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REPORT

Trends in Ecosystem Service Research: Early Steps and Current Drivers

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Abstract Over the past 50 years, human beings have influenced ecosystems more rapidly than at any similar time in human history, drastically altering ecosystem functioning. Along with ecosystem transformation and degradation, a number of studies have addressed the functioning, assessment and management of ecosystems. The concept of ecosystem services has been developed in the scientific literature since the end of the 1970s. However, ecosystem service research has focused on certain service categories, ecosystem types, and geographical areas, while substantial knowledge gaps remain concerning several aspects. We assess the development and current status of ecosystem service research on the basis of publications collected from the Web of Science. The material consists of (1) articles ($n = 353$) from all the years included in the Web of Science down to the completion of the Millennium Ecosystem Assessment and (2) more recent articles ($n = 687$) published between 2006 and 2008. We also assess the importance of international processes, such as the Convention on Biological Diversity, the Kyoto Protocol and the Millennium Ecosystem Assessment, as drivers of ecosystem service research. Finally, we identify future prospects and research needs concerning the assessment and management of ecosystem services.

Keywords Ecosystem change · Ecosystem goods · Environmental management · Environmental policy · International conventions · Millennium Ecosystem Assessment

INTRODUCTION

Over the past 50 years, the human impact on ecosystems has been more rapid and extensive than in any similar period of human history, largely owing to the growing demand for food, water, timber, fibres and mineral resources, as well as for fuel and other forms of energy (Millennium Ecosystem Assessment 2005). In the short run, this transformation of the planet has increased human well-being. Not all regions and people, however, have benefited from this process. Moreover, the gains have been achieved at a growing cost in the form of the degradation of ecosystem services, the increased risk of abrupt and irreversible ecosystem changes, and exacerbated poverty for part of the human population (Millennium Ecosystem Assessment 2005). While we have partly succeeded, by means of culture and technology, in creating buffers against environmental changes, we are fundamentally dependent on ecosystem services.

Ecosystem services can be described as the benefits people obtain from ecosystems (e.g. Millennium Ecosystem Assessment 2005). The Millennium Ecosystem Assessment (hereafter MA) has been a milestone in ecosystem service research, summarizing past ecosystem change and assessing the future of humankind. The concept of ecosystem services has been developed in the scientific literature since the end of the 1970s, and since the MA the number of publications has accumulated drastically.

In science, certain concepts can form buzzwords that take off rapidly. This applies to some extent to the term 'biodiversity', and more recently to that of 'ecosystem services'. These booms in popularity quite often reflect a wider change or even a shift in scientific paradigm (Kuhn 1962; Andrén et al. 2008). With regard to the influence and applicability of ecosystem service research, it is important to assess the extent to which the popularity of the term reflects a genuine paradigm shift. Has the increased awareness of over-used natural resources influenced the science of socio-ecological systems, or does the popularity

of the term 'ecosystem services' perhaps merely reflect a change in scientific vocabulary?

At present, serious effort is being invested into halting or reversing ecosystem degradation and the loss of ecosystem services. Approximately 60% of the ecosystem services examined in the MA are currently degraded or are being used unsustainably. The degradation of ecosystem services may grow significantly worse during the first half of this century, forming a barrier to achieving the Millennium Development Goals of the United Nations (2006a). The economic and public health costs associated with damage to ecosystem services can be substantial (Millennium Ecosystem Assessment 2005; Chivian and Bernstein 2008).

An increasing number of studies address the functioning, assessment and management of ecosystem services. The concept of ecosystem services may offer an invaluable tool for conservation, for example, in circumstances where public commons are used unsustainably (Ostrom 1990; Daily and Ellison 2002). Substantial gaps still remain, however, in our knowledge about many geographical areas and ecosystem types, as well as the status and valuation of many ecosystem services and options for their assessment and management. This lack of knowledge constrains the effective management and conservation of ecosystem functioning.

Scientific research should respond to and indeed anticipate societal information needs. During the past two decades several international processes, including the Convention on Biological Diversity (CBD) (United Nations 1993), the Kyoto Protocol (United Nations 1998), the Intergovernmental Panel on Climate Change (IPCC), and the MA, have been initiated to prevent ecosystem degradation and biodiversity loss. In order to enhance implementation of the CBD, the parties to the Convention have committed themselves to achieving a significant reduction in the current rate of biodiversity loss by 2010 (the 2010 Biodiversity Target). Other major milestones of sustainable development have been the Johannesburg World Summit of Sustainable Development in 2002 and the launch of the EU emission trade in 2005. These landmarks can be used in assessing how research responds to societal information needs.

The purpose of this article is to survey the development of ecosystem service research, from early studies to the most recent trends. We assess themes and target ecosystems, as well as the geographical and chronological distribution and multidisciplinarity of ecosystem service research. We also discuss the drivers behind ecosystem service research and the importance of international environmental policy and conventions. Finally, we identify future prospects and research needs concerning the assessment and management of ecosystem services.

