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ORIGINAL PAPER

Research needs for incorporating the ecosystem service approach into EU biodiversity conservation policy

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Abstract Using a range of different methods including extensive reviews, workshops and an electronic conference, 70 key research recommendations and 12 priority research needs to integrate the ecosystem services approach into biodiversity conservation policy and funding were identified by a cross-disciplinary group of over 100 scientists and 50 stakeholders, including research funders and policy-makers. These recommendations focus on the ecological underpinning of ecosystem services, drivers that affect ecosystems and their services, biological traits and ecosystem services, the valuation of ecosystem services, spatial and temporal scales in ecosystem service assessment, indicators of ecosystem services, and habitat management, conservation policy and ecosystem services. The

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recommendations in this paper help steer the research agenda on ecosystem services into policy-relevant areas, agreed upon by funders, researchers and policy-makers. This research agenda will only succeed with increased collaboration between researchers across disciplines, thereby providing a challenge to the research community and research funders to work in new, interdisciplinary ways.

Keywords Biodiversity · Conservation policy · Ecosystem services · Indicators · Knowledge base · Research priorities · Valuation

Introduction

Ecosystem services are the benefits that humans recognise as obtained from ecosystems that support, directly or indirectly, their survival and quality of life (see Harrington et al., this issue for an expanded definition). The Millennium Ecosystem Assessment (MA 2003) classified ecosystem services as provisioning services (e.g. food, fresh water and fuel), regulating services (e.g. water purification and climate regulation), cultural services (e.g. recreation and education), and the supporting services needed for the production of all other ecosystem services (e.g. nutrient cycling and soil formation). The delivery of ecosystem services depends in many cases on the maintenance of biodiversity, although it is recognised that other aspects of ecosystems may play an important role. Because of the role biodiversity plays in providing humans with essential goods and services, it has been referred to as 'the insurance policy for life itself' (WEHAB Working Group 2002). However, rapid global change has resulted in a global decline of biodiversity in recent decades (MA 2003), mostly due to anthropogenic causes such as land use change (e.g. Vitousek et al. 1997; Young et al. 2005; de Chazal and Rounsevell 2009) and climate change (Parmesan and Yohe 2003; Brooker et al. 2007). In light of this dramatic loss in species and landscape diversity, a number of political commitments to biodiversity

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conservation have been made at both international and European levels (Haslett et al. 2010). The majority of these political commitments traditionally focus on maintaining and restoring biodiversity through species and habitat protection. Attention is now shifting, however, increasingly towards the integration of ecosystem services into conservation efforts (Naidoo et al. 2008; EASAC 2009), particularly to complement and add value to existing conservation strategies (Harrison et al. 2010; Haslett et al. 2010).

Despite the recent attention given to ecosystem services, few sub-global assessments have been carried out (Capistrano et al. 2005) and consequently, the ecosystem service approach has had a limited influence on policy formulation and decision-making (Haines-Young and Potschin 2008). A series of conceptual and practical limitations prevent the integration of ecosystem services into conservation programmes. A key aspect is the limited understanding of the ecological underpinnings of ecosystem services (Balmford et al. 2003; Luck et al. 2003; Palmer et al. 2004; Kremen 2005) and the role of biodiversity as one part of the biophysical system responsible for providing ecosystem services. Trade-offs between different services (Rodríguez et al. 2006), mismatches between political and ecological scales, and difficulties regarding the quantification and valuation of ecosystem services (Turner and Daily 2008; Luck et al. 2009) also hamper the assessment, planning and management of ecosystem services.

The ecosystem service approach to biodiversity conservation needs to be developed into a more practical and transparent framework in order to be useful for decision-makers, and an important step in this direction is provided in the frameworks presented by Haslett et al. (2010), Rounsevell et al. (2010) and Samways et al. (2010). In the present paper we complement such work by drawing upon the large volume of information synthesized by the EU-funded RUBICODE project (www.rubicode.net). We identify and summarise gaps in present knowledge, which constrain the current development of conservation policies capable of integrating an ecosystem service approach. The integration of expertise and experience from the research, research funding and policy-making spheres in the identification of these gaps in knowledge ensures that the key research needs identified in this paper are both applicable and practical. As such, these research needs should contribute towards the development of future research programmes which can inform policies for the effective conservation of ecosystem services in Europe.

