem service science alone cannot provide a full response to all of the key needs of policy-makers and decision-makers [78]. Instead, we need co-production of knowledge through research programmes designed in collaboration with decision-makers and users of ecosystem services, to ensure that interventions and policies have appropriate impact and can operate across multiple temporal and spatial scales. In this sense, our knowledge should integrate local and traditional knowledge with other sources of information [79], recognizing the diversity of modes by which multiple stakeholders and users interact with ecological systems [80].

How can a Future Earth project such as ecoSERVICES contribute to the further development and application of transdisciplinary and co-designed ecosystem service science in practice and policy? Building on the DIVERSITAS legacy (Box 1), we aim to advance research efforts responding to all three challenges through improved networking, information exchange, and co-design with both funders and stakeholders. A first step will be the further conceptual elaboration of the challenges and tasks mentioned above, guiding transdisciplinary research on ecosystem services in the next decade. Additionally, there is a considerable amount of scattered, but very good, ecosystem service science in existence. Using approaches that bring multiple academic disciplines and stakeholders together to better integrate this information into new knowledge about ecosystem services, will advance our ability to manage ecosystems for ecosystem services. In parallel, we will develop deeper interactions with science-policy interfaces, including, but not limited to, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) [14•]; in order to assure co-design of research and policy. Finally, while the urgency of better management of natural resources may be self-evident to some, better communication is still essential for motivating advances in policy, as well as make a change to the impact of private actors' activities on the biophysical environment.

Acknowledgements

The core of this article is based on the discussions during a workshop, held at ICSU, Paris, in November 2013, with members of the new ecoSERVICES Scientific Committee, as well as a number of additional experts. We thank all participants for very constructive participation, ICSU for hosting the workshop, and DIVERSITAS for financial support to ecoSERVICES. We also thank the editors and two anonymous reviewers for very useful comments that helped us improve the paper.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Seppelt R, Manceur AM, Liu J, Fenichel EP, Klotz S: **Synchronized peak rate years of global resources use**. *Ecol Soc* 2014, **19**:50. •
A synthesis of time series on human appropriation of renewable and non-renewable resources, showing that a peak rate year of resource use has passed already and further development requires coping with limited options on substitution.

2. Millennium Ecosystem Assessment: *Ecosystems and Human Well-being: A Framework for Assessment*. Washington, DC: Island Press; 2003.

3. Kumar P, Brondizio E, Gatzweiler F, Gowdy J, De Groot J, Pascual U, Reyers B, Suhkdev P: **The economics of ecosystem services: from local analysis to national policies**. *Curr Opin Environ Sustain* 2013, **5**:78-86. •
This paper analyzes the problems found when scaling-up findings on relationships between ecosystem services, biodiversity and economics from the site/local scale to the national scale.

4. Howe C, Suich H, Van Gardingen P, Rahman A, Mace GM: **Elucidating the pathways between climate change, ecosystem services and poverty alleviation**. *Curr Opin Environ Sustain* 2013, **5**:102-107. •
Tackling trade-offs and in particular identifying opportunities for win–win situations in ecosystem service provision will be crucial to ensure that we

use manage landscapes and seascapes in a sustainable, efficient and equitable way. This paper provides a first large-scale analysis of win-wins and trade-offs in relation to ecosystem services, and highlights the importance of understanding competing goals and different stakeholder demands.

5. de Groot RS, Alkemade R, Braat L, Hein L, Willemen L: **Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making**. *Ecol Complex* 2010, **7**:260-272.

6. White PCL, Godbold JA, Solan M, Wiegand J, Holt AR: **Ecosystem services and policy: a review of coastal wetland ecosystem services and an efficiency-based framework for implementing the ecosystem approach**. In *Ecosystem Services*. Edited by Harrison RM, Hester RE. Royal Society of Chemistry; 201029-51. Issues in Environmental Science and Technology, vol 30.

7. Kremen C: **Managing ecosystem services: what do we need to know about their ecology?** *Ecol Lett* 2005, **8**:468-479.

8. Daw T, Brown K, Rosendo S, Pomeroy R: **Applying the ecosystem services concept to poverty alleviation: the need to disaggregate human well-being**. *Environ Conservation* 2011, **38**:370-379.

