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Ecosystem services of peatlands: Implications for restoration

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Abstract

The aim of this overview paper is to analyse the inclusion and use of the ecosystem services concept in scientific studies of degraded peatlands and peatland restoration. Publications indexed by the Institute of Science Information (ISI) Web of Science (WoS) from 1980 to October 2009 were analysed. Word combinations relevant to peatland ecosystem services in the title, keywords and abstract were used. We followed the division of ecosystem services into four categories: supporting, regulating, provisioning and cultural, as provided by the Millennium Ecosystem Assessment (2005). The analysis indicated that the concept of ecosystem services is not referred to explicitly in ISI WoS studies on peatland restoration. The interpretation of the content identified using search phrases related to various beneficial functions of peatlands showed that they mainly include information on regulating and supporting ecosystem services critical to sustaining vital ecosystem functions that deliver benefits to people. There are only a few articles addressing provisioning and cultural ecosystem services. One of the key issues concerning the effect of peatland restoration in the provisioning of ecosystem services is the balance of greenhouse gases and their role in global climate regulation.

Keywords

carbon dioxide, ecosystem functions, global warming potential, methane

1 Introduction

Increasing attention is being devoted to the value of ecosystems in providing ecosystem services. Ecosystem services, the benefits that people obtain from ecosystems, have been seen as a powerful tool to understand human relationships with the environment and to design environmental policy (Brauman *et al.*, 2007). The Millennium Ecosystem Assessment (2005) gave a great impulse to the concept and the further development of the ecosystem services framework (Turner and Daily, 2008), and encouraged scientific studies in the area of ecosystem services (Carpenter *et al.*, 2009).

There are calls and attempts to include the concept in conservation planning and assessment (Balvanera *et al.*, 2001; Chan *et al.*, 2006; Egoh *et al.*, 2007) and in ecological

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restoration (Palmer and Filoso, 2009). The concept of ecosystem services can be seen from a pedagogical viewpoint as an approach that helps to explain the value of ecosystems (Peterson *et al*., 2010), but the addition of monetary valuation makes it an economic approach that has developed rapidly and it is now included in global assessments (Millennium Ecosystem Assessment, 2005; European Communities, 2008). There is a growing trend to use ecosystem services on environmental markets (Mäler *et al*., 2009), where restoration-based credits can also be bought and sold (Palmer and Filoso, 2009). Despite the fact that there is also criticism of the ecosystem services approach (Peterson *et al*., 2010) and the classification system used (Boyd and Banzhaf, 2007), the understanding of ecosystems from the perspective of humans as beneficiaries is considered to have tremendous potential for the protection of ecosystems and the services they provide (Brauman *et al*., 2007).

Ecosystem services are related to ecosystem functions. The comprehensive assessment of ecosystem services involves the translation of ecological complexity (ecosystem structures and processes) into a more limited number of ecosystem functions that, in turn, provide the goods and services that are valued by humans (de Groot *et al*., 2002). Thus ecosystem services cannot be defined independently of human values and well-being. Whether or not the value of ecosystem services are monetized, the ecosystem services framework provides a way to assess trade-offs among alternative scenarios of resource use and landscape change (Brauman *et al*., 2007). It has, however, been emphasized (Daily and Matson, 2008) that a lack of scientific understanding of the factors influencing the provision of ecosystem services and of their economic benefits limits their incorporation into land-use planning and decision-making. On the other hand, ecosystem services approaches (such as mapping of services) can be useful to reveal the gaps in scientific knowledge and to direct research policy.

Peatlands, which represent at least a third of the global wetland resource (Parish *et al*., 2008), are important natural ecosystems with high value for biodiversity conservation, climate regulation and human welfare (Erwin, 2009). Peatlands are characterized by the accumulation of organic matter (peat) derived from dead and decaying plant material under conditions of permanent water saturation. A peatland is defined as an area with or without vegetation and with a naturally accumulated peat layer at the surface. For peatland where peat is currently being formed, the term mire is often used (Joosten and Clarke, 2002). Peatlands are characterized by an incomplete cycling of matter, resulting in a positive carbon balance. Peatlands cover over 4 million km^2 worldwide (3% of the world's land area), and contain 30% of all global soil carbon (Parish *et al*., 2008).

The maintenance and sustainable use of peatlands is of priority importance, as peatlands deliver a range of ecosystem services that contribute to human well-being, including climate regulation, water purification, recreational and educational opportunities and, increasingly, tourism. The Millennium Ecosystem Assessment (2005) stated that one of the most important roles of peatlands may lie in the regulation of global climate change through the sequestering and releasing of a major proportion of fixed carbon in the biosphere.