Methods

Reviews

This synthesis of gaps in knowledge and future research needs is based on information from various sources. Extensive reviews were undertaken on topics including terminology related to ecosystem services and biodiversity conservation (Harrington et al. 2010); the current status of European ecosystem services (Harrison et al. 2010); quantification of the contribution of biodiversity to ecosystem services (Vandewalle et al. 2008; Luck et al. 2009); economic values and preferences for ecosystem services (Kontogianni et al. 2008; Skourtos et al. 2010), drivers that affect ecosystems and their services (Anastasopoulou et al. 2007; Dawson et al. 2010; Rounsevell et al. 2010); indicators of ecosystem services (Feld et al. 2009, 2010; Vandewalle et al. 2010), functional traits and ecosystem services (De Bello et al. 2010), habitat management strategies (Haslett et al. 2008; Samways et al. 2010), and the effectiveness and appropriateness of existing conservation policies

(Jongman et al. 2008; Haslett et al. 2010). Gaps in knowledge were identified as an integral part of each of these reviews.

Workshops and electronic conference

In addition to the reviews, external expertise from the scientific and stakeholder community was gathered over the course of one electronic conference and five workshops (Table 1).

During the workshops, a range of stakeholders including researchers, research funders and policy-makers (and in some workshops NGOs and practitioners) discussed the usefulness of the ecosystem service concept, its integration into conservation policy, gaps in knowledge and future research needs. The workshops focussed specifically on assessing and monitoring ecosystems (March 2007); linking the ecosystem service concept to policy-making processes (May 2007); ecosystem services and drivers of biodiversity change (February 2008); and habitat management and conservation policy (April 2008).

The main findings of the workshop on "Ecosystem services and drivers of biodiversity change" were further discussed in a 2 week electronic conference held in April 2008. The electronic conference had a total of 146 participants, of which 47 actively participated in discussions. The e-conference was divided into four sessions focussing on frameworks and approaches for ecosystem service assessment; drivers and scenarios for ecosystem service assessment; valuation of ecosystem services; and research priorities for ecosystem service assessment. Contributors to this last session were required to consider future research needs related to stakeholder engagement, the development of concepts and frameworks, valuation, drivers of change, and indicators of ecosystem services.

The results obtained from the reviews, workshops and the electronic conference were compiled and compared with outputs from previous and ongoing European and national biodiversity research strategies and initiatives, including DIVERSITAS, BiodivERsA and The European Platform for Biodiversity Research Strategy (EPBRS). The interim report "The economics of ecosystems and biodiversity" (TEEB 2008), related workshop reports of the TEEB initiative and outputs from the EU-framework projects ALARM (Assessing Large Scale Risks for Biodiversity with tested Methods), ALTER-Net (A Long-Term Biodiversity, Ecosystem and Awareness Research Network), and BioStrat (Developing the

Table 1 Categories of participants involved in the five workshops

Workshops	Researchers	Research-funders	Policy-makers	NGOs	Practitioners/managers/business
1. Assessing and monitoring ecosystems	18	0	0	0	0
2. Linking the ecosystem service concept to policy-making processes	11	7	10	3	3
3. Ecosystem services and drivers of biodiversity change	94	1	1	1	0
4. Habitat management and conservation policy	20	9	15	2	2
5. Research needs for incorporating the ecosystem service concept into biodiversity conservation	39	13	15	0	3

N.B. 1: Some organisations were both policy-funders and policy-makers

N.B. 2: Workshops 1 and 3 were specifically aimed at scientists, while workshops 2, 4 and 5 aimed to capture a combination of researchers, research funders and policy-makers

EU Biodiversity Research Strategy) served as additional sources. This process led to the drafting of 70 research recommendations required to integrate the ecosystem services approach into conservation policy.