9. Barnaud C, Antona M: **Deconstructing ecosystem services: uncertainties and controversies around a socially constructed concept**. *Geoforum* 2014, **56**:113-123.

10. Raudsepp-Hearne C, Peterson GD, Bennett EM: **Ecosystem service bundles for analyzing tradeoffs in diverse landscapes**. *Proc Natl Acad Sci USA* 2010, **107**:5242-5247.

11. Carpenter SR, Mooney HA, Agard J, Capistrano D, DeFries R, Díaz S, Dietz T, Duraiappah AK, Oteng-Yeboah A, Pereira HM *et al.*: **Science for managing ecosystem services: beyond the Millennium Ecosystem Assessment**. *Proc Natl Acad Sci USA* 2009, **106**:1305-1312.

12. Liquete C, Piroddi C, Drakou EG, Gurney L, Katsanevakis S, Charef A, Egoh B: **Current status and future prospects for the assessment of marine and coastal ecosystem services: a systematic review**. *PLoS ONE* 2013, **8**:e67737.

13. Abson DJ, Von Wehrden H, Baumgärtner S, Fischer J, Hanspach J, Härdtle W, Heinrichs H, Klein AM, Lang DJ, Martens P *et al.*: **Ecosystem services as a boundary object for sustainability**. *Ecol Econ* 2014, **103**:29-37.

14. • Díaz S, Demissew S, Carabias J, Joly C, Lonsdale M, Ash N, Larigauderie A, Ram Adhikari J, Arico S, Baldi A *et al.*: **The IPBES Conceptual Framework — connecting nature and people**. *Curr Opin Environ Sustain* 2015, **14**:1-16.

This paper presents the conceptual framework of the Intergovernmental Platform of Biodiversity and Ecosystem Services, which updates the previous conceptual frameworks on ecosystem services and provides a good overview of the many science-policy challenges in biodiversity and ecosystem services.

15. • Reyers B, Biggs R, Cumming GS, Hejnowicz AP, Polasky S: **Getting the measure of ecosystem services: a social–ecological approach**. *Front Ecol Environ* 2013, **11**:268-273.

The paper explores the co-production of ecosystem services by social, as well as ecological components of systems. It explores how this co-production, as well as the bundled nature of ecosystem services, might be better measured in order to understand and track the consequences of ecosystem service change for human wellbeing. The paper presents a systems-based approach for measuring ecosystem services for setting policy targets, developing indicators, and establishing monitoring programs.

16. Gordon LJ, Peterson GD, Bennett EM: **Agricultural modifications of hydrological flows create ecological surprises**. *Trends Ecol Evol* 2008, **23**:211-219.

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

18. • Pascual U, Phelps J, Garmendia E, Brown K, Corbera E, Martin A, Gomez-Baggethun E, Muradian R: **Social equity matters in payments for ecosystem services**. *Bioscience* 2014, **64**:1027-1036.

This paper discusses the various pathways that link multiple dimensions of equity and the effectiveness of ecosystem services conservation policies. It challenges the view that equity, efficiency and sustainability can be seen as separate outcomes and points out at important feedbacks between them.

19. Goldman RL, Tallis H, Kareiva P, Daily GC: **Field evidence that ecosystem service projects support biodiversity and diversify options**. *Proc Natl Acad Sci USA* 2008, **105**:9445-9448.

20. • Ruckelshaus M, McKenzie E, Tallis H, Guerry A, Daily G, Kareiva P, Polasky S, Ricketts T, Bhagabati N, Wood SA *et al.*: **Notes from the field: lessons learned from using ecosystem service approaches to inform real-world decisions**. *Ecol Econ* 2013. available online.

The paper presents a very useful framework for exploring the impact of ecosystem service approaches in a variety of decision-making contexts. The framework moves from knowledge generation, through awareness, to policy shifts and outcomes for ecosystems and human wellbeing. The paper uses the framework to explore the impacts of the work of the Natural Capital program through 20 of its demonstration projects.

