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ORIGINAL PAPER

Identifying and prioritising services in European terrestrial and freshwater ecosystems

Paula A. Harrison · Marie Vandewalle · Martin T. Sykes · Pam M. Berry · Rob Bugter · Francesco de Bello · Christian K. Feld · Ulf Grandin · Richard Harrington · John R. Haslett · Rob H. G. Jongman · Gary W. Luck · Pedro Martins da Silva · Mari Moora · Josef Settele · J. Paulo Sousa · Martin Zobel

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Abstract Ecosystems are multifunctional and provide humanity with a broad array of vital services. Effective management of services requires an improved evidence base, identifying the role of ecosystems in delivering multiple services, which can assist policy-makers in maintaining them. Here, information from the literature and scientific experts was used to systematically document the importance of services and identify trends in their use and status over time for the main terrestrial and freshwater ecosystems in Europe. The results from this review show that intensively managed ecosystems contribute mostly to vital provisioning services (e.g. agro-ecosystems provide food via crops and livestock, and forests provide wood), while semi-natural ecosystems (e.g. grasslands and mountains) are

P. A. Harrison (✉) · P. M. Berry
Environmental Change Institute, Oxford University Centre for the Environment, South Parks Road, Oxford OX1 3QY, UK
e-mail: paharriso@aol.com

M. Vandewalle · M. T. Sykes
Department of Physical Geography and Ecosystems Analysis, Lund University, 223 62 Lund, Sweden

R. Bugter · R. H. G. Jongman
Alterra, Wageningen University and Research Centre, P.O. Box 47, 6700 AA Wageningen, the Netherlands

F. de Bello
Laboratoire d'Ecologie Alpine, UMR CNRS 5553, Université Joseph Fourier, BP 53, 38041 Grenoble Cedex 9, France

Present Address:
F. de Bello
Institute of Botany, Czech Academy of Sciences, Dukelská 135, 379 82 Třeboň, Czech Republic

C. K. Feld
Department of Applied Zoology/Hydrobiology, University of Duisburg-Essen, 45117 Essen, Germany

U. Grandin
Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, 750 07 Uppsala, Sweden

key contributors of genetic resources and cultural services (e.g. aesthetic values and sense of place). The most recent European trends in human use of services show increases in demand for crops from agro-ecosystems, timber from forests, water flow regulation from rivers, wetlands and mountains, and recreation and ecotourism in most ecosystems, but decreases in livestock production, freshwater capture fisheries, wild foods and virtually all services associated with ecosystems which have considerably decreased in area (e.g. semi-natural grasslands). The condition of the majority of services show either a degraded or mixed status across Europe with the exception of recent enhancements in timber production in forests and mountains, freshwater provision, water/erosion/natural hazard regulation and recreation/ecotourism in mountains, and climate regulation in forests. Key gaps in knowledge were evident for certain services across all ecosystems, including the provision of biochemicals and natural medicines, genetic resources and the regulating services of seed dispersal, pest/disease regulation and invasion resistance.

Keywords Agriculture · Ecosystem services · Forests · Grasslands · Heathlands/shrublands · Lakes · Mountains · Multifunctionality · Rivers · Soils · Trends · Wetlands

Introduction

Ecosystems provide a multitude of essential services to humankind. Ecosystems can only continue to provide these services in a rapidly changing world if such multifunctionality is taken into account in their management. To manage for multiple ecosystem services we must first identify, quantify and value the full suite of services provided by different ecosystems. Since publication of the seminal works by Daily (1997) and Costanza et al. (1997), research on ecosystem services has grown dramatically. Much of the early work was theoretical, but practical applications of the ecosystem service concept are increasing (e.g. Díaz et al. 2007; Cowling et al. 2008; Tallis et al. 2008) and the concept is creeping into policy strategies of government and non-government organisations (e.g. Defra 2007;

R. Harrington
Department of Plant and Invertebrate Ecology, Centre for Bioenergy and Climate Change, Rothamsted Research, Harpenden, Hertfordshire AL5 2JQ, UK

J. R. Haslett
Division of Zoology and Functional Anatomy, Department of Organismal Biology, University of Salzburg, Hellbrunner Strasse 34, 5020 Salzburg, Austria

G. W. Luck
Institute for Land, Water and Society, Charles Sturt University, Albury 2640, Australia

P. M. da Silva · J. P. Sousa
Department of Life Sciences, IMAR—Marine and Environment Research Centre, University of Coimbra, 3004-517 Coimbra, Portugal

M. Moora · M. Zobel
Institute of Ecology and Earth Sciences, University of Tartu, Lai St. 40, 51005 Tartu, Estonia

J. Settele
Department of Community Ecology, UFZ—Helmholtz Centre for Environmental Research, Theodor-Lieser-Str. 4, 06120 Halle, Germany

Haslett 2007). However, progress is hampered by a lack of knowledge on the importance of different services across ecosystems. Documenting this information is crucial for prioritising the protection of ecosystems that vary in their ecosystem service potential and informing decisions about the delivery of multiple, and sometimes conflicting, services. Also, the information is vital to schemes that aim to identify ecosystems with high service and biodiversity 'value' (e.g. Chan et al. 2006; Turner et al. 2007; Naidoo et al. 2008).

Ecosystem service and biodiversity priorities do not always overlap and the ecosystem service concept cannot be considered as an alternative to traditional biodiversity conservation strategies (RUBICODE 2008a). Yet, the concept has great potential to add value to current conservation approaches (see Haslett et al. 2010). This potential is, however, poorly explored across Europe and our study is one of the first attempts to systematically document the importance of European ecosystem services and to identify trends in their status and use over time (see also Schröter et al. 2005; EASAC 2009). This information can be combined with spatially referenced data on ecosystem location and biodiversity to identify congruence or divergence among ecosystem service and conservation priorities.

The Millennium Ecosystem Assessment (MA 2005a) is the most comprehensive global examination of the state of the world's ecosystems and the services they provide. Working Group I of the MA assessed the condition and trends of 24 services associated with 10 systems (marine fisheries, coastal, inland water, forest and woodland, dryland, island, mountain, polar, cultivated, and urban) at the global scale. It reported that human use of most ecosystem services is increasing, whilst the condition of most services has decreased over the past 50 years (Carpenter et al. 2009). Our study builds on the work of the MA (2005b) by using a more detailed classification of European[1] terrestrial and freshwater ecosystems. Similar to the MA, we defined an ecosystem as *a dynamic complex of plant, animal and microorganism communities and their nonliving environment interacting as a functional unit in which humans, where present, are an integral part* (see Harrington et al. 2010). The aim of our study was to document the variety and relative magnitude of the services provided by the main terrestrial and freshwater ecosystems in Europe, and past trends in their status and human use. In conducting the study, we used the most updated service classifications provided by the MA (Carpenter et al. 2009) for provisioning, regulating and cultural services (see Table 1) for consistency and to enable comparison between evidence at the European and global scales.

Evidence was collected through an exhaustive search of the literature for each ecosystem type. Searches of peer-reviewed literature using Google Scholar and Web of Science were supplemented with reports from the European Commission and the European Environment Agency, such as the EUROSTAT and EEA Reports on the State and Outlook of the European Environment (e.g. EEA 2005). Preliminary findings from the literature search (Vandewalle et al. 2008) were presented at an international workshop in Helsingborg, Sweden (25–28 February 2008). The workshop involved 96 scientists from various disciplines with expertise in a wide range of European ecosystems. Workshop participants provided critical feedback on the preliminary review and refined a proposed ranking of importance for different services within each terrestrial and freshwater ecosystem (RUBICODE 2008b). The workshop was followed by a 2-week long electronic conference (31

[1] Europe is defined as the 27 countries of the European Union: Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.