Commercial extraction and drainage for forestry and agriculture have caused the destruction of many peatlands, especially in or near urban areas of the northern temperate zone (Chapman *et al*., 2003). Europe is the continent with the largest peatland losses, where peat has ceased to accumulate in over 50% of former mire area (Joosten and Clarke, 2002). Peatland restoration is now a common land-use management practice. The regeneration of peatlands may act as a carbon sink, and may be important for rare and endangered species (Chapman *et al*., 2003). Therefore, much effort is directed to encouraging the re-establishment of peat-forming processes (Gorham and Rochefort, 2003). Ecosystem services are referred to in books including chapters on peatland restoration (Bonn *et al.*, 2009) and could be one of the sources informing setting of goals for restoration (Ehrenfeld, 2000). Peatland restoration practitioners are increasingly embracing the ecosystem services concept and valuation methods for peatlands (McInnes, 2007).

The objective of this paper is to analyse the inclusion and use of the ecosystem services concept in scientific studies of degraded peatlands and peatland restoration. The peer-reviewed literature on peatland restoration is analysed by evaluating the following questions. (1) To what extent have ecosystem services been included (as goals or study components) in scientific papers on peatland restoration? (2) What types of ecosystem services have been included? (3) Is there evidence of the effects of peatland restoration on the provisioning of ecosystem services?

II Data sources and methods

Publications indexed by the Institute of Science Information (ISI) Web of Science (WoS) from 1980 to October 2009 were analysed. Word combinations relevant to peatland ecosystem services in the title, keywords and abstract were used. Ecosystem services were classified according to the scheme developed by the Millennium Ecosystem Assessment (2005), which distinguishes four categories: (1) provisioning (eg, fuel, food, water); (2) regulating (eg, of climate, water supply); (3) cultural (eg, recreational and educational value); and (4) supporting (eg, nutrient cycling, biodiversity).

The phrases for the search were derived from Table 1, which summarizes the ecosystem services of inland wetlands by the Millennium Ecosystem Assessment (2005) and functions of peatlands for human beings (beneficial functions of peatlands) described by Joosten and Clarke (2002).

The phrases used in combination with 'peatland restoration' were: 'gas regulation', 'methane', 'nitrous oxide', 'carbon dioxide', 'carbon sequestration', 'climate regulation', 'water regulation', 'water storage', 'water quality', 'water purification', 'constructed wetlands', 'nutrient removal', 'nutrient cycling', 'peat accumulation', 'biodiversity', 'habitat', 'peat production', 'peat extraction', 'wild berries', 'biomass', 'energy crop', 'wood production', 'amenity', 'recreation', 'tourism' and 'cultural heritage'.

III Results and discussion

1 Ecosystem services in peatland restoration publications

There are 417 articles for the term 'peat extraction', 68 for 'peatland degradation' and 157 for the term 'peatland restoration' in the ISI Web of Science literature database (10 October 2009) (Figure 1). Many of the articles overlap. Only two publications contained the term 'ecosystem services'. The result was the same if the phrases 'peatland' and 'ecosystem services' were used. No publications on systematic analyses of peatland ecosystem services were found.

We made a further search using the combination 'peatland restoration' and phrases connected to different peatland ecosystem services (derived from Table 1) and found 102 publications. These publications were analysed in relation to what type of ecosystem service is included (Figure 2). The identification of the ecosystem service was made largely on the basis of the expert judgement of the authors, by referring to the context and objectives of each individual study. The list of publications is presented in the Appendix.

The first publications on peatland restoration and including ecosystem services are from the year 1992, and the number of relevant publications began to grow in 2000. The main target of the study has been peatlands degraded by peat extraction (terms used: cut-away, cutover, harvested, mined peatlands). There are also

Table 1. Peatland ecosystem services and relevant beneficial functions adapted from the Millennium Ecosystem Assessment (2005) and Joosten and Clarke (2002)