21. Sitas N, Prozesky HE, Esler KJ, Reyers B: **Exploring the gap between ecosystem service research and management in development planning**. *Sustainability* 2014, **6**:3802-3824.

22. Reed MS: **Stakeholder participation for environmental management: a literature review**. *Biol Conserv* 2008, **141**:2417-2431.

23. Martinez-Harms MJ, Bryan BA, Balvanera P, Law EA, Rhodes JA, Possingham HP, Wilson KA: **Making decisions for managing ecosystem services**. *Biol Conserv* 2015, **184**:229-238.

24. Nicholson E, Mace GM, Armsworth PR, Atkinson G, Buckle S, Clements T, Ewers RM, Fa JE, Gardner TA, Gibbons J *et al.*: **Priority research areas for ecosystem services in a changing world**. *J Appl Ecol* 2009, **46**:1139-1144.

25. Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, Narwani A, Mace GM, Tilman D, Wardle DA *et al.*: **Biodiversity loss and its impact on humanity**. *Nature* 2012, **486**:59-67.

26. Balvanera P, Siddique I, Dee L, Paquette A, Isbell F, Gonzalez A, Byrnes J, O'Connor MI, Hungate BA, Griffin JN: **Linking biodiversity and ecosystem services: current uncertainties and the necessary next steps**. *BioScience* 2014, **64**:49-57.

27. Harrison PA, Berry PM, Simpson G, Haslett JR, Blicharska M, Bucur M, Dunford R, Egoh B, Garcia-Llorente M, Geamănă N *et al.*: **Linkages between biodiversity attributes and ecosystem services: a systematic review**. *Ecosyst Services* 2014, **9**:191-203.

28. Reichstein M, Bahn M, Mahecha MD, Kattge J, Baldocchi DD: **Linking plant and ecosystem functional biogeography**. *Proc Natl Acad Sci USA* 2014, **111**:13697-13702.

29. Bonan GB, Oleson KW, Fisher R, Lasslop G, Reichstein M: **Reconciling leaf physiological traits and canopy flux data: use of the TRY and FLUXNET databases in the Community Land Model version 4**. *J Geophys Res – Biogeosci* 2012, **117**:10 1029/2011JG001913.

30. Godbold JA, Bulling MT, Solan M: **Habitat structure mediates biodiversity effects on ecosystem properties**. *Proc R Soc B – Biol Sci* 2011, **278**:2510-2518.

31. Mitchell MGE, Bennett EM, Gonzalez A: **Linking landscape connectivity and ecosystem service provision: current knowledge and research gaps**. *Ecosystems* 2013, **16**:894-908.

32. Hunter ML Jr, Bean MJ, Lindenmayer DB, Wilcove DS: **Thresholds and the mismatch between environmental laws and ecosystems**. *Conserv Biol* 2009, **23**:1053-1055.

33. Seppelt R, Lautenbach S, Volk M: **Identifying trade-offs between ecosystem services, land use, and biodiversity: a plea for combining scenario analysis and optimization on different spatial scales**. *Curr Opin Environ Sustain* 2013, **306**:1-6.

34. Turner BL II, Janetos A, Verburg PH, Murray AT: **Land system architecture: using land systems to adapt and mitigate global environmental change**. *Global Environ Change* 2013, **23**:395-397.

35. Viglizzo EF, Nosetto MD, Jobbagy EG, Ricard MF, Frank FC: **The ecohydrology of ecosystem transitions: a meta-analysis**. *Ecohydrol Early View* 2014 http://dx.doi.org/10.1002/eco.1540.

36. Hughes TP, Carpenter S, Rockström J, Scheffer M, Walker B: **Multiscale regime shifts and planetary boundaries**. *Trends Ecol Evol* 2013, **28**:389-395.

37. Mouchet MA, Lamarque P, Martín-López B, Crouzat E, Gos P, Byczek C, Lavorel S: **An interdisciplinary methodological guide for quantifying associations between ecosystem services**. *Global Environ Change* 2014, **28**:298-308.

38. Hoffmann A, Penner J, Vohland K, Cramer W, Doubleday R, Henle K, Kõljalg U, Kühn I, Kunin WE, Negro JJ *et al.*: **Improved access to integrated biodiversity data for science, practice, and policy — the European Biodiversity Observation Network (EU BON)**. *Nat Conserv* 2014, **6**:49-65.