MATERIALS AND METHODS

Our reference material includes early material down to February 2006 and current material from 2006 until 2008. The material comprises original articles, reviews and editorials collected from the Web of Science database.

The search for early material was carried out at the beginning of February 2006. The aim was to cover all English-language material from the beginning of ecosystem service research down to completion of the MA. We included only those references for which we found either the abstract alone or the whole text, and excluded book reviews and book chapters. In all searches the terms were truncated in order to include both singular and plural forms.

The search terms used were 'ecosystem service', 'environmental service', 'ecological service' and 'ecosystem good', both alone and combined with 'catchment', 'forest', 'mangrove', 'river', 'watershed' and 'wetland'. The terms were allowed to appear in titles, keywords or abstracts.

The references were entered into a database, which included bibliographical information and a classification of ecosystem type ('agricultural', 'forest', 'watershed', 'other' or 'more than one'), ecosystem service type, and topic. We also recorded the target area and the affiliation of the first author. In addition, we estimated the possible multidisciplinary nature of author groups. If an abstract did not include the relevant information, the category 'not applicable' was used.

The early reference material covered 353 articles in 124 international journals. The journals represented various aspects of ecology, the environmental sciences and other natural sciences, as well as engineering, law, economics and policy studies. Some journals specialized in forestry, agriculture, fishery, invasive species, toxicology or sustainable development and other development issues.

To detect the latest trends in ecosystem service research after completion of the MA, we conducted an update search, with the search term 'ecosystem service', for articles published between 2006 and the end of the year 2008. The update material comprised 687 publications.

Finally, we estimated the significance of the early publications by determining how often they were referred to. The most recent publications were not included because of the lag in the optimal reference period. We checked the number of citations for each article on the Web of Science a year and a half after publication of the last one, on 14 June 2007. In addition, we read the abstracts and introductions of the 60 most often cited articles with at least 20 citations, and assessed whether the studies had been induced by international background processes such as the CBD, the MA or the publications of the IPCC.

THE CONCEPT AND CLASSIFICATION OF ECOSYSTEM SERVICES

The research orientation to which the concept of ecosystem services belongs focuses on the study of socio-ecological systems, i.e. coupled human–environment systems (Holling 1973; Folke et al. 2002). The three main approaches to ecosystem services are those of ecology and the other natural sciences, economics and the social sciences, as well as multidisciplinary combinations of these, including the ecosystem approach.

The original idea of ecosystem services and goods was presented already in the 1950s by Odum, in his *Fundamentals of Ecology* (Odum 1959). Odum discussed the use of natural resources, in the form for instance of agriculture, forestry, hunting and fishery, and addressed human populations as part of ecosystems.

The term ecosystem services (or its synonyms, such as environmental services, ecological services and ecosystem goods) was established in the 1990s. The Web of Science lists only two articles with these terms from earlier decades (Nguyen 1979; Ehrlich and Mooney 1983), after which the terms were not used in scientific publications until the beginning of the 1990s. The concept, however, was undoubtedly explored during this period, under other titles. In the 1990s, Daily (1997) crystallized the content of ecosystem services, while Costanza et al. (1997) discussed the global valuation of nature's capital assets and ecosystem services. The scientific and especially the political relevance of the concept, however, was accepted when the term was used in the MA. Since then the number of publications on ecosystem services has increased drastically.

However, why was the term introduced? A new concept was clearly needed to connect human society and ecosystems, as well as to describe our dependence on nature and our increasing impact on the environment. There had already been a relatively long research tradition dealing with the theoretical framework of socio-ecological systems, including the launching of *Ambio: A Journal of the Human Environment* in 1972. However, only the concept of ecosystem services may have been sufficiently simple to crystallize the essence of ecosystem goods and services and their interdependence with human society (cf. Holling and Meffe 1996; Daily 1997; Millennium Ecosystem Assessment 2005).

The increment of publications on ecosystem services resembles the rise of the term 'biodiversity' in the 1980s. The concept of ecosystem services broadens the framework of biodiversity research to include the entire human–environment system. It translates complex ecological interactions into common language, and increases our awareness of our dependence on biodiversity and healthy ecosystems.

After almost 30 years of ecosystem service research, of which the last 5–10 years have been a time of intensive studies, a number of definitions and classifications of ecosystem services have been formed. Only few of these, however, are comprehensive. Daily (1997) presented one of the first lists of ecosystem services, which has been used as a baseline in several later classifications. De Groot et al. (2002) provided a classification of ecosystem goods and services, and the classification in the MA has already been referred to by many authors (e.g. Kremen 2005; Wallace 2007). Wallace (2007) summarized classifications of ecosystem services and developed a new one based on human interests, offering a new perspective on the consideration of social values.