Ecosystem services of inland wetlands (Millennium Ecosystem Assessment, 2005)	Beneficial functions of peatlands (Joosten and Clarke, 2002)	Explanation/examples
Provisioning services	**Production functions**	
Fibre and fuel	Peat extracted and used/wild plants (including forests and energy biomass)	Peat used in horticulture, agriculture, domestic heating and energy generation/ raw material for industry and energy generation; medicine
Food	Wild plants/wild and domestic animals	Used as food for people and domestic animals/wood, fur and medicine
Fresh water	Water	Public water supply is obtained from reservoirs draining peatlands
	Peat substrate	Peatland space used for agriculture, horticulture and forestry
	Carrier functions	Space in peatlands for water reservoirs, infrastructure, waste deposits, landfills and military exercises and defence
Regulating services	**Regulation functions**	
Climate regulation	Regulation of global climate/ regional and local climates	Regulation of greenhouse gases, regulation of climatic processes
Water regulation	Regulation of catchment hydrology	Water storage, groundwater recharge and discharge
Water purification and waste treatment	Regulation of catchment hydrochemistry	Retention, recovery and removal of excess nutrients and pollutants
Erosion protection	Regulation of soil conditions	Peat blanket protecting the underlying soils from erosion
Cultural services	**Informational functions**	
Recreational and aesthetic	Recreation and aesthetic functions	Opportunities for recreation and tourism; appreciation of nature
Spiritual and inspirational	Spiritual and existential functions	Personal feelings and well-being; religious significance
Educational	Signalization and cognition functions	Opportunities for education, training and research
Supporting services		
Biodiversity		Habitats for species
Soil formation		Accumulation of organic matter
Nutrient cycling		Storage, recycling, processing and acquisition of nutrients

studies on degraded fens and peatlands drained for forestry.

Regions with the highest proportions of peatlands, where industrial peat extraction or peatland drainage for forestry have played an important role, have produced the majority of studies. The leader is Canada with 36 publications, followed by Finland (10 publications). There are 34 papers from other European countries and some publications from the USA

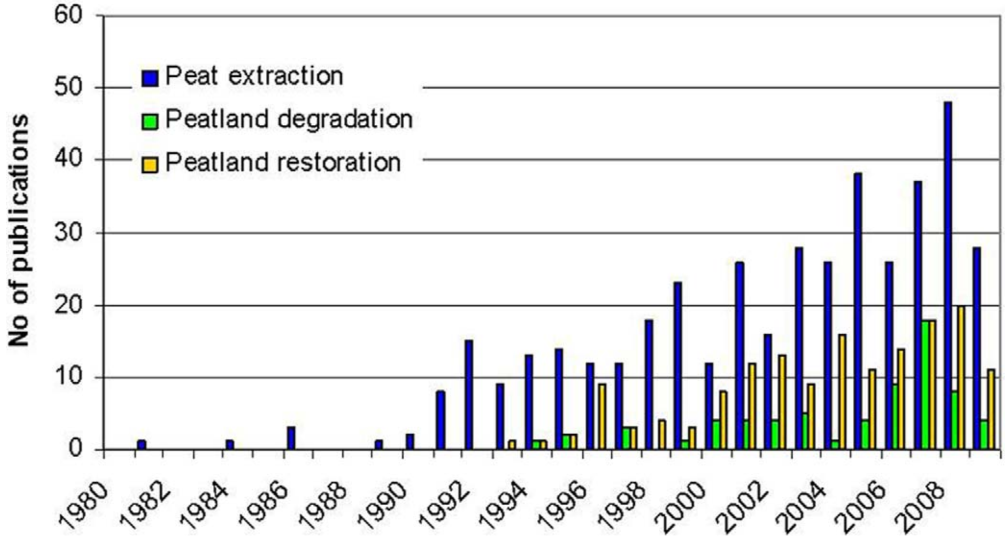

Figure 1. The number of publications on peat extraction, peatland degradation and peatland restoration identified in international peer-reviewed scientific papers by titles, abstracts and/or keywords. The analysis has been performed on the basis of journal papers indexed by the ISI Web of Science from 1980 to October 2009.