Table 1 Qualitative ranking of importance for services within European terrestrial and freshwater ecosystems

MA category	Ecosystem service	Key contribution	Some contribution	No contribution	Poorly known
Provisioning services	Food and fibre	A, G, M, R	F, H, S, W		
	Timber/fuel/energy	A, F, M, R	G, H, S, W		
	Freshwater	F, M, R	G, H, W	A(−), S	
	Ornamental resources		A, F, G, H, M, R, W	S	
	Biochemicals/natural medicines		A, F, G, H, M, W	R	F, G, H, M, S, R, W
	Genetic resources	F, G, H, M	A, R		A, F, M, S, R, W
Regulating services	Pollination	A, F, G, H	M	S, R, W	A, F, M
	Seed dispersal	F	A, G, H, M, S, R, W		A, G, H, M, R, W
	Pest regulation	A, S	G, M	H, R	F, M, R, W
	Disease regulation		M, S	A(−), G, H, R	F, G, H, M, R, W
	Invasion resistance	G, H	F, S, W	A(−), R(−)	A, F, M, W
	Climate regulation	F, M, S, W	G, H, R	A(−)	A, F, W
	Air quality regulation	F, M		A(−), G, H, S, R, W	A
	Erosion regulation	F, M	G, H, S, R, W	A(−)	
	Natural hazard regulation	M, R, W	F, G, H, S	A	
	Water flow regulation	F, M, S, R, W	A, G, H	G	A
	Water purification/waste treatment	S, R, W	F, G, H, M	A(−)	A, G, M
Cultural services	Spiritual and religious values		A, F, M, S, R, W		A, F, G, H
	Education and inspiration	F, G, H, M, R	A, W	S	A
	Recreation and ecotourism	A, F, G, H, M, R, W	S		
	Cultural heritage	A, G, H, M	F, S, R, W		F
	Aesthetic values	F, G, H, M, R, W	A, S		
	Sense of place	A, G, H, M, R, W	F		F, S

A Agro-ecosystems, *F* forests, *G* semi-natural grasslands, *H* heathlands/shrublands, *M* mountains, *S* soil systems, *R* rivers and lakes, *W* wetlands

If no documented evidence exists to support key/some contribution then this is indicated by an additional symbol in the “poorly known” column. When an ecosystem as a whole has a negative impact on a service, this is indicated in the table by (−) after the letter representing the ecosystem

March–11 April 2008), which evaluated the representativeness of the recommendations from the workshop with a wider scientific community of 154 contributors (Grant et al. 2008). A final trawl of the literature was undertaken to follow up any suggestions from the workshop and e-conference. The consensus reached through discussions in breakout groups and plenary sessions at the Helsingborg workshop, and subsequent e-conference, was only modified if evidence was found in this final trawl of the literature to support a change in the status of a service.

Selection of European terrestrial and freshwater ecosystems

The selection of terrestrial and freshwater ecosystems was based on their representativeness at the European scale. European terrestrial ecosystems were divided into agro-ecosystems, forests, semi-natural grasslands, heathlands and shrublands, mountains, and soils. European freshwater ecosystems were divided into rivers, lakes, and wetlands.

Over half of European territory is used for agriculture (Robinson and Sutherland 2002) and, therefore, farm management practices have a tremendous impact on biodiversity and ecosystem services (Donald et al. 2002). Forest ecosystems cover approximately one-third of Europe, and many exist as plantations, often of a single or very few exotic tree species, managed for timber (EASAC 2009). Temperate grasslands are among the most species-rich vegetation types in Europe and have great conservation value (Eriksson et al. 2002; Poschlod and WallisDeVries 2002; WallisDeVries et al. 2002). They usually endure due to moderate human-induced disturbances such as animal husbandry, mowing and collection of firewood (Settele and Henle 2003) and are classified as 'semi-natural' (van Dijk 1991), although their flora is spontaneous (Svenning 2002; Mitchell 2005). Likewise, European heathlands and shrublands are semi-natural ecosystems which have been coevolving for millennia with human societies and represent a distinctive set of European habitats for their biodiversity, and aesthetic and cultural values (Wessel et al. 2004; Quétier et al. 2007; de Bello et al. 2009).

Mountain ecosystems were considered as a separate category as they are inherently different to other areas because of their altitudinal variations, complex topography and associated habitat mosaics, atmospheric influences and because gravity links higher areas to places below. They are also areas of particularly high biodiversity (e.g. Körner and Spehn 2002; Nagy and Grabherr 2009). Mountain municipalities cover 41% of Europe (EU27 plus Norway and Switzerland) (EC 2004) and provide a disproportionately large number of ecosystem services to many communities due to their high multifunctionality (Messerli and Ives 1997).

Freshwater ecosystems include pure aquatic ecosystems, such as rivers and lakes, and transitional systems, such as wetlands and floodplains. Although the area covered by rivers and lakes is relatively small, they are almost omnipresent and closely interlinked with terrestrial ecosystems in all European regions. Wetlands are spatially and temporally diverse in their ecology, hydrology and geomorphology and include a wide variety of landscape units, including marsh, fen and peatland, which share the fundamental characteristic of being strongly influenced by water. Wetlands in Europe cover approximately 36 million ha or 7% of the total land area (Nivet and Frazier 2004). Around 70% are bogs and fens with the remainder being marshes and river wetlands.

Importance of European ecosystem services

The relative importance of services provided by each terrestrial and freshwater ecosystem was ranked into four categories (Table 1): key contribution, some contribution, no contribution and contribution poorly known. This latter category helps distinguish where the ranking was based solely on expert opinion, while other rankings were supported by evidence from the literature. The evidence presented represents Europe as a whole, although if the ranking differs across European regions this is described in the following sub-sections. Moreover, the ranking is based solely on service supply and does not consider who benefits from the service (directly linking service production to beneficiaries so the flow of services can be mapped is something that is sorely lacking), cost–benefit ratios of service protection, threats to the service, or the availability of human-derived alternatives to service production.

Provisioning services

The *provision of food* was found to be of key importance in agricultural, grassland, mountain, river and lake ecosystems. In Europe, food is primarily produced in intensively managed agro-ecosystems which comprise 45% of the EU's land area (EASAC 2009) and have a total annual economic value of around €150 billion (Gallai et al. 2009). There are also large areas of Europe where more extensive and traditional agriculture takes place, such as in the uplands and temperate semi-natural grasslands. Although the role of oligotrophic grasslands in providing food has considerably decreased due to massive abandonment of grasslands during the 20th century (Poschlod et al. 2005), the significance of semi-natural grasslands for sustainable fodder production has been recently re-emphasised (Bullock et al. 2007). Traditional extensive agricultural practices in European mountains continue to provide foods (such as dairy products, meat and honey), and there is also more intensive agriculture on fertile valley floors (e.g. in the Alps; Stone 1992). Further, wild populations of animals and plants are harvested to provide foods, such as game, fish, berries and mushrooms. All these food products are particularly important to local communities for their own consumption and/or for marketing further afield. However, it is recognised that these food services may not be as important as those in more intensively managed ecosystems at the European level. In heathlands and shrublands, the provision of food through livestock production was ranked as some importance due to lower productivity and stocking rates compared to other ecosystems (Bokdam and Gleichman 2000). Provision of fodder for livestock in heathlands and shrublands is principally for sheep, but also goats in drier regions (Fleischer and Sternberg 2006; Rodriguez et al. 2006; Rogosic et al. 2006), and game animals (Wessel et al. 2004; Stewart et al. 2005). Rivers and lakes are important sources of freshwater fish, crayfish and molluscs. In 2005, total inland water catches in all European countries and non-European EIFAC members (i.e. Cyprus, Israel and Turkey) amounted to 407,128 tonnes (Garibaldi 2007). Fish produced from wetlands, such as trout and carp, were ranked as some importance, though in Europe they are mainly produced in constructed ponds and wetlands (Květ et al. 2002). Seasonal wetlands and river floodplains also provide a valuable resource for livestock grazing as a result of the high biomass associated with these areas (Pott and Hüppe 1991).

The *provision of fibres* is a key contribution of agro-ecosystems. Fibre production (e.g. wool, cotton, silk, flax and hemp) was particularly important in Europe in the past, but many fibres are now imported from outside the EU, although sheep grazing remains a substantial activity as does flax production in Belgium and northern France (France, for example, produces around 86,000 tonnes of flax per year; FAOSTAT 2004).

Timber production and the *provision of wood fuel* is a key provisioning service of forests. European roundwood production in 2007 was 728 million m^3 (or 33.8% of global production; FAOSTAT 2009) and forest products are particularly important in the economies of the Nordic countries and Baltic States (EASAC 2009). The provision of biofuel is a key contribution of the agro-ecosystem. The EU 'biofuels directive' (Dir 2003/30/EC) set indicative targets of 5.8% of transport fuel to come from biofuels by 2010. To reach this target, 17.5 million ha of agricultural land would be needed, almost 20% of that currently available (EC 2007). The Energy Policy for Europe puts an obligation on each Member State to have 10% biofuels in their transport fuel mix by 2020. This target is expected to be met through the use of 'second generation' biofuels from timber, such as willow, rather than the current 'first generation' biofuels produced from crops, such as sugar beet and oilseed rape. Fuel provision from heathlands was ranked as some importance where shrubs and turfs can be used as a fuel source (Pardo 2002), and fuel extraction and prescribed burning also regenerate herbs for fodder while decreasing shrub dominance (Papanastasis 2004; Wessel et al. 2004). Many mountain rivers in Europe are dammed for hydropower generation and hence make a key contribution to energy supply (WCD 2000). Hydropower generation continues to increase in Europe (Lehner et al. 2009), influenced by an increasing trade in green energy. A wetland's ability to regulate and store water was ranked as being of some importance to the production of hydro-electric power by moderating and improving the constancy of water supply [e.g. the Veluwe brook systems (Jongman 1990) and the pond systems in Banska Ctiavnica in Slovakia (see http://www.fao.org/fishery/countrysector/naso_slovakia/en)].