In the MA, ecosystem services have been classified as provisioning, regulating, cultural and supporting; this classification has also been followed here. Provisioning services include goods, such as food, water and fibre. Regulating services have to do, for example, with climate, water quality, floods, disease and waste treatment. Cultural services provide recreational, aesthetic, social, educational and spiritual benefits. Supporting services include soil formation, photosynthesis and primary production, as well as water and nutrient cycling. This classification is widely used nowadays, but it has also been criticized for its vague benefits and its generic categories of cultural services (Gatto and De Leo 2000; Heal 2000; Boyd and Banzhaf 2007).

There is a wide consensus on ecosystem goods and services possessing either market or non-market utilitarian value (Hooper et al. 2005; Boyd and Banzhaf 2007). Nonetheless, Boyd and Banzhaf (2007) stipulate a more concrete definition of *final* ecosystem services, to enable the establishment of universal ecosystem accounting units. Similarly, Wallace (2007) stresses that the concepts of means, such as ecosystem functions, and final ecosystem services, such as goods, are often confused. This may cause the double counting of ecosystem services.

TRENDS AND THEMES IN ECOSYSTEM SERVICE RESEARCH

Ecosystem Service Categories

In this study, we used the ecosystem service classification provided by the MA to determine which categories of ecosystem services are represented in our early reference material (Fig. 1). Most studies focused on provisioning and regulating services, or on a combination of more than one category. In several studies the categories were not defined. In addition, gaps in the MA classification made the assessment challenging: certain relevant aspects of ecosystem functioning, such as seed dispersal, soil quality and

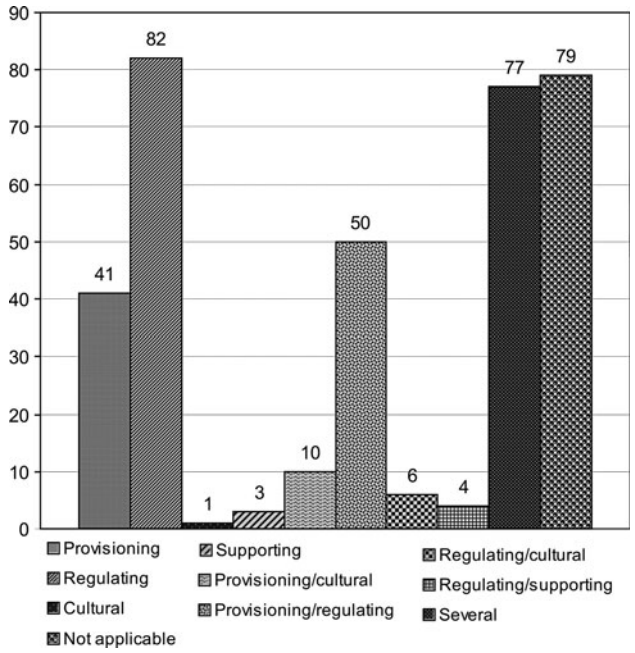

Fig. 1 Number of publications by ecosystem service category

soil regulation, as well as the ethical and existential values of ecosystems, were not included. Hydropower is presented in the MA merely as part of the provisioning services of fresh water, even though another source of energy, wood fuel, was included in a separate subcategory, distinct from other wood products. Furthermore, the widely used concept of non-timber forest products was difficult to assign to any single category.

Some discrepancies between the MA classification and the concepts used in our target studies reflect differences in the definition of ecosystem services. Concepts such as biodiversity maintenance and habitat provisioning are difficult to assign to any particular ecosystem service category, even though they form the very basis of most ecosystem services. One of our target studies actually addressed the concept of habitats for people, which is consistent with the definition of ecosystem services but too wide to be covered by any single ecosystem service category.

Ethical and aesthetic aspects of ecosystem degradation are recognized in some studies (Hooper et al. 2005; Wallace 2007), but they are not the focus of discussion. While cultural ecosystem services are considered important, there seems to be a lack of tools for their assessment; the only exception is ecotourism and recreation, which have a market value.

Thematic Assessment of Ecosystem Service Research

We classified the topics of ecosystem service studies in our early reference material as 'function', which includes studies describing the function of ecosystems, 'assessment', comprising studies assessing the state or value of ecosystem services, and 'management', comprising studies on concrete management issues. 217 studies (61.5%) were assigned to the class 'assessment', 97 (27.5%) to 'management' and 39 (11.0%) to 'function'.

These approaches to ecosystem service studies may reflect the relative importance of basic versus applied research. The dominance of the 'assessment' class is partly due to the fact that it covers several topics, ranging from ecosystem service valuation to assessment of the state of ecosystem services. However, the fact that 89.0% of the studies belonged to the categories of 'assessment' and 'management' may reflect the nature or at least the status quo of ecosystem service research.