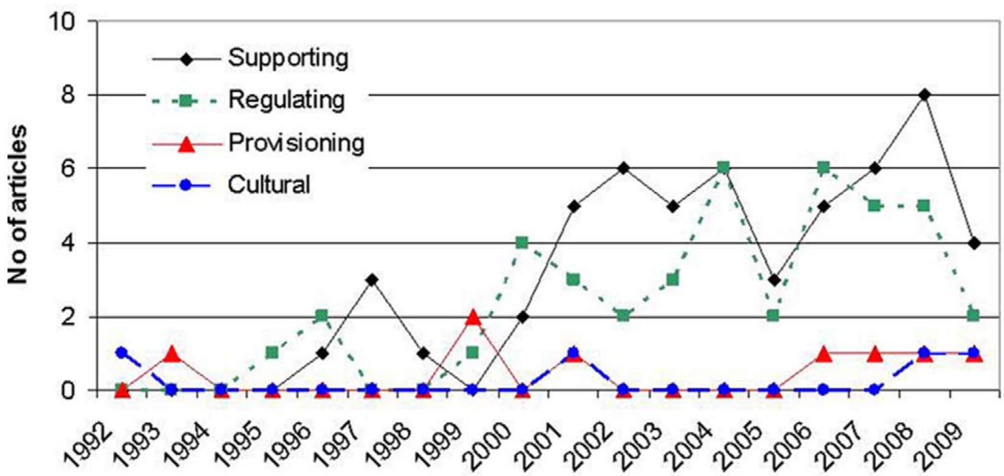

Figure 2. The number of publications on peatland restoration identified using the phrases connected to peatland ecosystem services (supporting, regulating, provisioning or cultural) in titles, abstracts and/or keywords of international peer-reviewed scientific papers. The analysis has been performed on the basis of journal papers indexed by the ISI Web of Science from 1980 to October 2009.

and some other regions plus several conceptual papers.

The analysis indicates that studies often include information on several functions, and the link to several ecosystem services can be interpreted. It must also be taken into account that the categories of services overlap (Millennium Ecosystem Assessment, 2003). It is mainly supporting ecosystem services (in 55 publications) and regulating ecosystem services (in 42 publications) that have been treated. There are few studies on provisional (five studies) and cultural (three studies) ecosystem services. The result is expected, as the main goal of the restoration is the revitalization of the basic functions of the ecosystem that are responsible for the provisioning of supporting services. It must be pointed out that it was not easy to differentiate between regulating and supporting services (for example, carbon storage can be interpreted to represent both regulating and supporting services). Frequently, publications focused on supporting ecosystem services also contained information on regulating services.

Most of the selected publications contain information on supporting ecosystem services – peat accumulation (Francez *et al*., 2000; McNeil and Waddington, 2003; Waddington *et al*., 2009), nutrient cycling (Croft *et al*., 2001; Glatzel *et al*., 2004; Graham *et al*., 2005; Kieckbusch and Schrautzer, 2007) and biodiversity (Joy and Pullin, 1997; Jauhiainen *et al*., 2002; Campbell *et al*., 2003; Cobbaert *et al*., 2004; Mälson and Rydin, 2009). There are also publications containing information related to the regulating ecosystem services, particularly on water regulation (Wassen *et al*., 1996; Kennedy and Price, 2004; Banaszuk and Kamocki, 2008). The most important and assessed function regarding peatlands and peatland restoration is their global climate regulation, ie, the role in the sequestering and releasing of greenhouse gases (CO_2, CH_4 and N_2O). There are many publications on carbon dioxide and methane dynamics in restored cut-away peatlands (Tuittila *et al*., 2000; Waddington *et al*., 2001; Wilson *et al*., 2007) and also in peatlands drained for forestry (Jauhiainen *et al*., 2008).

Provisioning ecosystem services have only been highlighted in a few papers. This is not surprising, as peat extraction and the use of peatland surface for forestry, agriculture or horticulture, which are the main causes of peatland degradation, are antagonistic to restoration. Still there are cases when peatland restoration and the provisioning ecosystem services are linked together. According to Waddington *et al*. (2009), the new acrotelm transplant method that restores natural peatland function by preserving and replacing the surface layer vegetation as part of the extraction process re-establishes peat accumulation and peatland carbon storage function more effectively than traditional extraction techniques that are associated with delayed restoration efforts, and therefore has the potential to greatly reduce the carbon footprint of the Canadian peat industry.

The continuous removal of plant biomass that can be used as an energy source is described by Wichtmann and Schäfer (2007) in connection with degraded fen restoration. They argue that, in terms of their ecological value and environmental benefits, managed rewetted fens clearly surpass drained grasslands and that in northern Germany more than 200,000 hectares of lowlands could be rewetted for biomass production. The harvest from these areas could feed 20 power plants of 20 MW capacity each. Wild *et al*. (2001) tested the combination of water purification and peatland restoration in a degraded fen area in southern Germany where a water regime typical for fen was re-established, and the cultivated *Typha* stands showed a high phytomass production. Consequently, due to restoration activities the function of the peatland as a sink in the nutrient cycle may be reactivated.