Finally, a 3-day stakeholder workshop, held in Leipzig (Germany) in January 2009 brought together a cross-disciplinary group of 31 stakeholders including researchers, research funders and policy-makers from 16 countries and 39 scientists including 23 researchers from the RUBICODE project (see Table 1) to evaluate critically these research needs, identify further gaps in knowledge and prioritise research recommendations. This was achieved through discussion in plenary sessions and four thematic working groups (ecosystem service assessment and drivers of change, quantification and valuation of ecosystem services, indicators and traits for ecosystem service assessment, and integrating habitat management, conservation policy and ecosystem services).

To reflect the methodological approach adopted during the RUBICODE project, this paper consists of two parts. The first part outlines a complete list of research recommendations identified through the reviews, electronic conference and workshops. The second part presents the prioritisation of these research needs based on the values of the Leipzig workshop participants.

Results

Complete list of research recommendations

The research recommendations identified through the reviews, workshops and electronic conference are grouped into seven sections reflecting the thematic areas identified throughout the duration of the RUBICODE project. These relate to the ecological underpinning of ecosystem services, drivers that affect ecosystems and their services, biological traits and ecosystem services, the valuation of ecosystem services, spatial and temporal scales in ecosystem service assessment, indicators of ecosystem services, and habitat management, conservation policy and ecosystem services. The 70 research recommendations are listed within these groups, but unranked, below.

Ecological underpinning of ecosystem services

The importance of ecosystems services for human well-being is now widely recognised (Daily 1997), however, much remains to be understood in terms of the ecological underpinnings of ecosystem service provision (Kremen 2005; Kremen and Ostfeld 2005; Carpenter et al. 2009), including the identification and quantification of the factors influencing the provision of ecosystem services. Ecosystem services may be provided by individual species, functional groups of species or entire ecological communities. Further research is needed to identify and quantify the role of biodiversity in ecosystem service provision with a view to informing strategies to promote its conservation. Specific research needs to address this issue include:

1. Assessing the current status of ecosystems in terms of their capacity to deliver services and identifying which services are most under threat.
2. Quantifying the characteristics of biodiversity (from populations to communities, habitat types and landscapes) required to provide ecosystem services, i.e. their service provider properties.

3. Understanding how changes in service provider properties affect service provision.
4. Quantifying the role of uncharismatic, but species-rich groups of organisms, such as invertebrates, lower plants and fungi, in ecosystem function and service provision.
5. Understanding interactions between service providers, supporting habitat and ecosystem service delivery, and determining whether minimum habitat area thresholds for the sustainability of services can be defined.
6. Understanding the impact of intra- and inter-specific species interactions on ecosystem service provision, including circumstances where organisms might provide multiple ecosystem services, support the provision of ecosystem services by other organisms or adversely affect ecosystem service providers.
7. Quantifying the effect of spatial habitat mosaic heterogeneity on ecosystem service provision and how changes over time may have a role in mitigating the effects of climate change.
8. Examining 'bundles' of ecosystem services whereby multiple services are provided by a collection of organisms.
9. Quantifying the supply of ecosystem services relative to thresholds of service demand defined in relation to the needs of beneficiaries of these services.
10. Quantifying the effects of invasive species on ecosystem structure, function and services.
11. Obtaining evidence on whether increased biodiversity per se contributes positively to ecosystem stability and to securing the continuation of ecosystem services.
12. Conducting case studies to understand interactions between biodiversity and ecosystem services from which consistent trends can be identified with broader applicability.
13. Developing methods to delineate and assess sensitivities, uncertainties and risks associated with quantifying the contribution of biodiversity to ecosystem service provision.