The *provision of freshwater* is the principal service delivered by river and lake ecosystems. The contribution of river and lake biodiversity to this service is manifold, yet often indirect. Rather, abiotic characteristics of river ecosystems provide this service, whereas aquatic animals and plants account for regulating services (e.g. preventing deterioration or supporting rehabilitation of freshwater resources). The provision of freshwater was also ranked as a key contribution from mountain and forest ecosystems. In the Nordic countries, about 50% of the population uses drinking water originating from surface waters that primarily spring from forested catchments (Anonymous 2000). Wetlands were ranked as providing some contribution to freshwater provision because groundwater is extracted from below wetlands in remote areas of Europe from western Ireland to Belarus. Intensive agro-ecosystems have a negative impact on freshwater provision, as increasing nitrate levels in groundwater caused by fertilisers threatens the quality of drinking water, while the use of pesticides, phosphate, silage and slurry leakages lead to the contamination of water bodies, residues in water supplies and eutrophication (EEA 1995). Furthermore, erosion of soils can clog up waterways, and ammonia emissions, of which 90% originate from agriculture, cause increased levels of nutrients in rain water.

Relative to other provisioning services, *ornamental resources* were not found to be highly important. Indeed, changes in attitudes and trade regulations across Europe and globally (e.g. the CITES Convention, www.cites.org) mean that demand for some ornamental resources has declined, such as displays of rare butterflies, birds and mammals, and this is to be welcomed. Nevertheless, many European terrestrial and freshwater species can be ranked as being of some ornamental importance. Hunting trophies of game animals and fish are still cherished in some communities, which may be acceptable as long as the species concerned are not threatened. Also, many plant species are ornamental in gardens and parks, such as alpine species (e.g. edelweiss) or aromatic shrubs or other plants from the Mediterranean, such as lavender, rosemary and olive trees. As the climate changes, southern plant species may become increasingly important, especially in gardens further north in Europe (Bisgrove and Hadley 2002). However, these ornamental resources are currently not exploited to their full potential as gardening has often relied on exotic species (Lambdon et al. 2008). Increased public awareness about the ornamental potential of European native species is needed.

The importance of global biodiversity in the development of *biochemicals and natural medicines* is well established with the majority of prescribed medicines in the United States and as much as 80% of all medicines used in developing nations being derived from plant and animal species (Chivian and Bernstein 2008). However, the contribution of most European ecosystems to the provision of biochemicals/natural medicines is poorly studied and our ranking was generally based on expert opinion (RUBICODE 2008b). All terrestrial ecosystems were ranked as providing some contribution to biochemicals/natural medicines. For example, medicinal plants are provided by mountains (e.g. arnica and many others; Planta Europa and Council of Europe 2002) and species-rich semi-natural grasslands (e.g. Michler and Arnold 1999), while agro-ecosystems provide basic materials for luxury products such as perfumes. Mediterranean shrubs, such as rosemary (Mulas and Mulas 2005) are being screened for their potential to provide essential oils and, like many other Mediterranean species, rosemary is a culinary herb. *Opuntia* scrub is important in hosting cochineal insects which are a source of carminic acid, a natural dye used in the food, textile, and pharmaceutical industries (Rodriguez et al. 2006). Activities to identify new sources of established biochemicals and discover novel biochemicals are anticipated to increase and may create new high-value industries (EASAC 2009).

Genetic resources were ranked as being of key importance in forests, semi-natural grasslands, heathlands and shrublands, and mountains. However, knowledge is limited on the full potential of genetic resources and many are still unrecognised or untapped. In particular, natural rangelands (Fleischer and Sternberg 2006) and semi-natural grasslands (van der Maarel 2005; Skórka et al. 2007) are among the most genetically diverse ecosystems in Europe. They are not only rich in species, but also rich in genetic variability within plant species (Prentice et al. 2006) and within and between insect species, such as Large Blue butterflies (*Maculinea arion*) (Als et al. 2004; Thomas and Settele 2004). Agro-ecosystems were ranked as providing some contribution to genetic resources. Over large areas, genetic diversity within crops becomes increasingly important in order to cater for a variety of end uses, to cope with spatially and temporally variable conditions and to provide resilience. It is also critical for supporting future crop breeding programmes. The same is true for the genetic resources of the non-cropping parts of agro-ecosystems. Yet this service has been eroded through landscape simplification (Thrupp 2000; Jackson et al. 2007) and its extent and importance are still poorly known. Rivers and lakes should also provide genetic resources, but little is known about the extent, and knowledge of genetic diversity in soil systems is poor.

Regulating services

Among regulating services, *pollination* was ranked as being of key importance in agro-ecosystems, forests, semi-natural grasslands, and heathlands/shrublands. The annual economic value of insect pollinated crops in the EU is about €15 billion (10% of the annual economic value for all food production) (Gallai et al. 2009). Particularly reliant on insect pollination are fruits, vegetables, edible oil crops and nuts: 30% of the 60 million tonnes of fruits, 7% of the 65 million tonnes of vegetables, 8% of the 32 million tonnes of edible oil crops and 48% of the 0.82 million tonnes of nuts produced in the EU depend on pollinators (2005 figures; Gallai et al. 2009). Plants with traits which encourage the timely presence of pollinators on farms are of great importance, and can be promoted by appropriate management techniques, although mechanisms are still poorly understood. These plants are sometimes present in an adjacent ecosystem and hence provide a cross-ecosystem service. For example, semi-natural grasslands and heathlands/shrublands harbour diverse communities of natural pollinators (Potts et al. 2006), but reductions in their area and an increase in intensively managed land is leading to a decline in pollination services in agricultural landscapes (Tscharntke et al. 2005; Biesmeijer et al. 2006; Öckinger and Smith 2007). In order to sustain the abundance and diversity of insect pollinators, preservation or re-creation of semi-natural habitats, including flower-rich grasslands, forest edges and hedges are essential. Pollination was ranked as some importance in mountain ecosystems because a large proportion of alpine herbs depend heavily on sexual reproduction (Forbis 2003) and recruitment of alpine vascular plant flora is dependent on a sufficiently abundant and diverse pollinator community (Körner 1999).

Seed dispersal was ranked as a key service in only one ecosystem, forests. For example, Hougner et al. (2006) described the seed dispersal service provided by Eurasian jays (*Garrulus glandarius*) in the oak forest of the Stockholm National Urban Park, Sweden (Luck et al. 2009). All other ecosystems had seed dispersal ranked as being of some importance based on expert opinion. Some published evidence was available for Mediterranean ecosystems where vertebrate-dispersed species account for 32–64% of local woody species richness and 20–95% of woody plant cover (Herrera 1995). Other studies report significant decreases in dispersal events among patches of semi-natural habitat in northwest (Bruun and Fritzbøger 2002), central (Poschlod and Bonn 1998) and southern Europe (Manzano and Malo 2006). This is related to changes in livestock husbandry, particularly dramatic decreases in the freedom of movement of livestock. River ecosystems provide an important vector for plant and animal dispersal, such as the distribution of plants through river corridors in the Central European lowlands. However, this has also led to the introduction of non-native species and many riparian areas and floodplains along European waterways are dominated by exotic plants [e.g. Giant Hogweed (*Heracleum mantegazzianum*; Jahodova et al. 2007) and Japanese Knotweed (*Fallopia japonica*; Tiebre et al. 2007)].

Pest regulation is a key service of agro-ecosystems and soil systems. Evolutionary interactions between crops and their pathogens mean that any improvements in crop resistance through breeding programmes are likely to be transitory and greater crop diversity and integrated pest management should play increasingly important roles alongside biotechnology (Tilman et al. 2002). Biological control of pests is dependent on the presence of appropriate flora to provide shelter for the biocontrol agents and to support alternative prey at times when these are not provided by the crop itself (Wratten et al. 1998; Landis et al. 2000; Zehnder et al. 2007). Such flora may exist in adjacent semi-natural grasslands and such habitats may also contribute some pest regulation services through resisting outbreaks of newly-introduced pests (Květ et al. 2002; Tscharntke et al. 2005). In soil systems, plant diseases may be decreased by the selective feeding activity of soil fauna on pathogenic micro-organisms (e.g. Koehler 1999; Shiraishi et al. 2003; Cole et al. 2006). Plant pathogens, such as bacteria, fungi or plant parasitic nematodes, can be controlled by micro-organisms living in the rhizosphere (e.g. bacteria and symbiotic mycorrhizal fungi) (Azcón-Aguilar et al. 2002). Moreover plant parasitic nematodes can also be controlled by soil-borne nematophagous fungi (Lavelle and Spain 2001). Physical conditions and topography in mountains may act to influence pest and disease regulation, for example, fox distribution patterns and the potential for spread of rabies in the Bavarian Alps (Berberich and d'Oleire'-Oltmanns 1989; Haslett 1990) or ticks carrying lyme disease in the Northern Italian Alps (Rizzoli et al. 2002), though there are few studies on the dynamics of other such organisms in European mountains.