Very little information can be found on cultural services and their response to restoration activities. Assessing the key local narratives in relation to harvested peat landscapes and their rehabilitation in Ireland, Collier and Scott (2008) explored local people's after-use preferences and found that there is strong support for amenity and biodiversity after-uses, and this should be reflected in policy debates. However, although the cultural services of peatlands are not analysed in the academic literature, the significance of these non-material life support

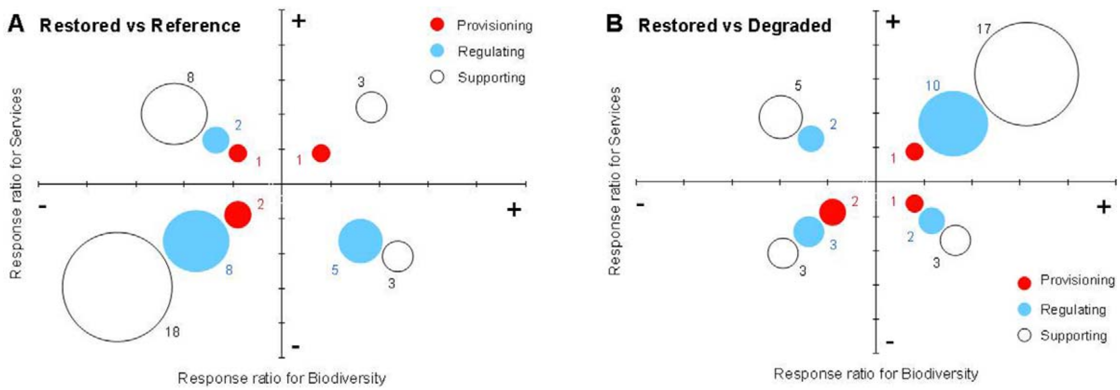

Figure 3. Relationship between theoretical response ratios for biodiversity services and provisioning, regulating and supporting services in (A) restored versus reference ecosystems and (B) restored versus degraded ecosystems. Provisioning services: production of, for example, timber, fish and food crops. Regulating services: regulation of climate, water supply and soil characteristics. Supporting services: nutrient cycling and primary production. A plus sign indicates enhanced services and a minus sign shows reduced services. The size of squares and relevant numbers indicate the number of restoration projects analysed. Restored ecosystems demonstrate lower biodiversity services and higher regulating/supporting services than the reference ecosystems and *vice versa*. In most of the restored ecosystems both biodiversity and regulating/supporting services increased in comparison to degraded systems.
Source: Adapted from Benayas *et al.* (2009)

functions and services is indicated by the large amounts of money that are spent in such areas as recreation, arts, religion, species conservation and pure science (Joosten and Clarke, 2002).

2 Effect of restoration on provision of ecosystem services

There is a widespread assumption that ecological restoration will increase the provision of ecosystem services, but this has not been systematically tested (Benayas *et al.*, 2009). The analysis by Benayas *et al.* (2009) based on the quantitative analysis of measured attributes related to the ecosystem services and biodiversity of 89 restoration assessments in a wide range of ecosystem types (but including only two publications on peatland ecosystems) across the globe indicates that ecological restoration increased the provision of biodiversity and ecosystem services, although the values of both remained lower in restored versus intact reference ecosystems (Figure 3). The results of this study had a strong emphasis on biodiversity and therefore cannot be directly transferred to peatland ecosystems.

In publications on peatland restoration, there were few cases where the situation of degraded, restored and intact peatland ecosystem was compared. However, the brief analyses of studies show that there is a positive response to restoration activities. Several studies report the enhancement of ecosystem functions (which can be translated into the provision of ecosystem services) compared to degraded peatlands, but that the values remain lower than those of the intact ecosystems. According to Waddington and Price (2000), peatland restoration enhances CO_2 sequestration, although restoration (at least in the short term) does not restore the net carbon sink function to that in natural bogs. Jauhiainen *et al.* (2002) studied the vegetation of two boreal mires drained for forestry and found that the restoration (filling in ditches and removal of tree stand) caused relatively rapid positive changes in plant species

Table 2. Changes in regulating functions (material cycling) in restored peatlands

		Gaseous emission			Nutrient/carbon losses			
Reference	Peatland type, country	CO_2	CH_4	N_2O	NO_3	NH_4	PO_4	DOC
Waddington *et al.*, 2009	Peatlands, Canada	+						
Trinder *et al.*, 2008a	Bog, Scotland							–
Jauhiainen *et al.*, 2008	Tropical peatland, Indonesia	+	–					
Glatzel *et al.*, 2008	Bog, Germany		0	–				
Zak and Gelbrecht, 2007	Fen, Germany						–	
Kieckbusch and Schrautzer, 2007	Fen, Germany				+	–	–	–
Basiliko *et al.*, 2007	Northern peatlands, North America	+	–				–	–
Bortoluzzi *et al.*, 2006	Mountain bog, France	+	–					
Andersen *et al.*, 2006	Bog, Canada	+	–					
Silvan *et al.*, 2005	Restored fen, Finland			–	+			
Glatzel *et al.*, 2004	Bog, Canada	+	–					
Marinier *et al.*, 2004	Restored harvested peatland, Canada	+	–					
Davidsson *et al.*, 2002	Fen, Germany				+			
Silvan *et al.*, 2002	Fen, Finland			–				
Roulet, 2000	Peatlands, Canada		–					