Applied aspects are vital to the management and conservation of ecosystem services, and there is certainly a need for more studies on concrete management issues. The current gaps in our understanding of ecosystem functioning, however, should not be ignored; the proper assessment and cost-effective management of ecosystem services depend on a comprehensive basic knowledge of ecosystem functions.

Ecosystem Types

We categorized our early reference material into three ecosystem types. 110 (31.2%) studies concerned watersheds, 85 (24.1%) forest ecosystems and 13 (3.7%) agricultural ecosystems. In addition, 98 studies (27.8%) covered more than one ecosystem type, 42 studies (11.9%) did not concern any particular ecosystem and five studies (1.4%) concerned ecosystem types other than forest, agricultural or watershed (Fig. 2). 208 studies (58.9%) concerned only one ecosystem type.

Watersheds and forests were the most commonly studied environments, which may be due to the higher

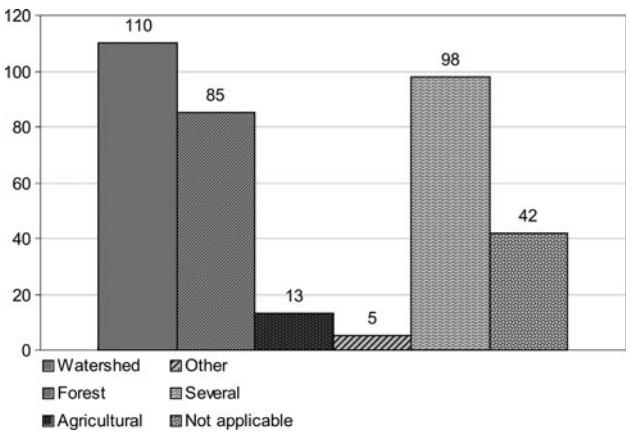

Fig. 2 Number of publications by ecosystem type

biodiversity in these habitats. Quite a few studies were conducted in agricultural ecosystems, and some of them also covered surrounding habitats or the landscape as a whole (e.g. Rounsevell et al. 2005).

Many of the studies that concerned several ecosystem types had a general topic, such as the valuing of ecosystem services. There were also many studies that covered a certain biogeographical or geographical region and several or all ecosystems within it. Some studies combined two or more ecosystem types, for instance agricultural and forest ecosystems, or addressed agricultural or forest ecosystems as parts of watersheds. Some studies concerned a particular part of the ecosystem, such as soil, that was common to several ecosystem types.

It makes sense to focus on a single ecosystem type for instance when a study is concerned with its assessment, management or valuation. However, since different ecosystem types are connected and share common threats and drivers of change, it is often necessary to include multiple ecosystem types.

Geographical Distribution of Target Areas and Research Groups

We divided the geographical target areas of our reference material into 10 categories: Africa, Asia and the Pacific, Australia and New Zealand, Europe, Latin America, North America, the Atlantic, several, general and not available. The category 'several' comprised studies that covered more than one area; the category 'general' comprised studies that did not concern any specific area. The category 'not available' covered abstracts of studies concerning a particular ecosystem whose location was not identified.

The largest group of target areas consisted of general studies (112 articles, 31.7%), reflecting the large proportion of abstract and conceptual studies. The geographical areas best represented were North America (69, 19.5%), Latin America (51, 14.4%), and Asia and the Pacific (46, 13.0%). Of continental areas, Australia and New Zealand (14, 4.0%) and Africa (17, 4.8%) were the least studied. There were also only two studies (0.6%) concerning the Atlantic. Europe was the target area of 24 (6.8%) of the studies (Fig. 3a).

We divided the affiliations of the senior authors into six geographical categories: Africa, Asia and the Pacific, Australia and New Zealand, Europe, Latin America and North America. Of these authors, 176 (49.9%) were affiliated in North America and 88 (24.9%) in Europe. The rest of the affiliations were divided quite evenly among Asia and the Pacific (27, 7.6%), Australia and New Zealand (22, 6.2%), Africa (20, 5.7%), and Latin America (20, 5.7%) (Fig. 3b).