Invasion resistance is a key service delivered by semi-natural grasslands, since these ecosystems are among the least invaded in temperate Europe (Pyšek et al. 2002; Chytry et al. 2008). Heathlands and shrublands also make a key contribution to invasion resistance, as their nutrient poor status might limit the expansion of exotics, which are often plants of high fertility sites (Alpert et al. 2000). Forest ecosystems were considered to contribute some resistance against invasion, although evidence is lacking and inconsistent (Martin et al. 2009). Although mountains appear to present a clear physical barrier to many organisms, their role in invasion resistance remains unclear. Ecosystems which are strongly influenced by human activity often have the greatest risk of invasion, such as large scale intensive agro-ecosystems, which were ranked as having a negative impact on resistance to invasive organisms (Pyšek et al. 2005). Rivers and riparian areas could also act as migration pathways for non-native (exotic) species. Large navigable rivers have become major pathways for aquatic invasions due to increasing ship traffic and the transport of multiple non-native stowaways attached to ships or contained in ballast water (Minchin 2007; Arbačiauskas et al. 2008; Panov et al. 2009).

Climate regulation was ranked as being of key importance in forest, mountain, soil and wetland ecosystems. Forests play an important role in the global carbon cycle and contribute to climate regulation through the long term storage of carbon in forest soils and woody biomass. However, there remain many unknowns about the net carbon balance of European forests. Estimates range from a source of 100 Tg C year^{-1} to a sink of 460 Tg C year^{-1} (Lindner et al. 2004). European forests differ in their ability to act as net carbon sinks, depending on management intensity and policy. Articles 3.3 (mandatory afforestation, reforestation and deforestation) and 3.4 (optional forest management strategies for carbon sequestration) of the Kyoto Protocol recognise that forest management can influence the carbon balance. In Europe, 17 countries with large expanses of forest have elected forest management under Article 3.4 (see Nabuurs et al. 2008). Large mountain forests (e.g. Pielke et al. 1994) and large forested floodplains (e.g. along the Danube) also provide a key contribution to climate regulation. Wetlands are vital net carbon sinks, particularly bogs in Scandinavia, Russia, Scotland and Ireland, and may account for as much as 40% of the global reserve of terrestrial carbon (Sheng et al. 2004; Silva et al. 2007). However, bog and peatland systems only remain carbon sinks when in good status. When damaged, drained or burnt, or when peat is extracted for fuel, peatlands turn from being net carbon sinks to net carbon sources as has happened in northern Germany, the Netherlands and is still happening in Poland, the Baltic states and Ireland (Nivet and Frazier 2004; Sheng et al. 2004). In soil systems, climate regulation is delivered by carbon sequestration in stable biogenic macroaggregates, mainly due to earthworm burrowing and casting activities (Hedde et al. 2005; Jiménez and Lal 2006; Lavelle et al. 2006). However, in Europe, estimates of soil organic carbon loss of 15% from arable and rotational grass soils, 16% from soils under permanent managed grassland and 23% from soils on agriculturally managed, semi-natural land are cited in EASAC (2009). Semi-natural grasslands and heathlands/shrublands make some contribution to regulating the climate, but biomass production and carbon sequestration tends to be modest due to nitrogen and phosphorus limitation (Rogers et al. 1988; Niklaus and Körner 2004). At present, agro-ecosystems contribute negatively to climate regulation through the emission of methane (NH_4, around a quarter to one-third of emissions in Europe stem from livestock) and nitrous oxide (N_2O, from use of fertiliser and denitrification) (EEA 1995). Further, agricultural soils tend to have low carbon stores due to intensive production methods, but higher organic matter input and the introduction of zero or conservation tillage could improve the carbon sequestration potential of cultivated soils (EASAC 2009).

Air quality regulation was ranked as being a key service of forest ecosystems, but the effects of forests on air quality outside the tropics are not fully understood (MA 2005b). Mountains extract water from the rising air masses passing over them which feeds back to regulate the regional climate, and the air mixing also contributes to air quality regulation. Agriculture was ranked as providing a negative service to air quality regulation due to emissions of nitrogen oxides (NO_x) from cultivated soils which increases tropospheric ozone (Tilman et al. 2002), ammonia (NH_3) from livestock farming and manure applications, and pesticide drift which can result in the long-distance atmospheric transport of pesticides (EEA 1995).

Erosion and natural hazard regulation were ranked as being of key importance in mountain ecosystems. Due to their topography and often slow-forming, fragile soils, high mountain landscapes are especially vulnerable to irreversible physical changes precipitated by human activities. The instability of upslope areas has a multitude of detrimental effects to human welfare even in the lowlands, including, for example, floods or mud slides, which are often widely publicised (Stone 1992). The only means of securing upslope stability is intact mountain vegetation (Körner 2002), which is likely to be threatened especially by climate change (Grabherr 2003; Nagy and Grabherr 2009). Forest ecosystems also make a key contribution to erosion regulation with deforestation often resulting in erosion and flooding (Bradshaw et al. 2007), although some studies have shown that deforestation has a minor effect on flooding (e.g. Mudelsee et al. 2003). Well managed grassland and heathland/shrubland ecosystems were ranked as providing some contribution to erosion (Boeken and Orenstein 2001; Rodriguez et al. 2006) and natural hazard regulation (Scott et al. 1998) under particular conditions like steep slopes (Quétier et al. 2007).

Rivers, lakes and wetlands fulfil key regulating functions with respect to the quantity and quality of freshwater. The Rhine system, for example, includes several lakes and wetlands that play a role in *water retention and regulation*. Functioning floodplains (literally) serve human well-being in that they provide the area to retain floods and to balance the hydrograph including during low-flow conditions (summer drought period). Microbial communities (bacteria and fungi) are the main processors of organic sewage and regulate *water purification* in rivers (Spellman and Drinan 2001). The extensive eutrophication of rivers by plant nutrients originating from agricultural practices is regulated by their floodplains (if present and functioning) and by riverine plants and other primary producers. Gren et al. (1995) estimated the value of this service provided solely by the Danube floodplain to be equivalent to €650 M. The riparian vegetation at the transition of the river and its floodplain is key to buffering sediments, pollutants and nutrients from adjacent areas. Width, density and zonation of riparian vegetation determine retention effectiveness (Dosskey 2001; Correll 2005). In temperate and boreal regions of the northern hemisphere the storage of sediment (and of water and organic matter) in upstream reaches is greatly enhanced by beavers (*Castor fiber*) (Naiman et al. 1986).

Water regulation and purification were also ranked as being of key importance in soil systems. Soil fauna burrowing and casting activities contribute to the creation of surface roughness and the maintenance of stable porosity, which play a critical role in regulating water runoff and water retention in soils (e.g. Langmaack et al. 2001; Leonard and Rajot 2001; Lavelle et al. 2006). Further, the buffer capacity of soils via adsorption processes of colloidal particles (Sipos et al. 2005), as well as direct biodegradation of organic compounds through bacterial activities, helps to prevent water contamination in terrestrial and freshwater ecosystems.

Mountains store water in glaciers, snowpacks, soil, vegetation and underground aquifers, and regulate water flow by modulating the run-off regime and groundwater seepage. Mountain ecosystems are also important for water purification. Results from the study of moss mats in arctic systems (Jones et al. 2002) indicate that the alpine moss flora, which is especially threatened by climate change and nitrogen deposition, may be particularly important for providing this service. The role of semi-natural grasslands in the provision of water purification is poorly known. A recent experimental study by Phoenix et al. (2008) indicates that grass-rich semi-natural grassland turf may reduce the leaching of nitrogen from the soil and thus potentially buffer the effects of nitrogen pollution on groundwater. At present, agro-ecosystems contribute negatively to water quality (Stoate et al. 2001), although effects are poorly understood and options for future positive contributions exist (e.g. combining reed as a biofuel crop with its role in water purification).

Cultural services

The shear extent of agricultural landscapes, and the role they played historically in providing work and housing, makes their cultural heritage and sense of place values key contributions to the well-being of a large part of the population. Recreation and ecotourism are also of key importance in agro-ecosystems. A Eurobarometer survey on “Europeans on Holiday (1997–1998)” showed that 23% of Europeans chose the countryside as their most preferred tourism destination (EC 1998) and “new” forms of tourism in rural and regional settings are emerging and growing almost three times as fast as the classic tourism market (EC 2002a). Fleischer and Tsur (2000) and Pouta (2006) also provide examples which illustrate how agricultural landscapes attract tourists. This trend is linked to the aesthetic and cultural historic values of landscapes (EC 2002a). No evidence on the role of other cultural services, particularly education/inspiration and spiritual/religious values was found for agro-ecosystems, but the expert group thought that they would have some contribution, particularly in older traditional landscapes with a strong cultural heritage.