39. Ghaley BB, Vesterdal L, Porter JR: **Quantification and valuation of ecosystem services in diverse production systems for informed decision-making**. *Environ Sci Policy* 2014, **39**:139-149.

40. Cowling RM, Egoh B, Knight AT, O'Farrell PJ, Reyers B, Rouget M, Roux DJ, Welz A, Wilhelm-Rechman A: **An operational model for mainstreaming ecosystem services for implementation**. *Proc Natl Acad Sci USA* 2008, **105**:9483-9488.

41. • Nieto-Romero M, Oteros-Rozas E, Gonzalez JA, Martin-Lopez B: **Exploring the knowledge landscape of ecosystem services assessments in Mediterranean agroecosystems: insights for future research**. *Environ Sci Policy* 2014, **37**:121-133.
This paper presents the main knowledge gaps in ecosystem services research in the Mediterranean agro-ecosystems and offers insights for the scientific agenda from an interdisciplinary perspective.

42. Reed MS, Graves A, Dandy N, Posthumus H, Hubacek K, Morris J, Prell C, Quinn CH, Stringer LC: **Who's in and why? A typology of stakeholder analysis methods for natural resource management**. *J Environ Manage* 2009, **90**:1933-1949.

43. Wegner G, Pascual U: **Cost–benefit analysis in the context of ecosystem services for human well-being: a multidisciplinary critique**. *Global Environ Change* 2011, **21**:492-504.

44. Martin-Lopez B, Iniesta-Arandia I, Garcia-Llorente M, Palomo I, Casado-Arzuaga I, Garcia Del Amo D, Gomez-Baggethun E, Oteros-Rozas E, Palacios-Agundez I, Willaarts B *et al.*: **Uncovering ecosystem service bundles through social preferences**. *PLoS ONE* 2012:7.

45. • Howe C, Suich H, Vira B, Mace GM: **Creating win-wins from trade-offs? Ecosystem services for human well-being: a meta-analysis of ecosystem service trade-offs and synergies in the real world**. *Global Environ Change* 2014, **28**:263-275.
Meta-analysis of 231 studies investigating how synergies and/or trade-offs are analyzed and quantified and how these might support multifunctional use of landscapes.

46. Nagendra H, Reyers B, Lavorel S: **Impacts of land change on biodiversity: making the link to ecosystem services**. *Curr Opin Environ Sustain* 2013, **5**:1-6.

47. Rodríguez JP, Beard TD Jr, Bennett EM, Cumming GS, Cork SJ, Agard J, Dobson AP, Peterson GD: **Trade-offs across space, time, and ecosystem services**. *Ecol Soc* 2006, **11**:28.

48. Garcia Nieto AP, Garcia Llorente M, Iniesta Arandia I, Martin Lopez B: **Mapping forest ecosystem services: from providing units to beneficiaries**. *Ecosyst Services* 2013, **4**:126-138.

49. • Schulp CJE, Burkhard B, Maes J, Van Vliet J, Verburg PH: **Uncertainties in ecosystem service maps: a comparison on the European scale**. *PLoS ONE* 2014:9.
A visualisation of the similarities and differences in four mapping ecosystem services methods.

50. Meyfroidt P, Lambin EF, Erb KH, Hertel TW: **Globalization of land use: distant drivers of land change and geographic displacement of land use**. *Curr Opin Environ Sustain* 2013, **5**:438-444.

51. Liu J, Hull V, Batistella M, DeFries R, Dietz T, Fu F, Hertel TW, Izaurralde RC, Lambin EF, Li S *et al.*: **Framing sustainability in a telecoupled world**. *Ecol Soc* 2013:18.

52. Fischer J, Dyball R, Fazey I, Gross C, Dovers S, Ehrlich PR, Brulles RJ, Christensen C, Borden RJ: **Human behavior and sustainability**. *Front Ecol Environ* 2012, **10**:153-160.