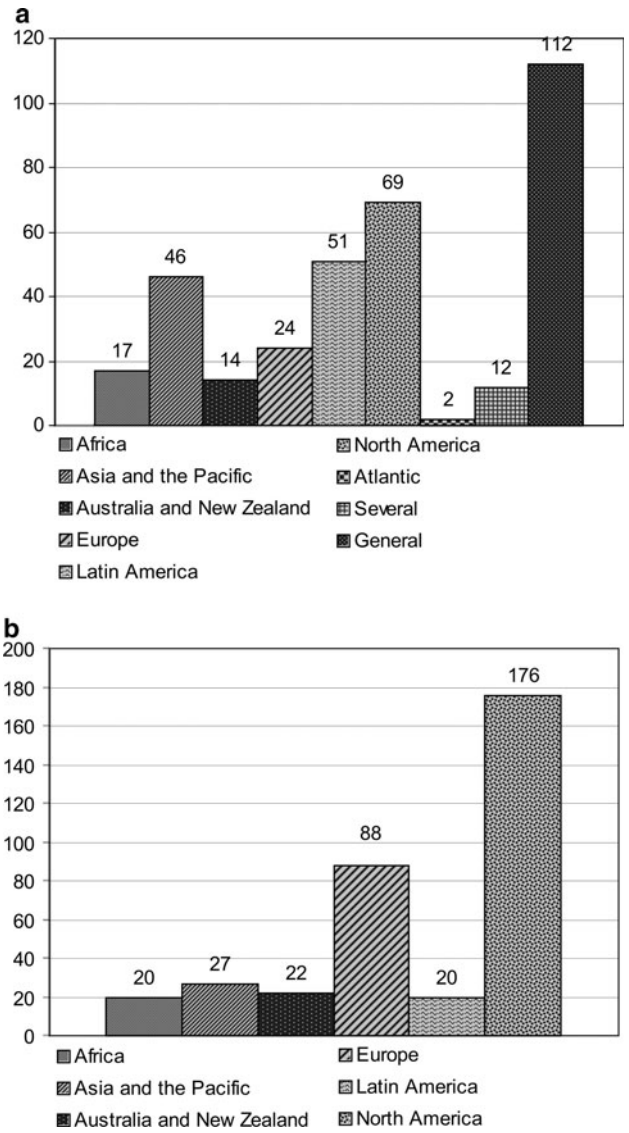

Fig. 3 Number of publications by target area (**a**) and by geographical area of researcher affiliation (**b**)

The geographical distribution of the senior authors indicates the prominence of the North-American and European science community in ecosystem service research. There was, however, one interesting aspect of research activity in the two areas: given that only one out of 15 studies dealt with Europe, it seems that many ecosystem service researchers with European affiliations do not conduct research there, at least under the concept of ecosystem services. It may also be that the concept of ecosystem services has been more widely applied in North America than in Europe, where ecosystem studies may have been designed in terms for instance of resilience; the latter can be seen a research orientation parallel to ecosystem service research, despite certain differences in emphasis.

Relatively few studies have been conducted in some marine areas, as well as in Africa; the latter includes areas with high species richness and endemism (Lamoreux et al. 2005), and with populations that are highly dependent on local ecosystem services and poorly buffered against current environmental degradation (Millennium Ecosystem Assessment 2005).

Most of our target studies covered only one part of the world. Two or more areas were included in 13 studies (3.7%). Considering the global nature of many ecosystem services and environmental change drivers, as well as linkages between ecosystems in different parts of the world, ecosystem service research would certainly benefit from a more global approach. However, local and regional studies are needed in addressing smaller-scaled issues (Vihervaara et al. 2009).

Some ecosystem service studies consider biogeographical zones rather than states, or focus on entities, such as a drainage basins or forest patches. However, a considerable number of studies is restricted to relatively small areas within single states. Certainly, there is a need for more insight into large natural entities crossing state borders.

Most of the senior authors were affiliated with universities. Research institutes and administrative research organizations formed the second largest group of affiliations. Especially in North America, some senior authors represented non-governmental organizations or consulting agencies. In Africa and Asia, some authors were affiliated with international environmental or development organizations.

Is Ecosystem Service Research Multidisciplinary?

We classified the author groups in our early reference data as multidisciplinary if the authors' affiliations represented more than one discipline. 77 (21.8%) of the studies were multidisciplinary, while 257 (72.8%) were not. In 19 cases (5.4%) the affiliations were not given in sufficient detail to allow classification.

Of the studies representing one discipline, 84 (32.7%) were conducted by a single author and 173 (67.3%) by a group. Studies conducted by a single author were not classified as multidisciplinary even if the affiliation of the author was multidisciplinary, which was the case in two studies.

Many research interests in ecosystem services require a multidisciplinary approach, especially those dealing with assessment and management. The proportion of multidisciplinary studies has in fact risen slightly. Of studies conducted between January 2000 and February 2006 ($n = 292$), 66 (22.6%) were multidisciplinary, 209 (71.6%) were monodisciplinary and 17 (5.8%) could not be classified. Of studies conducted in the 1990s ($n = 59$), 11 (18.6%) were multidisciplinary, 46 (78.0%) were monodisciplinary and 2 (3.4%) could not be classified. As there is a growing need to assess and manage ecosystem services and to understand the drivers of change, even more multidisciplinary studies are needed.