In Europe, the forest ecosystem has had a strong impact on cultural life, and aesthetic values, recreation/ecotourism and education/inspiration were ranked as key cultural services. Recreation or exercise in the form of forest walks is particularly important as highlighted in a recent meta-analysis by Zandersen and Tol (2009) who concluded that Europeans on average spend €4.52 in travel costs per forest trip. Spiritual/religious values, cultural heritage and sense of place were ranked as some contribution by the forest expert group. In the past, forests have been intrinsically linked to myths of many European societies (Larousse 1975) and they are still an important element in aboriginal cultures. For example, the Sámi in northern Europe consider forests important not only for their livelihood and reindeer herding, but also for their spiritual values and links to the land. Most European communities are still linked spiritually and emotionally to the land and forests, for example, the Swedish “allmänsrätt” (everyone’s right) allows public access anywhere in the countryside (apart from private gardens) and is a reflection of this relationship.

The importance of cultural services provided by semi-natural grasslands is unequivocally high with respect to cultural heritage, education, recreation, aesthetic and sense of place values. Semi-natural grasslands have developed under the impact of traditional agriculture and the landscapes they are part of may be valued as cultural heritage (WallisDeVries et al. 2002; Poschlod et al. 2005; Quétier et al. 2007). Diverse semi-natural grasslands with their many charismatic plant, bird and insect species (WallisDeVries et al.

2002; Moora et al. 2007; Aavik et al. 2008; Settele and Kühn 2009) serve as focal points for local tourism and ecotourism in particular, enabling inhabitants to enjoy their aesthetic values. Protected grassland areas provide a framework for ecotourism and education, particularly with the help of informative exhibitions, nature trails and guided walks. For instance, the Öland Research Station Linneaus located in the 'Great Alvar', Sweden, which is the largest north European calcareous grassland (Rosén and Borgegard 1999), has become an attractive and frequently visited information centre providing knowledge of nature and cultural values related to grassland ecosystems and traditional landscapes (http://www.portentillalvaret.nu/). Even if local inhabitants only know about a particularly interesting and endangered element in the grasslands of their direct surroundings, it is the combination of "knowledge system" and "sense of place" which creates a surprisingly high willingness to pay for the maintenance of grassland management (Wätzold et al. 2008).

Heathlands and shrublands also make a key contribution to all cultural services, apart from spiritual and religious values, which are expected but poorly known. In many countries they are viewed as important cultural landscapes and may contribute to a sense of place (Wessel et al. 2004; English Nature et al. 2006). They have also inspired writers like Thomas Hardy and artists such as J.M.W. Turner. Recreation and tourism can be important services (Wessel et al. 2004; Fleischer and Sternberg 2006), as illustrated by the economic impact of the 2001 foot and mouth disease epidemic in the UK which closed large areas of the uplands, including some heathlands, to tourism and was estimated to cause a drop in GDP of £3.3 billion (EASAC 2009). Species with high conservation status, such as the Iberian lynx (*Lynx pardinus*) in southern Spain, increase the recreation and ecotourism value of heathlands and shrublands (van den Berg et al. 2001; Lozano et al. 2003) and may contribute to their aesthetic value.

The cultural services provided by mountains are manifold. Mountains may have spiritual or religious values for local inhabitants and/or serve as places of pilgrimage (Bernbaum 1997; Price et al. 1997). However, religious values in mountains are not considered key in Europe although they can vary by location. For example, many monasteries in Greece and Spain are in mountain regions, while the Croagh Patrick mountain in Ireland is a place of pilgrimage and religious tourism. Humans have inhabited and used mountains for so long that traditional mountain ways of life and the landscape mosaics that have been created result in a strong sense of place and cultural heritage (Messerli and Ives 1997; Körner et al. 2005). The Alps and other European mountains serve as focal points of international tourism (Stone 1992; Price et al. 1997), to the extent that human use in this way is now often detrimental and even destroys those services that originally attracted visitors [e.g. winter sports such as skiing (Wipf et al. 2005), climbing (Hanemann 2000), walking and biking]. With ever-increasing demand across Europe, identification and conservation of the species and landscape features most relevant to such services are essential for promoting sustainable mountain ecotourism. Species diversity, with many endemic or charismatic animals and plants (Nagy et al. 2003), together with spectacular landscapes, are of strong aesthetic value. The associated National Parks, UNESCO Biosphere Reserves and other protected areas in mountains provide a structured setting for ecotourism and also have an important role in education and awareness (e.g. Price 1995; IUCN 2009).

Humans have been attracted and inspired by rivers and lakes for millennia. At the European scale, however, the religious worship of rivers is insignificant. Rather, rivers and lakes play a significant role in various kinds of recreational activities, such as bathing, rafting, canoeing, angling, hiking, photography or wildlife viewing. In general, the nearnatural and most diverse sections of rivers are more attractive to people due to their high aesthetic value coupled with a sense of wilderness. These areas are often in the upper reaches of rivers and are connected to the cultural services described earlier for mountains. Particular riverine organisms (mainly fish and crayfish) and birds are of economic importance for ecotourism and related local businesses (e.g. travel, lodging, accommodation and licensing) as illustrated by Everard (2004) who provides an overview of the significant economic benefits of rural areas from sport anglers. Educational aspects of rivers and lakes are addressed by National Parks and other large protected areas, where nature trails and information centres are used to inform the public about nature and natural processes. The inspiring value of river ecosystems is well documented by a comprehensive body of arts (e.g. paintings, drawings and dioramas) dating back several hundreds of years. Meander patterns frequently used in ancient mosaics and pottery, for example, were originally derived from meandering rivers and have been documented since the New Stone Age.

Wetlands also have important functions in many cultures in the world. How these cultural services are valued depends on the community, varying from the sacred source of life to the permanent threat of dangerous nature, which is often the case for bogs. Aesthetic values, sense of place and recreation/ecotourism were ranked as being of key importance for wetlands. People are attracted by the beauty of wetlands, as can be seen in paintings of the Dutch painters through the centuries. Numerous tourists go to the Camargue, the Danube delta and the Coto Doñana. Possibly one of the most attractive landscapes of Europe is the Pripjat and Polesia region in Belarus and northern Ukraine. Spiritual and religious values were ranked as some importance as there are a few examples of European cultures where wetlands or water have a spiritual significance; for example, in north-western Europe, the story tellers tell about the bogs and wetlands where ghosts, witches and dwarfs live.

Trends in European ecosystem services

Trends in the human use and status of services in Europe provided by each terrestrial and freshwater ecosystem are shown in Figs. 1 and 2, respectively. Trends are divided into increasing, decreasing or mixed for human use and enhanced, degraded or mixed for status using the same definitions as the MA (2005a). The MA identified trends for a single time frame from 1950 to 2000, although if the trend had changed within that time frame they indicated the most recent trend (MA 2005a). Analysis of the information for Europe from the literature review and expert opinion revealed that opposing trends were often exhibited in the distant past to the recent past. Hence, trends were divided into two time periods: 1950–1990 and 1990 to present. European trends are compared with the global trends reported by the MA in the discussion section. The evidence presented represents Europe as a whole, although if trends differ across European regions this is entered as "mixed" in Figs. 1 and 2 and described in the relevant sub-sections. The availability of evidence varied considerably between ecosystems and services within ecosystems. For example, direct evidence from the literature was found for many services in agricultural, forest and river ecosystems and supporting statistics were available for most provisioning services. On the other hand, very little direct evidence from the literature was found for services in semi-natural ecosystems, such as semi-natural grasslands, heathlands/shrublands, wetlands and mountains, and trends were mainly based on expert interpretation of proxies such as trends in habitat area or condition per unit area across Europe.