Drivers that affect ecosystems and their services

With biodiversity increasingly threatened by rapid global anthropogenic change, it is essential for continued human well-being to understand better how various drivers, including climate change, are affecting ecosystem services (Haines-Young and Potschin 2009) and to develop tools to predict how these changes might affect the provision of ecosystem services in the future (e.g. Schröter et al. 2005; Metzger et al. 2006). Future research should focus on understanding socio-economic and environmental drivers that affect ecosystem services and capturing uncertainties in their evolution over time. This will require research on:

14. Understanding the sensitivity and dynamics of ecosystem services to environmental change, particularly less frequently studied indirect socio-economic drivers such as science and technology, and culture and religion, and less frequently studied direct drivers such as natural, physical, and biological phenomena, diseases and wars.
15. Understanding environmental limits of ecosystems and identifying non-linear responses and thresholds beyond which the level of ecosystem service delivery changes dramatically and perhaps irreversibly.
16. Assessing the implications of ecosystem service disruption for human well-being and social conflict.

17. Evaluating the effect of agriculture and forestry practices on biodiversity and ecosystem services.
18. Creating scenarios of trends in drivers that can be applied to models or frameworks of ecosystem services at multiple scales, and which include scenario variables of relevance to both ecosystem service beneficiaries and ecosystem service providers.
19. Participatory approaches to scenario construction that build on a range of stakeholder perspectives and policy relevance to capture changing demand and supply of ecosystem services under a range of alternative futures.
20. Developing conditional probabilistic futures and shock or 'wildcard' scenarios for the different sectors involved in ecosystem service provision to explore uncertainty, extreme events and 'surprises'.
21. Identifying those components of scenarios where uncertainty can be quantified, identifying which variables have high or low uncertainty and quantifying their influence on future projections of ecosystem service delivery.

Biological traits and ecosystem services

Most ecosystem services can be provided by many species (Kremen 2005). Therefore it is useful to consider ecosystem service providers in terms of their traits, rather than their taxonomy. A functional trait can be defined as "a feature of an organism, which has demonstrable links to the organism's function" (Lavorel et al. 1997). As such, a functional trait determines the organism's response to pressures (response trait), and/or its effects on ecosystem processes or services (effect trait). If traits in these two groups are the same or are linked in some way, it is likely that environmental change will have an impact on the provision of the service. Trophic interactions are almost always important in service provision and thus traits affecting relationships between organisms in different trophic levels must be considered when linking environmental change to service provision. Although traits have emerged as an important area of research (e.g. Diaz and Cabido 2001; Balvanera et al. 2006; Díaz et al. 2007), additional research is needed to improve knowledge on traits across organisms (trait databases exist for snails, hoverflies and plants; Falkner et al. 2001; Speight et al. 2008; Kleyer et al. 2008), investigate the linkages within and between trophic levels (Montoya et al. 2003) and assess their relevance to predicting the impact of environmental changes on ecosystem service provision. This will require research on:

22. Developing trait concepts, lists and protocols for trait assessments of ecosystem services.
23. Assembling databases of effect traits, including algorithms to couple them to ecosystem service provision, particularly for less studied organisms.
24. Identifying traits that act as linkages across trophic levels and describing trait-based interactions that contribute to the delivery of key ecosystem services.
25. Understanding the effect of environmental or management drivers of change on traits that act as linkages across trophic levels involved in ecosystem service provision.
26. Analysing how trait-based interactions control the delivery of bundles of ecosystem services, i.e. the ecological basis for multifunctionality.
27. Identifying sources of vulnerability of service delivery relating to trait interactions.
28. Quantifying linkages between components of functional diversity (e.g. trait means and functional divergence) and ecosystem services.