+ Enhanced service; – reduced service. Reduced service means increased emission of greenhouse gases (GHG) and/or losses of nutrients.

composition and cover indicating a change towards a functional mire ecosystem. Kivimäki *et al.* (2008) studied CO_2 exchange in stands of different plants in a restored cut-away peatland to quantify their ability to form a carbon sink. Five different types of stands were sampled: monocultures of *Eriophorum vaginatum* and *Carex rostrata* (pure plots), mixtures of *Eriophorum* or *Carex* and *Sphagnum* mosses (mixed plots) and control plots without vegetation. The mixtures of sedge and *Sphagnum* mosses were clearly more efficient in sequestering CO_2 than pure stands. However, Basiliko *et al.* (2007) who examined carbon dioxide and methane exchange in peat samples at natural, mined, mined-abandoned and restored peatlands have pointed out that although restoring hydrology similar to natural sites may re-establish CH_4 dynamics there is geographic or site-specific variability in the ability to restore peat decomposition dynamics.

Negative responses have also been reported. Fenner *et al.* (2001) have found that the rewetting of peatlands following drought (eg, due to climate change) has the potential to reduce water quality, and that interest in restoration (rewetting) of drained peatlands could create an additional source of water rich in dissolved organic carbon (DOC). On the other hand, a drained lowland peatland may act as a buffer to flood events, whereas a restored lowland peat may offer no flood storage capacity and hence that service is lost (Holden *et al.*, 2004; Erwin, 2009). A detailed understanding of hydrological, hydrochemical and ecological process-interactions will be fundamental in adequately restoring degraded peatlands and understanding the impacts of such management

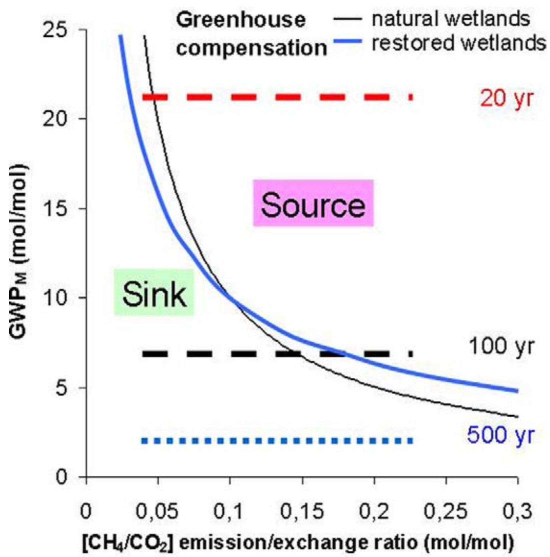

Figure 4. A model of the relationship between the greenhouse warming potential of methane (GWP_m), expressed as CO_2 equivalents, and the molar ratio of CH_4 emitted to CO_2 taken up (CH_4/CO_2) by a wetland, adapted from Whiting and Chanton (2001). The curve for restored wetlands is added on the basis of theoretical assumptions. The lines represent the sites used for analyses by Whiting and Chanton (2001), over 20-year, 100-year and 500-year time horizons, respectively. In the short term, wetlands enhance global warming, whereas in the long-term perspective all wetlands become compensators of the greenhouse effect.

actions at the catchment scale (Holden *et al.*, 2004; Ramchunder *et al.*, 2009).

3 Peatland restoration and the balance of greenhouse gases

One of the key issues concerning the effect of peatland restoration on the provisioning of ecosystem services is the balance of greenhouse gases and their role in global climate regulation. Drainage, harvesting and restoration change the ability of the peat profile to produce and emit CO_2 and CH_4. In establishing restoration goals on degraded peatlands, it is important to consider the effect of restoration activities on various components of the ecosystem and the timescales. Table 2 summarizes the data reported in publications on changes in regulating functions in peatlands under restoration.

The carbon sequestration process is intimately linked to methane emission from wetlands. The balance of CH_4 and CO_2 exchange can provide an index of a wetland's greenhouse gas contribution to the atmosphere (Whiting and Chanton, 2001). In the short term, wetlands enhance global warming, whereas in the long-term perspective all wetlands become compensators of the greenhouse effect (Figure 4).

The restoration of wetlands should be carefully designed to curtail the emission of methane while sequestering soil carbon (Whiting and Chanton, 2001). Rewetting of drained peatlands is an effective means of reducing emissions of CO_2 and N_2O, but revives CH_4 emissions. In the mid- and long term, however, the rewetting of peatlands leads to a substantial net reduction of climate relevant emissions from the peat body compared with the drained baseline (Joosten, 2009).