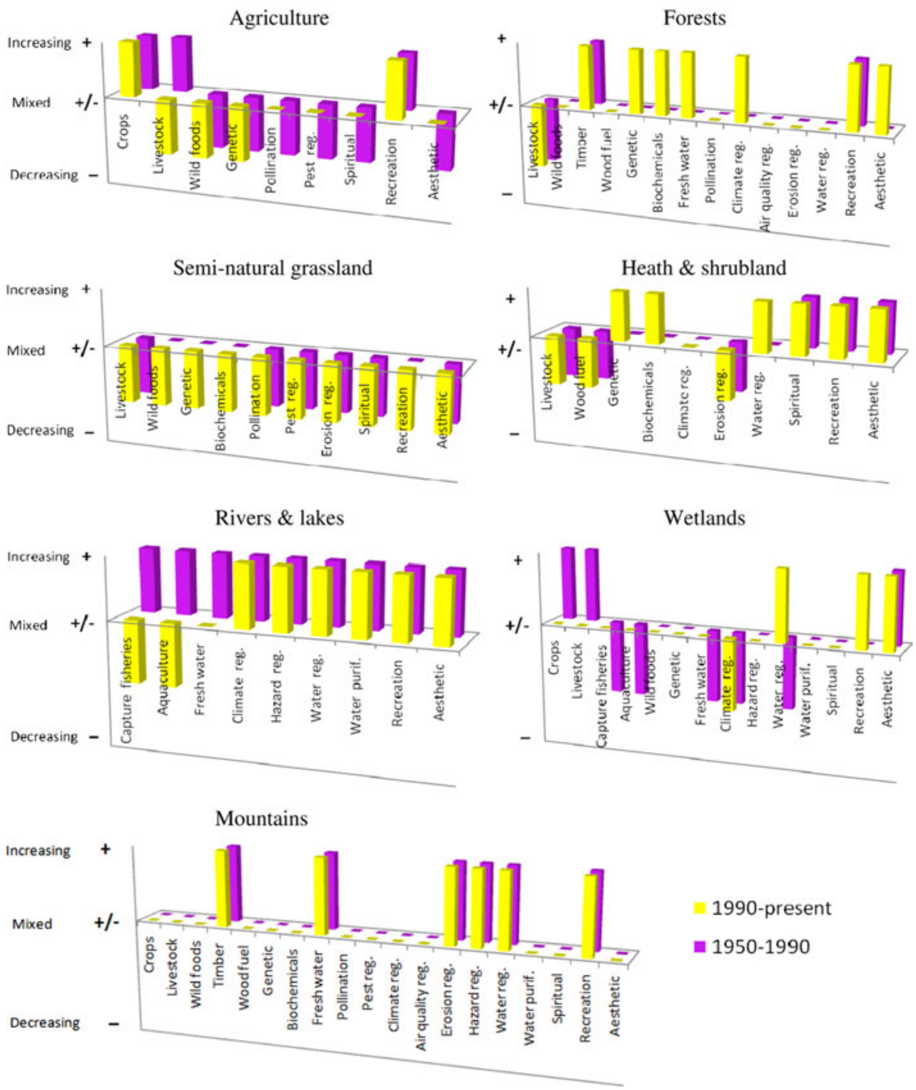

Fig. 1 Trends in the human use of European ecosystem services. For provisioning services, human use increases if the human consumption of the service increases (e.g. greater food consumption); for regulating and cultural services, human use increases if the number of people affected by the service increases (MA 2005a). Mixed refers to mixed trend across Europe

Agro-ecosystems

Human use and status of crops and livestock produced by agro-ecosystems increased dramatically between 1950 and 1990 (Figs. 1, 2). One of the most important developments for Europe, resulting from the renewed demand for food security after the Second World War, was the introduction of the common agricultural policy (CAP) in the newly formed European Community. This led to a 'green revolution' with such an increase in productivity that food security could be guaranteed by comparatively few farms in a relatively

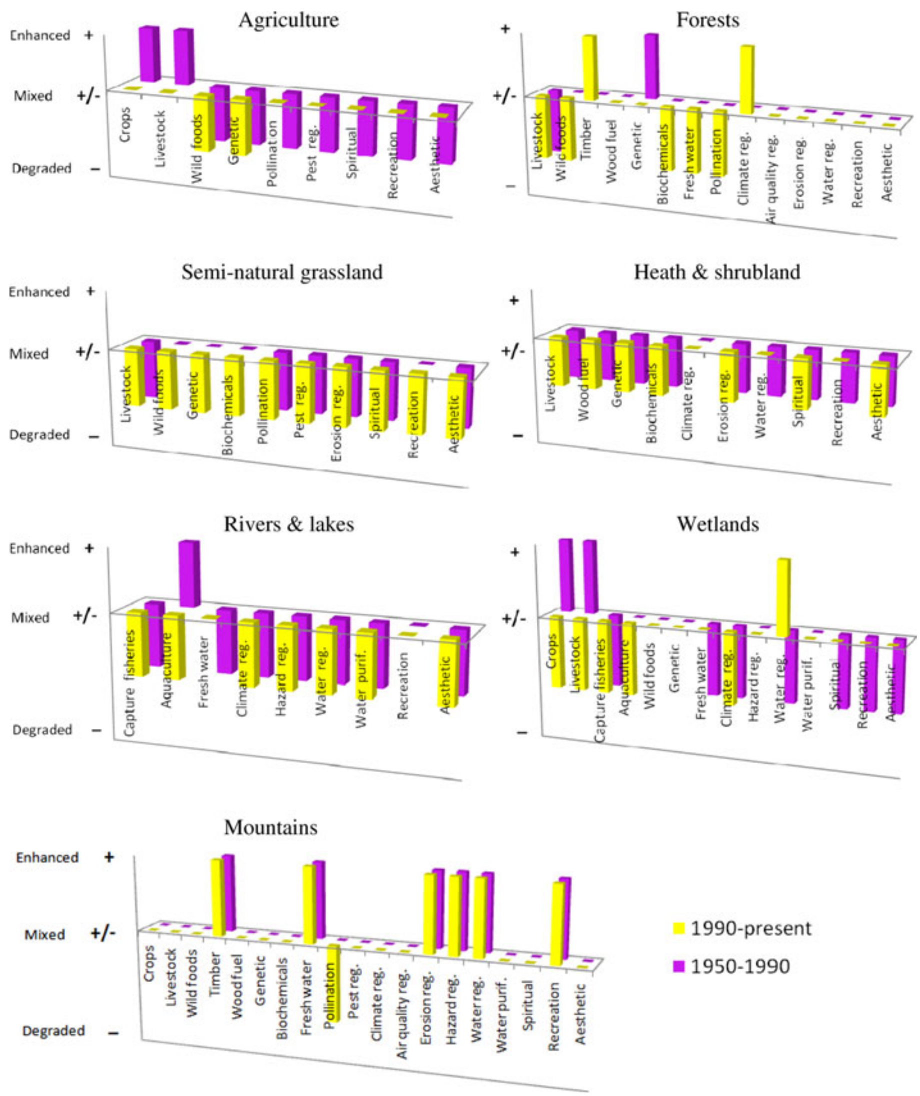

Fig. 2 Trends in the status of European ecosystem services. Enhancement refers to increases in production area or amount, or a change in service which leads to greater benefits for people, while degradation refers to current use exceeding sustainable levels or a reduction in the benefits for people either through a change in the service or through human pressures on the service exceeding its limits (MA 2005a). Mixed refers to mixed trend across Europe

small area, but also to overproduction (e.g. cereal production rose from 94 to 115% and butter production from 97 to 134% of domestic consumption from 1975 to 1989; Rabbinge and van Latesteijn 1992) and significant pollution and environmental problems (MA 2005b; Koning 2006). In the mid 1980s, concern about the environmental side effects of the agricultural opulence began to surface (see EEA 1995), resulting in revisions to the CAP in 1992 (reduced guaranteed prices for cereals, beef and veal, production limits for some commodities, and introduction of specific measures to encourage environmentally friendly farming) and 1999 (CAP was reorganised into a 'market policy' and a 'sustainable development of rural areas' pillar) (Leguen de Lacroix 2003). For the period from 1990 to present, the effect of the last reforms of the CAP and EU rural development policy (EEA 2007) has resulted in a mixed trend for the status of crop and livestock production across Europe. The fourth assessment of Europe's environment shows important improvements concerning the environmental impact of agriculture, such as decreasing use of fertiliser and pesticides and decreasing livestock numbers (EC 2002b; EEA 2007), but it also expresses continuing concern.

EUROSTAT statistics between 1950 and 1990 (Jerabek 1999; Vidal 1999, 2000) and the first assessment of Europe's environment by the European Environment Agency (EEA 1995) show substantial increases in farm and field sizes and the intensity of agricultural land use as well as a loss of non-productive landscape elements. These changes are directly related to losses of biodiversity within agricultural landscapes (Birdlife International 2004; Billeter et al. 2008), and explain the degraded status of wild foods, genetic resources, pollination and pest regulation services (Fig. 2). However, renewed appreciation and concern for pollination and pest regulation services post 1990 results in a mixed trend where services are still decreasing in areas with intensive agriculture, but are increasing in extensified and restoration areas.

The, as yet unpredictable, need for, and effects of, biofuel production may be a very important factor determining the future environmental impact and service delivery of agro-ecosystems (EEA 2007). To avoid competition with food crops, biofuel targets should be increasingly met by 'second generation' biofuels from crops that can be grown in marginal areas (EC 2007). The area requirements resulting from this could threaten low intensity farming systems with high biodiversity value, which are at present already vulnerable to rapid change and degradation (Beaufoy et al. 1994). Glendining et al. (2009) also showed for the UK that larger area requirements resulting from agricultural extensification can result in decreasing sustainability, due to the loss of ecosystem services provided by the natural land that would need to be converted.