Most of the multidisciplinary studies had been conducted by natural scientists and economists, but there were also groups consisting of natural scientists and engineers, sociologists or lawyers. The composition of the author groups reflects the foci of the studies. Enhancing cooperation between natural scientists and sociologists, anthropologists and philosophers would help to assess the cultural aspects of ecosystem services. In addition, social studies could provide new insights into the valuation of ecosystem services, as well as into public opinion and the political climate with regard to the degradation or management of ecosystems.

Accumulation of Studies and Connections to International Background Processes

In our early reference material, the first study dates from 1979. However, only 10 studies were published before 1996, after which the annual number of publications began to rise. 292 studies (82.7%) were published in the twenty-first century and 88 studies (24.9%) in 2005 alone. Our update material contained 174 articles published in 2006, 217 in 2007, and 296 in 2008. This rapid accumulation of studies may be due in part to increased public interest in ecosystem service research since the MA, and to the 2010 Biodiversity Target of achieving a significant reduction in the current rate of biodiversity loss by 2010.

Up to the end of 2008, our search yielded 1,678 hits. In spite of overlapping terms linked to the same publications, the search term 'ecosystem service' produced 1,144 (65.0%) hits, 'environmental service' 352 (20.0%) hits, 'ecological service' 180 (10.0%) hits and 'ecosystem good' 93 (5.0%) hits. The search returned publications from many fields; in particular the term 'environmental service' was often linked for instance to waste management and environmental hygiene. Among the articles yielded by the search term 'ecosystem service', the first had been published in 1983 and the second in 1991. The years 1992 and 1994 yielded two articles; after this the number of publications began to grow, reaching 296 in 2008 (Fig. 4).

We compared the 10 most cited articles, all of which were cited more than 60 times (Table 1). The articles showed only few common elements. Six of the 10 were reviews, as compared to a figure of only 8.7% for the reference material as a whole. The geographical perspective was mostly general, although one article focused on several areas and one on Latin America. Nine had been written by North-American researchers, one by European

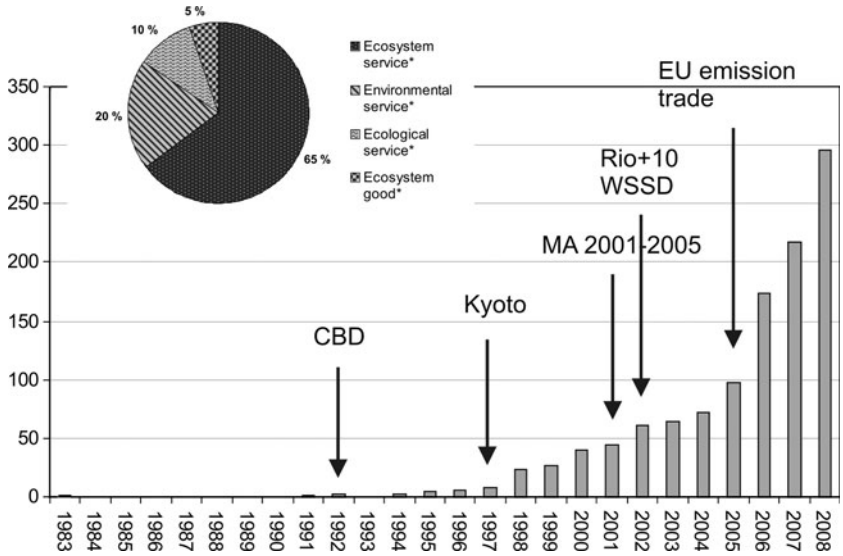

Fig. 4 Accumulation of ecosystem service studies and timing of background processes: Convention on Biological Diversity (CBD), Kyoto Protocol (Kyoto), Millennium Ecosystem Assessment (MA), Johannesburg World Summit of Sustainable Development (WSSD) and launch of EU emission trade. Pie chart depicts proportions of studies by search term (* indicates truncation of term)

Table 1 Ten most often cited ecosystem service articles published as of February 2006

Number of citations	Author(s), year	Publication type	Ecosystem type	Study area	Affiliation of researchers
905	Costanza et al. (1997)	Article	Several	General	North America
238	Debinski and Holt (2000)	Review	Several	General	North America
236	Ehrlich and Wilson (1991)	Article	Not applicable	General	North America
221	Kearns et al. (1998)	Review	Agricultural	General	North America
163	Hooper et al. (2005)	Review	Not applicable	General	North America
115	Allen-Wardell et al. (1998)	Article	Agricultural	Several	North America
73	Lambin et al. (2003)	Review	Several	Latin-America	Europe
69	Jackson et al. (2001)	Review	Watershed	General	North America
67	Coates and Burton (1997)	Article	Forest	General	North America
63	Cochrane (2003)	Review	Forest	General	North America

The citations were retrieved from the Web of Science in June 2007

researchers. The majority of the articles discussed the management or functioning of ecosystems, covering such aspects as habitat fragmentation, forest fires, water usage, the dynamics of land use and land-cover change. Pollination was at the focus of two articles. Only two publications considered ecosystem services from an economic or political perspective.