53. Ehrlich PR, Kareiva P, Daily GC: **Securing natural capital and expanding equity to rescale civilization**. *Nature* 2012, **486**:68-73.

54. Geijzendorffer IR, Roche PK: **Relevant scales of ecosystem service demand**. *Ecosyst Services* 2014, **10**:49-51.

55. Serna-Chavez HM, Schulp CJE, van Bodegom PM, Bouten W, Verburg PH, Davidson MD: **A quantitative framework for assessing spatial flows of ecosystem services**. *Ecol Ind* 2014, **39**:24-33.

56. Brown G, Fagerholm N: **Empirical PPGIS/PGIS mapping of ecosystem services: a review and evaluation**. *Ecosyst Services*, in press.

57. Roebeling P, Alves H, Rocha J, Brito A, Almeida P, Mamede J: **Gains from transboundary water quality management in linked catchment and coastal socio-ecological systems: a case study for the Minho region**. *Water Res Econ* 2014, **8**:32-42.

58. Dearing JA, Bullock S, Costanza R, Dawson TP, Edwards ME, Poppy GM, Smith G: **Navigating the perfect storm: research strategies for social–ecological systems in a rapidly evolving world**. *Environ Manag* 2012, **49**:767-775.

59. Vilardy S, González JA, Martín-López B, Montes C: **Relationships between hydrological regime and ecosystem services supply in a Caribbean coastal wetland: a social–ecological approach**. *Hydrol Sci J* 2011, **56**:1423-1435.

60. Dearing JA, Yang X, Dong X, Zhang E, Chen X, Langdon PG, Zhang K, Zhang W, Dawson TP: **Extending the timescale and range of ecosystem services through paleoenvironmental analyses: the example of the lower Yangtze basin**. *Proc Natl Acad Sci USA* 2012, **109**:E1111-E1120.

61. Lautenbach S, Kugel C, Lausch A, Seppelt R: **Analysis of historic changes in regional ecosystem service provisioning using land use data**. *Ecol Ind* 2010, **11**:676-687.

62. • Cumming GS, Buerkert A, Hoffmann EM, Schlecht E, von Cramon-Taubadel S, Tscharntke T: **Implications of agricultural transitions and urbanization for ecosystem services**. *Nature* 2014, **515**:50-57.
Identification of increased risks of societies to crash and they get further developed and increase their distance from local ecosystems.

63. Bagstad KJ, Johnson GW, Voigt B, Villa F: **Spatial dynamics of ecosystem service flows: a comprehensive approach to quantifying actual services**. *Ecosyst Services* 2013, **4**:117-125.

64. Vatn E: *Institutions and the Environment*. Cheltenham, UK: Edward Elgar Pub; 2005.

65. Viglizzo EF, Paruelo JM, Laterra P, Jobbagy EG: **Ecosystem service evaluation to support land-use policy**. *Agric Ecosyst Environ* 2012, **154**:78-84.

67. Ostrom E, Janssen MA, Anderies JM: **Going beyond panaceas**. *Proc Natl Acad Sci USA* 2007, **104**:15176-15178.

68. Underdal A: **Complexity and challenges of long-term environmental governance**. *Global Environ Change* 2010, **20**:386-393.

69. Fidélis T, Roebeling P: **Water resources and land use planning systems in Portugal — exploring better synergies through Ria de Aveiro**. *Land Use Policy* 2014, **39**:84-95.

70. Hilborn R, Orensanz JM, Parma AM: **Institutions, incentives and the future of fisheries**. *Philos Trans R Soc B* 2005, **360**:47-57.

71. Stevenson GG: *Common Property Economics: A General Theory and Land Use Applications*. Cambridge, UK: Cambridge University Press; 2005.

72. • Lambin EF, Meyfroidt P, Rueda X, Blackman A, Börner J, Cerutti PO, Dietsch T, Jungmann L, Lamarque P, Lister J *et al.*: **Effectiveness and synergies of policy instruments for land use governance in tropical regions**. *Global Environ Change* 2014, **28**:129-140.