The large-scale simplification of landscapes caused the degradation of cultural services provided by agro-ecosystems between 1950 and 1990. In many parts of Europe this process is on-going, but the increasing importance of agro-tourism (Fleischer and Tsur 2000; Pouta 2006), linked to an appreciation of the aesthetic value and cultural heritage of old and relatively intact agricultural landscapes (EC 2000, 2002a), explains the mixed trend across Europe from 1990 to present for these services (Fig. 1). The only exception to the mixed trend is recreation, which was virtually absent in 1950 and hence could only increase.

Forests

Overall, European timber production has increased since 1950. The annual increment of forest available for wood supply between 1950 and 2000 increased in western Europe by 87% or 234 million m^3 overbark (ob), and in eastern Europe (excluding the Baltic states and some countries of the former Yugoslavia) by 45% or 57 million m^3 ob (FAO 2005). However, losses in forest area in some regions result in a mixed status for the pre 1990 period (Fig. 2). Human use of forests also varies between regions (Fig. 1). In some areas, especially in northern Europe, forest products are in great demand resulting in active forest management and tree plantations on former arable fields. In other regions, especially the Mediterranean area, the use of forests for fuel, shelter and protection against erosion has decreased significantly during the last century (Biagioli 2006). Forest status has generally been enhanced since 1990 with the last decade in particular showing an increasing re-growth of forests (Velders 2003). This, combined with reforestation and afforestation programmes across Europe, has resulted in an increased status of carbon sequestration (Bonan 2008). Livestock production in forest ecosystems has decreased in both time periods due to cessation of forest grazing except for small scale nature conservation purposes. Human use of other provisioning services, such as genetic resources (Lefèvre 2004), biochemicals/natural medicines and freshwater, cultural services (recreation, ecotourism and aesthetic values; Bell et al. 2007) and one regulating service (climate regulation) show an increasing trend from 1990 to present (Fig. 1). Use of wood fuel for bioenergy has also increased across most of Europe (Wright 2006), except the Mediterranean region (Biagioli 2006). However, the provision of wild foods, biochemicals and natural medicines and freshwater, in addition to pollination services, have become degraded between 1990 and present (Fig. 2) as natural habitats are under increasing pressure (MA 2005b) and forest condition has generally declined in Europe (Lorenz et al. 2005). The status of all other services shows a mixed trend related to afforestation and deforestation patterns which vary between European regions (Gold et al. 2006).

Semi-natural grasslands

Human use of all services from semi-natural grasslands has either declined or shows a mixed trend because the number and size of semi-natural grasslands have dramatically declined in Europe (Fig. 1). This is related to the abandonment of traditional small-scale farming during the last century and the intensification of agriculture, resulting in the conversion of some semi-natural grasslands to either cultivated permanent pastures or hayfields (Willems 2001; WallisDeVries et al. 2002; Poschlod et al. 2005). Unfortunately, there are no valid EU-wide statistics on the area of semi-natural grasslands as they are lumped into the category 'permanent pastures' which mostly contains intensively managed cultivated monospecific grasslands. In Estonia, approximate statistics show that only about 100,000 ha remain (about 6–7%) of around 1,500,000 ha in the late 1930s (Aug and Kokk 1983; Pärtel et al. 1999). Remaining grasslands often suffer due to intensive land use, irregular management (Dullinger et al. 2003; Alard et al. 2006) or eutrophication via air pollution (Bobbink et al. 1998; Huhta and Rautio 2005), resulting in impoverishment of species communities and disappearance of many typical grassland species (de Bello et al. 2009). This has resulted in the degradation of the ecosystem services provided (Fig. 2), although there are only a few papers addressing specifically ecosystem services provided by grasslands (Quétier et al. 2007). Mixed trends are shown for some services as their value considerably increased after the 1950s, but at the same time there was a dramatic decline in area. More recently, European agri-environment schemes encourage farmers to create species-rich grasslands on arable land (Pywell et al. 2002) or agriculturally improved pastures (Pywell et al. 2004) resulting in small local increases in the area of semi-natural grasslands.

Heathlands and shrublands

Human use of heathlands and shrublands for livestock production has declined over all time periods because modernisation has led to declining use of extensive rangelands and grasslands in the last few decades (Rook et al. 2004) and increases in agriculture and urbanisation have led to their transformation into croplands and urban areas (Fig. 1). Use of other services, such as wood fuel and erosion regulation, has also decreased as Europe is estimated to have lost about 90% of its heathlands (Web 2005), although this figure varies between countries and regions (Piessens and Hermy 2005). These large losses in area mean that the status of almost all services has been degraded over both time periods (Fig. 2). The interaction of broadscale environmental drivers (e.g. land use changes and atmospheric pollution), management and local ecological processes, result in significant changes in ecosystem composition, condition and functioning, and in the delivery of associated services.

In contrast, human use of other services, such as genetic resources and biochemicals/natural medicines, has increased since 1990 and is expected to become more important in the future for the development of alternative and natural medicines. However, this was based on expert opinion only. Cultural services from heathlands and shrublands have also been used to a greater extent over both time periods due to a combination of habitat losses leading to greater appreciation and increasing trends in recreation (Wessel et al. 2004). Habitat restoration and re-creation in the 1990s, partly to fulfil conservation objectives (e.g. EU Habitats Directive), has meant that some, especially cultural, services are being enhanced in a few regions of Europe.

Mountains

There are great variations in the human use and status of different services between mountain regions in Europe. For example, considerable regional differences arise in peoples' attitudes, values and available resources between western Europe and post-socialist Europe (e.g. Svajda 2008; Szabo et al. 2008). Thus, spatio-temporal trends are mixed, with little distinction between pre and post 1990 periods (Figs. 1, 2). However, there are a few important services that may be exceptions to this and appear to exhibit overall patterns. Demand for timber from mountain forests in Europe has been vast over the last centuries, and remains so today (Hamilton et al. 1997). The MA reports that there has been an overall expansion of natural forest area of 1.2% in the temperate regions of the world between 1990 and 2000, mainly as a result of increasing forest cover in the mountainous countries of Europe (Körner et al. 2005). Similarly, as human demands for clean freshwater continue to increase, mountains remain central to the provision of this pivotal resource (Körner et al. 2005). The need for sustainability of water from mountains is now appreciated, and water regulation not only for human consumption but also to meet industrial needs and energy provision has generally been enhanced. Recreation and eco-tourism have increased dramatically over the last half century. The industry is complex, involving both foreign and domestic visitors. The widespread increases in service use may be attributed to a range of factors, from attractiveness of the region and improved accessibility to the characteristics of the tourists themselves and the expansion of the range of leisure activities (Price et al. 1997). Increases in recreation and tourism have been responsible, to varying extents, for parallel (necessary) increases in regulating services on mountains that deal with natural hazard regulation (e.g. avalanches, landslides, floods) and general erosion regulation. A last group of ecosystem services that appears to show a trend, this time in a negative direction, is that provided by pollinators. Though there is little or no documentation specifically for European mountain ecosystems, the recent global decline (including Europe) of wild and managed pollinator species, involving both wild and crop plant species in all types of environments (e.g. FAO 2008) implies a seriously degraded status of pollination services in recent years. The importance of this trend is not to be underestimated, as pollination services regulate and are essential for the provision of many of the other services in mountain ecosystems.

Rivers and lakes

Net abstraction of freshwater from rivers and lakes in Europe has increased over the past 50 years, although a slightly reversed trend has been obvious since 1990 (EEA 2005) (Fig. 1). Urban and agricultural expansion over the past few decades were inevitably linked with an increasing consumptive (e.g. food, cooking and sanitation) and non-consumptive (e.g. irrigation, hydropower and cooling) use of freshwater resources. The total freshwater abstraction is still at a high level in Europe, and the decreasing trend of cooling water withdrawal in Central Europe will probably be masked by an increasing demand for irrigation water in Mediterranean countries (EEA 2005). Human use of freshwater capture fisheries and freshwater aquaculture in Europe increased between 1950 and 1990, but then slightly decreased after 1990 (EEA 2005). This decline is presumably simply the result of a declining supply of natural and aquacultural freshwater fish—unlike the dramatically increasing demand for maricultural fish in Europe. Human demand for natural hazard and water regulation, specifically flood protection, has increased since 1950, in particular in the large cities along major European waterways. Demand for cultural services, specifically recreation and ecotourism, has significantly increased during the past decades and continues to increase. It is expected that, due to the infrastructural development of large reserves and their increasingly acknowledged economic value for tourism, this trend will continue to increase in the future and will pose a major threat to freshwater ecosystems.