29. Identifying thresholds for traits in relation to ecosystem service delivery in a range of ecosystems.

Valuation of ecosystem services

The benefits derived from ecosystem services should act as powerful incentives to conserve biodiversity (Costanza et al. 1997; Balmford et al. 2002). However, the valuation of ecosystem services, which is essential in terms of communicating the importance of these services and developing effective policy tools, has proved difficult (Daily 2000). Although efforts to value ecosystem services are increasing, information is often scattered, the data on ecosystem services often appears at incompatible scales of analysis and data are frequently classified differently by different authors (de Groot et al. 2002). Ecosystem services are, on the whole, not captured by conventional, market-based economic activity and analysis (Balmford et al. 2002). As few ecosystem services are marketed, we still lack important information pertaining to the prices that reflect the economic value of services (Carpenter et al. 2006, 2009), therefore, in order to explore the multiple value dimensions, as well as the psycho-cultural contexts (Kumar and Kumar 2008), of ecosystem services, new non-market valuation techniques based on group discussion methods (such as deliberative monetary valuation, Spash 2007, 2008) should further be developed and applied (Vatn 2009). As such, concepts and practical attempts to value ecosystem services (particularly regulating services) are urgently needed and could result in decision-support tools for practitioners and policy-makers (Carpenter et al. 2006; CBD 2008). Specific research recommendations include:

30. Developing improved taxonomies for ecosystem services and values, including better understanding and expression of distinctions between final and intermediate services, and between values of flows of ecosystem services and stocks of ecosystem assets.
31. Improving coverage, quality, depth and access to valuation databases.
32. Adopting a strategic research programme to fill key gaps in valuation evidence, including agreed protocols for comparing and transferring value estimates.
33. Improving methods for assessing risk and uncertainty in ecosystem service valuation.
34. Developing interfaces between valuation or benefits-transfer methods and various integrated assessment and modelling tools.
35. Improving knowledge on the social values associated with ecosystem services to advance understanding of human perceptions of ecosystem services and how human behaviour changes demand for services.
36. Improving methods for assessing changes in economic systems, preferences and technologies.
37. Improving understanding of the cultural and political acceptability of different approaches to the estimation, communication and uses of ecosystem service values.

Spatial and temporal scales in ecosystem service assessment

Demand from ecosystem service beneficiaries and the supply of services by biodiversity operate and interact at different spatial and temporal scales. As such, gaining a basic understanding of the scales at which ecosystem services operate is integral to the development of any landscape-scale conservation programme (Kremen 2005). This will require a multi-disciplinary research approach which can be delivered through integrated

assessment modelling involving physical, ecological and socio-economic methods (Steffen 2009). Specific research needs to address this issue include:

38. Quantifying the most appropriate scale for study and management of different ecosystem services.
39. Understanding interactions between biotic, abiotic, and human factors that influence ecological processes and ecosystem services at multiple scales.
40. Developing methods for up-scaling local impacts and responses to landscapes and regions.
41. Developing spatially-explicit mapping studies which account for the location of ecosystem service production, the location of service beneficiaries and their demands for ecosystem services, and the flow of ecosystem services between them.
42. Understanding temporal dynamics and time scale mismatches between impacts on ecosystem services and their governance.
43. Developing frameworks and models for analysing trade-offs between multiple ecosystem services across nested scales.
44. Developing methods that enable better use of valuation results across different scales and take account of how values at one scale may be dependent on factors at other scales.

Indicators of ecosystem services

Indicators represent a fundamental requirement for monitoring ecosystems and their services and for measuring the success of conservation actions. They also represent an essential tool for communicating complex patterns and processes to decision-makers (National Research Council 2000; EASAC 2005). Therefore, indicators should be robust, repeatable, widely accepted, and easily understood (Balmford and Bond 2005). Although a number of indicators have been suggested by scientists there is no consensus over what indicators would best meet the needs of decision-makers and researchers (Carpenter et al. 2006). Research is therefore required to improve indicators of ecosystem services. This includes:

45. Developing indicators of genetic diversity, particularly those that indicate the adaptive capacity of organisms to changing environments.
46. Developing indicators of the structural and functional components of ecosystems which are related to ecosystem services.
47. Investigating the potential of biological traits as indicators of regulating and supporting services.
48. Developing indicators that incorporate economic and other values of ecosystem services.
49. Developing suitable biological indicators that directly refer to the component of biodiversity or to the functions and processes behind a certain ecosystem service.
50. Developing indicators for ecosystem services at large spatial scales to address conventions and agreements at the international level.
51. Developing and applying reference conditions and benchmark values with which to compare the observed condition.
52. Developing and applying standardised protocols to sample and gather high quality comparable data at all relevant scales.