This article reviews evidence on the effectiveness of market-based and/or demand-led policy instruments to promote sustainable land use. It explores interactions between new demand-led interventions and formal regulatory public policies, so called hybrid public–private instruments, including eco-certification and payment for environmental services. The authors propose a typology of interactions, and evidence for supportive and hindering actions. The goal is to identify most viable and beneficial land-use policies for longer term trajectories.

73. Duraiappah AK, Tanyi Asah S, Brondiizio E, Kosoy N, O'Farrell PJ, Prieur-Richard A-H, Subramanian SM, Takeuchi K: **Managing the mismatches to provide ecosystem services for human well-being: a conceptual framework for understanding the New Commons**. *Curr Opin Environ Sustain* 2014, **7**:94-100.

74. Cash DW, Clark WC, Alcock F, Dickson NM, Eckley N, Guston DH, Jäger J, Mitchell RB: **Knowledge systems for sustainable development**. *Proc Natl Acad Sci USA* 2003, **100**:8086-8091.

75. Kenter JO, Hyde T, Christie M, Fazey I: **The importance of deliberation in valuing ecosystem services in developing countries — evidence from the Solomon Islands**. *Global Environ Change* 2011:21.

76. Reid WV, Chen D, Goldfarb L, Hackmann H, Lee YT, Mokhele K, Ostrom E, Raivio K, Rockström J, Schellnhuber H-J *et al.*: **Earth system science for global sustainability: grand challenges**. *Science* 2010, **330**:916-917.

77. Carpenter SR, Folke C, Norström A, Olsson O, Schultz L, Agarwal B, Balvanera P, Campbell B, Castilla JC, Cramer W *et al.*: **Program on ecosystem change and society: an international research strategy for integrated social–ecological systems**. *Curr Opin Environ Sustain* 2012, **4**:134-138.

78. Laurans Y, Rankovic A, Billé R, Pirard R, Mermet L: **Use of ecosystem services economic valuation for decision making: question a literature blindspot**. *J Environ Manage* 2013, **119**:208-219.

79. Tengö M, Brondiizio E, Elmqvist T, Malmer P, Spierenburg M: **Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach**. *Ambio* 2014, **43**:579-591.

80. Martin-Lopez B, Montes C: **Restoring the human capacity for conserving biodiversity: a social–ecological approach**. *Sustain Sci*, http://dx.doi.org/10.1007/s11625-014-0283-3, in press.

81. Bulte EH, Hector A, Larigauderie A: In *ecoSERVICES Science Plan and Implementation Strategy*, vol. 3. Edited by DIVERSITAS Report. 2005:40 Paris, France.

82. Balvanera P, Pfisterer AB, Buchmann N, He J-S, Nakashizuka T, Raffaelli D, Schmid B: **Quantifying the evidence for biodiversity effects on ecosystem functioning and services**. *Ecol Lett* 2006, **9**:1146-1156.

83. Cardinale BJ, Srivastava DS, Duffy JE, Wright JP, Downing AL, Sankaran M, Jouseau C: **Effects of biodiversity on the functioning of trophic groups and ecosystems**. *Nature* 2006, **443**:989-992.

84. Naeem S, Bunker DE, Hector A, Loreau M, Perrings C (Eds): *Biodiversity, Ecosystem Functioning, and Human Wellbeing — An Ecological and Economic Perspective*. Oxford University Press; 2009.

85. Butchart SHM, Walpole M, Collen B, Strien Av, Scharlemann JPW, Almond REA, Baillie JEM, Bomhard B, Brown C, Bruno J *et al.*: **Global biodiversity: indicators of recent declines**. *Science* 2010, **328**:1164-1168.

86. Arriagada R, Perrings C: **Making payments for ecosystem services work**. *Policy Brief*. UNEP; 2009.

87. Touza JM, Perrings C: **The provision of international environmental public goods**. *Ecosystem Services Economics (ESE) Working Papers*. UNEP; 2011.

88. Díaz S, Reyers B, Bergendorff T, Brussaard L, Cooper D, Cramer W, Anantha Duraiappah, Elmqvist T, Daniel P Faith, Fonseca G *et al.*: **Biodiversity and ecosystems for a planet under pressure.Rio+20 Policy Brief**. DIVERSITAS-STAP-CBD-GEF; 2011.