With regard to the applicability of ecosystem service research, research can be expected to respond to societal information needs, but it should also anticipate them. Science should thus both precede and inform policy-making, and should also evaluate its implementation, in a two-way interaction. As an indicator of information needs we used the international processes for instance of the CBD, the Kyoto Protocol (and the publications of the IPCC), and the MA (Fig. 4). These processes were mentioned as the drivers or background processes in 10 of the 60 most cited articles, while the UN Millennium Development Goals and the 2010 Biodiversity Target were not mentioned. The CBD (or UNCED conference) was mentioned as a driver in three articles published in 1998, 1999 and 2003, the MA in three articles published in 2004 and 2005, and the IPCC in four articles published in 2003 and 2005. In addition, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the Ramsar Convention on Wetlands were the background processes of two studies.

It should be noted that some of the above-mentioned conventions focus rather strictly on biodiversity protection; this lessens their relevance to ecosystem service research in intensively managed environments, such as agricultural or silvicultural areas. However, we cannot draw the conclusion that these processes did not influence ecosystem service publications. International agreements may have had a positive albeit tacit effect on ecosystem service research, via science policies and funding.

The focus of the background processes on biodiversity protection in more or less pristine habitats may also be reflected in the apparent differences in ecosystem research activity between North America and Europe. In Europe, ecosystem services may have been studied to a greater extent in managed environments using other concepts such as *resilience*, while in North America there may have been greater awareness and thus more research focus on ecosystem services of natural habitats. This difference between Europe and North America in attention to pristine versus managed habitats, and the resulting differences in research paradigms, may be reflected for instance in public perception and land management policies concerning farmlands (Martin et al. 2009).

FUTURE PROSPECTS AND RESEARCH NEEDS

Despite its relative newness as a research area, ecosystem service research has developed during the first decade of the twenty-first century into a significant area of science. However, scientific understanding of a number of ecosystem service issues is still deficient, and our knowledge of different ecosystems and habitats remains patchy (Andrén et al. 2008).

The availability of data and information processing, and mechanisms for the dissemination and sharing of research results, are crucial for the development of ecosystem service research. They are also a prerequisite for the application of research results to efficient management, conservation and sustainable use. The exchange of information, scientific cooperation and the enhancement of decision-makers' access to biodiversity information are also major components of the CBD (Glowka et al. 1994; Juma 1997).

In a number of countries, data are insufficient either absolutely or in relation to the complexity of biodiversity (Allkin 1998). Where plenty of data are available, there may be a need for the further development of technical tools for the production and delivery of information (Schalk 1998). Under the CBD, difficulties in biodiversity information management, storing and sharing are addressed by the establishment of a biodiversity Clearing House Mechanism (CHM) (UNEP 1997). CHMs also provide important prospects for the development and dissemination of biodiversity-related ecosystem service research. More attention should thus be paid to ways in which local and regional biodiversity data and information can be processed and shared through national CHMs (Laihonen et al. 2003).

One of the main interests of natural scientists is in developing a methodology for the mapping and assessment of ecosystem services (Mezger et al. 2008; Naidoo et al. 2008; Vihervaara et al. 2009). Databases available through CHMs are highly useful for instance in the early selection of criteria for locally and regionally relevant ecosystem services. Chan et al. (2006) have suggested that the most important service categories are biodiversity, carbon storage, flood control, forage production, pollination, recreation and water provision.

Currently, the role of biodiversity in ecosystem service production (as in the whole functioning of ecosystems) is the subject of broad debate (Hooper et al. 2005; Andrén et al. 2008), which in turn is closely connected to the debate concerning resilience (Holling 1973; Folke et al. 2002). The importance of biodiversity may actually have been exaggerated (Andrén et al. 2008), but its relevance to resilience is nevertheless recognized (Holling and Meffe 1996). In any case, retelling 'the golden rule' in genetics will put biodiversity in its right place in the system: *biodiversity makes ecosystem makes ecosystem services*.

The scientific community has currently reached a broad consensus on many aspects of the relationship between biodiversity and ecosystem functioning. Future progress will require the integration of knowledge about biotic and abiotic controls with ecosystem properties and processes, the structure of ecological communities, and the forces driving species extinctions and invasions (Loreau et al. 2001; Hooper et al. 2005). There also still remains a need for information about current rates of population and habitat changes in some areas and ecosystems (Balmford and Bond 2005). Geographical information systems (GIS) and ground-truthed remote sensing could be used cost-efficiently over wide areas to quantify changes in key habitats, and existing data on population and habitat trends could be assessed using meta-analytical approaches (Balmford and Bond 2005).