53. Developing a consistent indicator framework linking small scale biotic indicators to landscape scale abiotic indicators for ecosystem services, including methods for improving the scalability of indicators.

Habitat management, conservation policy and ecosystem services

Biodiversity policy in Europe relies heavily on protected areas as a means to protect biodiversity (Fairbrass 2000). Within the EU, the Natura 2000 network, comprising Special Areas of Conservation (SACs) designated under the Habitats Directive and Special Protection Areas (SPAs) derived from the Birds Directive, are the main mechanism in place to protect habitats of special interest and the species they contain. This network is part of the larger Emerald Network of the Council of Europe under the Bern Convention, which also provides for protected areas in Council of Europe Member States outside the EU. However, there is a growing recognition for the need to broaden habitat management strategies in Europe, taking into account a wider range of societal needs, prioritising the delivery of ecosystem services from different types of land use and managing land in a way that promotes multiple ecosystem services (EASAC 2009). In addition, habitat management strategies will need to adopt a much more dynamic approach that takes account of ecosystem change in space and time (Haslett et al. 2010). A more holistic and integrated approach needs to be developed to integrate conservation into sectoral policy (e.g. agriculture, transport, industry, etc.) and rural development outside existing protected area networks.

Levels of ecosystem service provision are in part driven, and are otherwise strongly influenced, by policies and decision-making at different levels of governance, from local to national, European and global. Understanding how these drivers and levers interact is essential for efficient communication between all parties involved and for influencing decisions relating to ecosystem service provision and conservation needs. Research should focus on:

54. Developing mechanisms for factoring ecosystem service change into rural development planning and conservation planning, including the design of nature reserves and protected areas.
55. Quantifying the role of multifunctional land management and landscape patterns on the provision of ecosystem services and developing options to conserve biodiversity and maintain ecosystem integrity outside protected areas.
56. Evaluating the function of ecological corridors in dynamic ecosystems and the appropriateness of corridors and networks in ecosystem service provision and biodiversity conservation management.
57. Developing decision support systems for ecosystem service management to make information readily available to land managers.
58. Evaluating management strategies that ensure the continued provision of multiple ecosystem services under the influence of socio-economic and environmental drivers of change.
59. Assessing the contribution that the protection of ecosystem services will make to biodiversity conservation, including investigating the risks associated with conservation approaches based on ecosystem service delivery and developing methods to balance potential conflicts between ecosystem service provision and biodiversity conservation management.

60. Improving knowledge of how the ecosystem services approach could be integrated into other policy sectors to develop a more integrated approach to policy-making and delivery.
61. Integrating ecosystem service considerations into impact assessments, particularly into environmental impact assessment and strategic environmental assessment processes.
62. Understanding the impacts of governance and conflict management at different scales on the provision of ecosystem services, including the development of tools, methods and decision-support systems to assist the multi-level governance of ecosystem services and the engagement of multiple stakeholder groups.
63. Understanding the institutional context of ecosystem service change and how different institutional structures and property rights regimes impact on the behaviour of individual and collective beneficiaries.
64. Developing tools to facilitate communication within and between natural resources users, sectors, ministries and institutions, and policy communities.
65. Designing dynamic and inclusive institutions that help to maintain different ecosystem services and ensure the meaningful engagement of stakeholders under environmental and social change.
66. Identifying good practices to encourage two-way communication with the public and stakeholders in order to raise awareness of the key importance of natural systems and the risks and projected impacts of ecosystem services change.
67. Developing methods which promote public involvement in conservation and the sustainable use of ecosystem services, including setting objectives for ecosystem service delivery in relation to stakeholder preferences and values.
68. Analysing local knowledge, attitudes, preferences and perceptions of ecosystem services to improve understanding of the ways in which human societies, enterprises and well-being depend upon, or can be enhanced by, ecosystem services.
69. Developing and evaluating participatory adaptation strategies for sustainable service delivery at national, regional and local scales.
70. Developing tools for understanding and integrating ecosystem service conservation into corporate environmental management systems.