The status of virtually all services associated with freshwater ecosystems has become degraded over both time periods (Fig. 2). Intensified land use often causes physical degradation of streams, rivers and lakes due to drainage, discharge regulation and flood protection. Point source pollution (organic compounds and phosphorus) has significantly decreased due to improved waste water treatment during the past 50 years (EEA 2005), but eutrophication originating from non-point sources (nitrate), for example due to fertiliser and manure use in agriculture, dramatically increased in the 1960s and 1970s and has remained stable at a high level since the early 1990s. The combination of all these adverse effects—water abstraction, physical modification of river courses, drainage and devastation of floodplains, and eutrophication—continues to degrade the key service of self-purification of European river and floodplain ecosystems. The severe physical modification and degradation of freshwater ecosystems has also posed a major threat to several key regulating services of these ecosystems. River regulation and floodplain devastation have resulted in a reduced flood retention capacity and, hence, the risk and severity of floods has increased (Opperman et al. 2009). This negative trend has continued to increase since 1950 (MA 2005b) even though the economic implications of flood damages are disastrous (e.g. Barredo 2007). It can also be expected that the loss of extended floodplain forests has had negative implications for regional climate regulation services. A decline in natural river stretches and wetlands in the past decades means that the aesthetic value of many freshwater ecosystems has been degraded, but the status of the potential of recreation and ecotourism differs greatly among regions and cannot be generalised at the European scale.

Wetlands

Trends in the human use and status of services associated with European wetlands are strongly related to historic patterns of land use change. Between 1950 and 1980 many wetlands were drained in both western and eastern Europe and converted into forests (68%) and agricultural land (10%) (Silva et al. 2007). There are no reliable European statistics on wetland loss, but data for individual countries show that between 1950 and 1980 Germany and the Netherlands lost 53% and 48%, respectively, and even Finland, with a low population density, lost 24% (EUROSTAT 2009). These large decreases in the surface area of wetlands also decreased their ability to provide and store freshwater and regulate the climate during this time (Figs. 1, 2). A decline in the use of wetlands for fisheries also occurred before 1990 due to reductions in the quality and size of riverine wetlands because of sedimentation processes caused by regulation measures and pollution (Jongman 1992). Alternatively, agricultural production in wetland areas increased, including rice cultivation in a few regions (e.g. Puzta in Hungary, Rio Zezere in Portugal and the Camargue in France), although such activities often destroyed the wetland itself.

More recent changes in wetland area (post 1980) tend to be mixed, with some regions showing small declines and others local improvement in wetland status due to restoration projects (Møller 1995; Silva et al. 2007). For example, Denmark lost 14% of wetland area between 1980 and 2000, Germany lost 20% between 1980 and 1990, the Netherlands lost 28% between 1980 and 1990 (although the area remained stable after 1990), while Austria actually showed an increase in area of 10% (EUROSTAT 2009). This regionally mixed trend in wetland area is reflected in the human use and status of the services they provide (Figs. 1, 2). In a number of cases, wetland restoration has been undertaken to enhance water retention as a mitigation measure for climate change (Rohde et al. 2006). Human use of wetlands for cultural services, particularly recreation and aesthetic values, increased in both time periods as represented by increasing visits to wetlands to experience their peaceful setting (Blaauw 2003). However, the status of these services has been degraded in many cases.

Discussion and conclusions

The ecosystem services approach helps to demonstrate and explain how humans benefit from, and depend upon, ecosystems via the multiple services they provide (Haslett et al. 2010). It highlights that we should not just care about the natural environment for its own sake (i.e. its 'intrinsic value'), but that it is also vital for our health, well-being and prosperity (Defra 2007). People seek multiple services from ecosystems and so perceive the condition of given ecosystems in relation to their ability to provide all the services desired (MA 2005b). This promotes a multi-sectoral perspective shifting the focus of policy-making away from separate 'silos' and towards a more integrated approach which takes account of trade-offs between different services within and across ecosystems. The approach can effectively add value to traditional biodiversity conservation practices by capturing the value of ecosystem services across decision-making domains, providing access to new sources of financing and opening new avenues for advancing conservation with institutions that do not traditionally consider the environment in their decision-making (ConEx 2009).

This study documents the importance of different ecosystem services in Europe and trends in their use and status since 1950 using information from the literature and scientific experts. In completing Table 1, it was necessary to generalise information across Europe, although it is recognised that many services vary on local and regional scales and are dependent on environmental or management context. Results for provisioning services indicate that managed ecosystems (e.g. agro-ecosystems, forests, rivers and lakes) are of key importance for food, fuel, timber and freshwater provision, while semi-natural ecosystems (e.g. heathlands and wetlands) are of only some importance to these services. The opposite situation was found for the provisioning service of genetic resources where the semi-natural ecosystems were categorised as being more important than the managed ecosystems (Table 1). Cultural services were of key importance in all ecosystems, except soil systems. The only exception was spiritual and religious values which are of variable significance in Europe (Table 1). The pattern for regulating services is more complex depending on the service and ecosystem in question. Forests and mountains, in particular, were shown as providing a key contribution to a large number of regulating services, while agro-ecosystems were shown as providing a negative contribution to six regulating and one provisioning service. Although certain services were categorised as being more important within particular ecosystems, all ecosystems are multifunctional and deliver a wide range of services. This has important implications for the design of land use policy to manage for bundles of ecosystem services rather than prioritising provision of food, fibre or fuel over other services.

The literature review also revealed several gaps in knowledge related to the importance of services in different European ecosystems. There was a particular lack of evidence for the provisioning services of biochemicals/natural medicines and ornamental resources, and the regulating services of seed dispersal, pest/disease regulation and invasion resistance across virtually all ecosystems. Other research needs were specific to individual ecosystems, such as climate regulation in forests and peatlands, and pollination in agro-ecosystems, mountains and forests. Anton et al. (2010) describe 70 key research recommendations for integrating the ecosystem services approach into biodiversity conservation. These 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. Of particular relevance to this study is their recommendation to assess the current status of ecosystems in terms of their capacity to deliver services and examine 'bundles' of ecosystem services.

The MA identified global trends in human use and status of services over the past 50 years (MA 2005a). It reported that human use of all ecosystem services has increased, except for wood fuel, wild foods and freshwater capture fisheries. Results for Europe, obtained in the present study, are much more complex as changes in service provision across different ecosystems are included in addition to two time periods (Fig. 1). The MA results are based on the most recent trend in the past 50 years, so would be expected to be comparable with the later time period from 1990 to present. There are similarities between our study and the MA such as increases in demand for crops from agro-ecosystems, timber from forests and mountains, climate regulation from forests, water flow regulation from rivers, lakes, wetlands and mountains, and recreation and ecotourism in most ecosystems. Further, freshwater capture fisheries and wild foods show decreasing trends in human use. However, there are also notable differences such as increases in the use of wood fuel for bioenergy, particularly in northern Europe (Wright 2006), decreases in livestock production and decreases in services associated with ecosystems which have considerably declined in area or habitat quality, such as heathlands/shrublands and semi-natural grasslands. These differences are most likely to be related to the resolution of each study. General trends at the global level do not necessarily correspond with the trends observed at the continental scale in Europe. In fact, we found several diverging trends within the European study region itself, particularly between northern, southern and eastern Europe. Some differences will also be related to the ecosystem classifications used by the MA and this study. For example, the MA pays little attention to grasslands with scarce mention of the services of temperate grasslands (Safriel et al. 2005, p. 634), but the ecosystem services provided by semi-natural grasslands appear very significant on a local scale across Europe.

Figure 2 shows trends in the status of European services for the same ecosystems and time periods. The MA concluded that the global condition of most services, except for food production and climate regulation, has decreased over the past 50 years (Carpenter et al. 2009). Our study also showed that the majority of European services show either a degraded or mixed status over the most recent time period (post 1990). The only exceptions were an enhancement of timber production in forests and mountains, freshwater provision, water/erosion/natural hazard regulation and recreation/ecotourism in mountains, and climate regulation in forests. Further, food production shows a mixed trend across Europe after 1990 due to the effect of the last reforms of the CAP and EU rural development policy (EEA 2007).

Ecosystem services cannot be valued and managed actively unless they are effectively described and properly recognised in decision-making (EASAC 2009). Our work ensures that there is at the very least a narrative of what services are important and how they have changed at the European scale. This information, combined with knowledge on the role of biodiversity in the provision of services (e.g. Luck et al. 2009; de Bello et al. 2010), is essential to designing appropriate policies for the management of ecosystem services. Supplying services at levels relevant for beneficiaries, while also protecting biodiversity, requires that sectoral policy and management for ecosystem services is integrated with conservation objectives. A framework for adapting existing policies to this end is presented in Haslett et al. (2010). The continued delivery of ecosystem services is one of the most important challenges facing Europe's institutions and our study, and others (e.g. RUBICODE 2008a; EASAC 2009), suggest that a new European Directive focused on the conservation and management of important ecosystem services in Europe would be an effective means for setting priorities for key ecosystem services and the biological units which provide them.

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