Future research should also explore the effects of species richness and composition on different dimensions of stability (Loreau et al. 2001; Hooper et al. 2005). Stability refers to resistance to disturbance, resilience to disturbance, temporal variability in response to fluctuating abiotic conditions, and spatial variability in response to differences in either abiotic conditions or the biotic community (Holling 1973; Holling and Meffe 1996). Until recent years, most of the theoretical work has focused on temporal variability. There is also a need for experimental work on stability, especially field research and long-term experiments that assess the response to and recovery from disturbances. The challenge is to consider all the factors that covary with species diversity (Hooper et al. 2005), and to apply the results to larger spatial scales (Loreau et al. 2001).

The review of the economic impacts of biodiversity loss by the international The Economy of Ecosystems and Biodiversity (TEEB) project (TEEB 2009) is continuing

the work of the MA and the climate change impact assessment by Stern (2007). The target audience of the TEEB consists of policy and decision-makers. Models and tools for biodiversity economics have already been developed in traditional economics, as well as in environmental and ecological economics. In future, the input of institutional economics may offer important tools for the conserving of nature (Daily and Ellison 2002), and for handling societal problems and environmental conflicts arising from the unsustainable use of natural resources (Vatn and Bromley 1994).

Input is needed from social and natural scientists to improve our understanding of how the current drivers of change are likely to vary over time (Balmford and Bond 2005). Biodiversity and ecosystem services are affected by both direct and indirect drivers (Millennium Ecosystem Assessment 2005). Indirect drivers include demographic, economic, socio-political, scientific and technological factors, as well as cultural and religious ones. These can trigger or strengthen direct drivers, such as land-use change, climate change, species introduction or removal, pollution and the overexploitation of resources.

The management and conservation of ecosystem goods and services already forms an important part of environmental theory and practice (Daily 1997; Daily and Ellison 2002). However, there are global examples of inefficient management methods and land-use traditions, reinforced by poor governmental practice and by conflicts in environmental politics and among stakeholders (e.g. Scheffer et al. 2000). The non-monetary values of ecosystems should be considered as key components in decision-making (cf. Ostrom 1990). This concerns in particular poorly known ecosystems such as rainforests, where more than 80% of the biodiversity may still be unknown (Fearnside 1999; Godfray et al. 1999).

To strengthen the links between ecology, policy and management, ecological knowledge needs to be integrated with an understanding of the social and economic constraints of management practices (see Hooper et al. 2005). Our results show the bias towards ecological and economic research, while social and political contributions to ecosystem service research are minor. Effective management and conservation strategies need to consider the different drivers of global change, the forces that structure communities, and the controls of ecosystem properties (Holling and Meffe 1996; Hooper et al. 2005). These will become even more important in the future, considering that the global human population is estimated to increase by the year 2050 to 9.2 billion (United Nations 2006b). While gaps in current knowledge should not be taken as an excuse for inaction (Balmford and Bond 2005), a better understanding of human–environment systems will in future allow more focused policy interventions.

CONCLUSIONS

Our results do not explicitly confirm that international policy processes and conventions as such are the main drivers of ecosystem service research. Rather, the processes result from scientific evidence and societal pressure on the international environmental policy agenda. However, international agreements may affect research funding (cf. Andrén et al. 2008), and may implicitly lead to increased interest in ecosystem services. While there are a number of background processes that may influence ecosystem service research, the widely recognized and cited definition and classification of ecosystem services in the MA may have guided terminology in this research field.

At least two main reasons exist for the current momentum in ecosystem service research: (1) globally increased human pressure on nature, which underpins the need for the sustainable use of natural resources and the development of valuation and regulation methods and (2) the concept's ability to translate complex ecological functions into a common neutral vocabulary for multidisciplinary scientific and political discussion (cf. Norton 2000). The concept of ecosystem services deepens and extends the view of traditional environmental and conservation sciences so as to include human beings as a part of the systems.

Before 2006, most ecosystem service studies dealt with provisioning or regulating services, with a focus on assessment and management. This illustrates the applied nature of ecosystem service research. Watersheds and forests were the most often studied ecosystem types, while there were only few studies on agricultural systems or oceans. Most of the studies were conducted in North America, Latin America, and Asia and the Pacific by North-American and European researchers. There were fewer studies focused on Europe than might have been expected based on the number of European ecosystem-service researchers. There is a need to encourage more ecosystem service research in Africa. One-fifth of the studies had been conducted by multidisciplinary research groups, with ecologists as the most common corresponding authors and economists as the second most common.

In future, ecosystem change and vulnerability may be key issues in ecosystem service research due to current trends in population growth and land-use pressures. We believe that the ongoing mapping projects and vulnerability assessments will develop tools for a more efficient assessment of ecosystem services and planning of sustainable societies. Increasing cooperation among multidisciplinary researchers, as well as encouraging new international policy processes, such as the assessment of the economy of ecosystems and biodiversity, are worthwhile means towards achieving a sustainable future.

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