Prioritised list of research recommendations

While the above list of research recommendations is essential for both research funders and policy-makers, resources for research are usually limited and therefore, not all of these questions can be treated equally. To capture the priorities, the compilation of research needs presented above was discussed with researchers, research funders and policy-makers during a 3 day-long workshop. This interdisciplinary group of experts recommended twelve research priorities as shown in Table 2.

Although it is now widely recognised that ecosystem services play a key role in the conservation and sustainable use of natural resources, much remains to be understood in terms of how ecosystem services are provided and the factors influencing the provision of ecosystem services. Research is particularly needed regarding the quantification of the role of biodiversity, including uncharismatic and speciose groups of organisms, in ecosystem function and service provision. In addition, research is needed to develop methodologies and tools for ecosystem service assessment, such as the development of trait-based approaches to ecosystem service assessment and modelling techniques for the integrated

Table 2 Research priorities (unranked) identified by participants at the final RUBICODE workshop in Leipzig, January 2009

1. Quantify the role of biodiversity, including uncharismatic and speciose groups of organisms such as invertebrates, lower plants and fungi, in ecosystem function and service provision
2. Develop trait-based approaches to ecosystem service assessment which include: (i) improved knowledge of trait-based multi-trophic linkages within ecosystems; (ii) trait-based indicators to assess and define quantitatively service provision at multiple scales; and (iii) trait-based thresholds for the provision of services
3. Develop improved methods for the integrated assessment of ecosystem services at different spatial and temporal scales, including methods for: (i) investigating interactions between the demand and supply of multiple ecosystem services; (ii) upscaling and downscaling; and (iii) integrating valuation processes and results in impact assessments and models
4. Identify thresholds in the relationships between biodiversity, ecosystem functioning, ecosystem services and human well-being to identify points beyond which the level of ecosystem service delivery changes dramatically and perhaps irreversibly
5. Identify and quantify the impact of direct and indirect socio-economic and environmental drivers on ecosystem services, and develop tools to design and evaluate policy options for ecosystem service management under uncertain futures
6. Improve understanding of the role of the cultural, economic and policy contexts in ecosystem service assessment, particularly in the choice of: (i) metrics, valuation and appraisal methods; (ii) stakeholder involvement; (iii) required levels of precision; and (iv) policy instruments and decision support tools
7. Develop an improved classification for ecosystem services and values, which includes values of flows of ecosystem services and stocks of ecosystem assets and allows for the distinction between final and intermediate services
8. Enhance the usefulness of value, price and cost estimates for ecosystem services by: (i) improving database coverage, quality, depth and access; (ii) filling key gaps in valuation evidence; (iii) investigating replication, validity and transfer of functional assumptions and values estimates; and (iv) developing agreed protocols for comparing and transferring value estimates
9. Develop indicators for ecosystems services based on scientifically developed and proven benchmarks using standardised sampling schemes that cover the functional
10. Develop tools, methods and decision-support systems to assist the multi-level governance of ecosystem services
11. Quantify the role of multifunctional land management and landscape patterns on the provision of ecosystem services and develop options to conserve biodiversity and maintain ecosystem integrity outside protected areas
12. Develop tools and methods to promote the uptake of business opportunities associated with the sustainable management of ecosystem service delivery

assessment of ecosystem services at different spatial and temporal scales that take account of multiple drivers.

Despite the important role of biodiversity in providing essential ecosystem services, biodiversity is increasingly being threatened by rapid global change, mostly due to anthropogenic drivers such as land use change, pollution, and climate change (de Chazal and Rounsevell 2009). It is essential for continued human well-being to understand how various drivers are affecting ecosystem services and to develop tools to predict how these changes might affect the provision of ecosystem services in the future. Future research should focus therefore on identifying and quantifying the impact of direct and indirect socio-economic and environmental drivers on ecosystem services, and develop tools to design and evaluate policy options for ecosystem service management under uncertain futures. In particular, it is essential to develop an "early warning system" for biodiversity and identify thresholds in the relationships between biodiversity, ecosystem functioning, ecosystem services and human well-being to identify points beyond which the level of

ecosystem service delivery changes dramatically and perhaps irreversibly (Dawson et al. 2010).