According to Waddington *et al.* (2001), it is essential to begin restoration once a cutover peatland is abandoned. Rewetting is necessary to prevent an increase in peat temperature and CO_2 production. A decrease in overall peatland oxidation should reduce the persistent source of atmospheric CO_2 from cutover peatlands and the irreversible changes in peat structure that impede *Sphagnum* re-establishment. In Figure 5 the theoretical dynamics of the radiative forcing of a restored and afforested peat extraction fen is shown based on the study by Kirkinen *et al.* (2007) in which greenhouse impacts were presented as a function of time. Radiative forcing can be seen as calculational heating power in the atmosphere due to greenhouse gas emissions from the considered peat fuel utilization chain. The considered time span is 300 years. During the first 20 years in which peat production and combustion occurs, radiative forcing increases strongly. After that the post-treatment of the area starts. The consequent

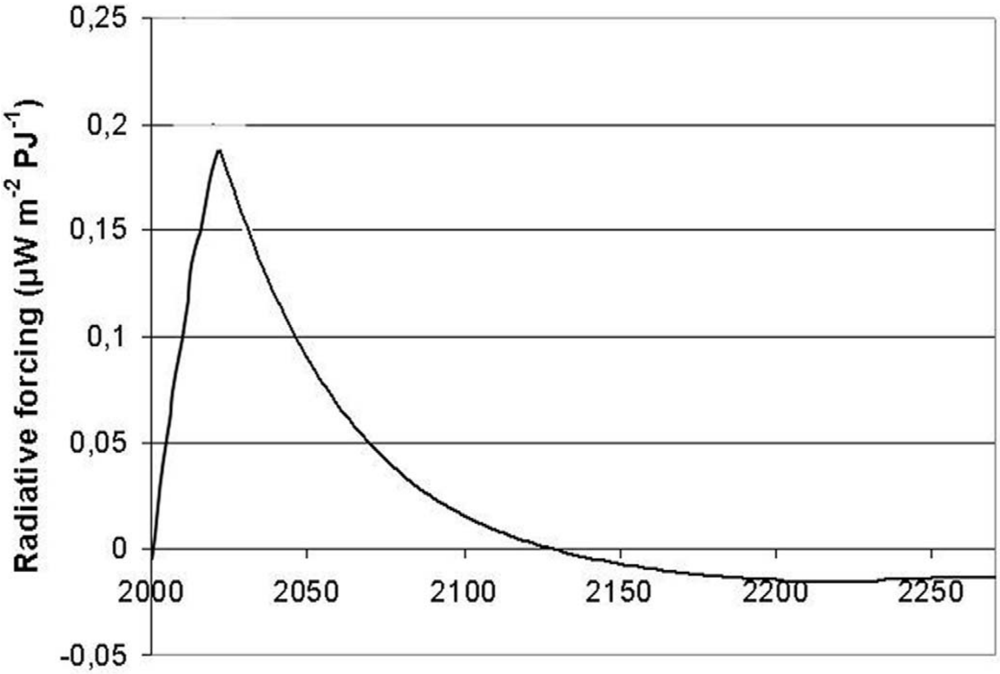

Figure 5. Theoretical dynamics of radiative forcing of restored and afforested peat extraction fen
Source: Adapted from Kirkinen *et al.* (2007)

decrease in radiative forcing is due to the carbon transfer from atmosphere to oceans and to the sequestration of carbon into growing biomass and litter.

IV Conclusions

The literature analysis on the term 'peatland restoration' in combination with phrases related to peatland ecosystem services indicates that the concept of ecosystem services is not referred to explicitly in ISI WoS studies on peatland restoration. An attempt to identify the ecosystem services behind the goals, targets and results described in 102 relevant publications showed that it is mainly information related to supporting and regulating ecosystem services that is included. The result is expected, as regulating and supporting services (such as nutrient cycling) are critical to sustaining vital ecosystem functions that deliver benefits to people. There are few papers with information on provisioning and cultural services. The analysis also reveals that there is a positive response to restoration activities. Several studies report the enhancement of ecosystem functions (which can be translated into the provision of ecosystem services) compared to degraded peatlands. Further research is needed to enhance scientific understanding of the factors influencing the provision of ecosystem services and the effects of restoration activities on them. One of the critical issues regarding peatlands and peatland restoration is their role in sequestering and releasing greenhouse gases (CO_2, CH_4 and N_2O) – ie, the global climate regulation ecosystem service and how this service will alter under a changing climate. Thus, there is a need for long-term research on restoration impact on the carbon and nitrogen balance in restored peatlands. Detailed research on hydrological, hydrochemical and ecological processes and interactions will also be fundamental in understanding the impacts of peatland restoration at the catchment scale. Likewise, cultural services and social aspects of other services should be studied comprehensively to integrate restoration of peatlands into the sustainable development arena.