The valuation of ecosystem services is essential in terms of communicating the importance of these services and developing effective policy tools. Although methodologies for the valuation of ecosystem services exist, there is a real need for more research to develop an improved classification for ecosystem services and values, which includes values of flows of ecosystem services and stocks of ecosystem assets and allows for the distinction between final and intermediate services. There is also a clear need to enhance the usefulness of value, price and cost estimates for ecosystem services by improving database coverage, and developing protocols for comparing and transferring value estimates.

Indicators for monitoring ecosystem services are an essential tool for communicating complex patterns and processes to decision-makers and measuring the success of conservation actions. However, the majority of existing indicators assess trends in biodiversity and habitat quality for monitoring local or sectoral conservation strategies and do not address ecosystem services directly. Research is needed to develop indicators that cover the functional, structural and genetic components of biodiversity and to test the relevance of trait-based indicators for ecosystem services. Assessments should also be based on scientifically developed and proven benchmarks using standardised sampling schemes at all necessary scales to generate high quality comparable data.

To incorporate effectively an ecosystem services approach into policy, it is essential that any research on ecosystem services be closely linked with the context in which it is embedded. To achieve this, it is essential to carry out research on the links between governance, public perceptions and attitudes, planning and communication. Research should in particular focus on understanding the role of the cultural, economic and policy contexts in ecosystem service assessment and should contribute to the development of tools, methods and decision-support systems to assist the multi-level governance of ecosystem services. Generally, a more holistic, inclusive and integrated approach needs to be developed to integrate conservation into sectoral policy (e.g. agriculture, transport, industry) and rural development outside existing protected area networks. To achieve this, account will need to be taken of different scales of perception (e.g. human versus other organisms) in maintaining landscape heterogeneity and in monitoring and reacting to changes in service provision levels and ecosystem dynamics.

Businesses also have an increasing interest in ecosystem service management. Tools and methods are needed to help engage business stakeholders, appraise business opportunities, analyse trade-offs between different management options, evaluate incentives for ecosystem service management, and explore externalities.

Discussion

In total, 70 research needs were identified to ensure the implementation of the ecosystem service concept in innovative biodiversity conservation approaches. These research recommendations were prioritised by a group of researchers, research funders and policy-makers during a workshop.

The research priorities presented in this paper are the result of a lengthy and thorough cross-disciplinary consultation process involving over a hundred scientists and over 50 stakeholders. Such an interdisciplinary approach may have a number of limitations. The majority of institutions were represented by only one member, which may result in

individual views. In addition, contrasting views between members of different disciplines or even between members of the same discipline were also evident. The close cooperation with research funders and policy-makers, however, represents one of the strengths of this approach. Motivated by the strong interest of the public in sustaining biodiversity conservation, the engagement of stakeholders in this process represents an attempt to enhance knowledge exchange between scientists, funding organisations and policy-makers. Consequently, the research needs presented in this paper are the direct outcome of cooperation across a broad range of research organisations, research funding institutions and governmental and non-governmental organisations and businesses.

We believe that the set of priorities for future research presented here will support research requirements on ecosystem services for both funders and researchers and that it will stimulate future research on ecosystem services which, in turn, will help promote the integration of the ecosystem service approach into European habitat management strategies and biodiversity conservation. In addition, we believe that whilst this work was undertaken within a European context, the list of research priorities is applicable worldwide. Key to any future research will be the development of closer links between researchers working on ecosystem services from different disciplines (Carpenter et al. 2006, 2009; Chan et al. 2006; Haines-Young and Potschin 2009) and the support of such interdisciplinary work by research funding programmes that promote stronger institutional and trans-disciplinary cooperation.

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