There is a challenge to integrate the ecosystem services framework into peatland restoration planning, which provides possibilities to assess trade-offs among alternative scenarios of resource use and landscape management. Better scientific understanding of the factors influencing the provision of ecosystem services would help to define and prioritize restoration goals. On the other hand, ecosystem services approaches can also be useful to reveal the gaps in scientific knowledge and to direct research policy.

Acknowledgements

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Appendix

The table on the following pages shows publications indexed by the Institute of Science Information (ISI) Web of Science (WoS) from 1980 to October 2009 identified using the phrase 'peatland restoration' in combination with phrases connected to different peatland ecosystem services (eg, gas regulation, water purification, peat accumulation). The identification of the ecosystem services was made largely on the basis of the expert judgement of the authors, by referring to the context and objectives of each individual study. The response estimation made by authors is added when possible.

Publication	Peatland type	Target of the study	Ecosystem service (interpreted)	Restoration activity	Response (estimation)
Aerts *et al*., 2003	Peat grassland	Nutrient cycling Plant species	Supporting	Experimental manipulations with nutrients	No result
Andersen *et al*., 2006	Restored cut-away peatland	Functional status	Supporting Regulating	Blocking ditches Reintro-duction of plants	Positive
Banaszuk and Kamocki, 2008	Fluviogenous mire	Water regulation	Regulating		
Basiliko *et al*., 2007	Natural, mined, mined-abandoned and restored peatlands	Decomposition methane dynamics	Supporting Regulating	Restoring hydrology	Geographic or site-specific variability
Beltman *et al*., 2001	Fens				
Berube and Lavoie, 2000	Vacuum-mined peatland	Vegetation	Supporting	Natural revegetation	
Boeye *et al*., 1996	Rich fen		Regulating	Artificial infiltration	
Boeye *et al*., 1995	Rich fen		Regulating		
Bortoluzzi *et al*., 2006	Cutover bog	Carbon balance	Regulating	Natural regeneration	Positive
Buttler *et al*., 1996	Cutover bog	Biodiversity/testate amoe-bae and peat-forming vegetation	Supporting	Post-abandonment development	Positive
Cagampan and Waddington, 2008	Cutover peatlands	Carbon storage	Regulating	Acrotelm transplant method (acrotelm restoration)	Positive
Campbell *et al*., 2003	Milled peatland	Biodiversity Plants	Supporting		
Cleary *et al*., 2005	Peatlands mined by peat industry	Greenhouse gases emissions	Regulating		
Cobbaert *et al*., 2004	Fen	Biodiversity Plant community	Supporting	Rewetting Straw mulch	

(continued)

(Appendix continued)

Publication	Peatland type	Target of the study	Ecosystem service (interpreted)	Restoration activity	Response (estimation)
Collier and Scott, 2008	Harvested peatlands	Local people after-use preferences	Cultural		
Cox *et al*., 2001	Mire	History, Archaeology	Cultural		
Croft *et al*., 2001	Post-harvested peatlands	Bacterial population Nutrient cycling	Supporting	Restoration	Positive
Davis and Wilkinson, 2004	Lowland raised mires	Testate amoebae	Supporting		
Erwin, 2009	Wetlands including peatlands		All		
Fenner *et al*., 2001	Peatlands	Water quality/DOC	Regulating	Rewetting	Negative
Ferland and Rochefort, 1997	Post-harvested peatlands	Colonization of *Sphagnum*	Supporting	Sphagnum re-introduction Phosphorus amendment	Positive
Francez *et al*., 2000	Used peatland	Peat accumulation Carbon balance	Supporting Regulating	Restoration of hydrological conditions	Positive/negative
Gaudig *et al*., 2008	Bogs	*Sphagnum* biomass	Provisioning		
Girard *et al*., 2002	Disturbed ombrotrophic peatland			Natural regeneration	
Glatzel *et al*., 2004	Natural, mined and restored peatlands	Carbon cycling	Supporting	Various restoration stages	
Glatzel *et al*., 2003	Natural, harvested and restored peatland	CO_2 efflux Dissolved organic matter	Regulating Supporting	Various restoration stages	
Gorham and Rochefort, 2003	Cut-away peatlands		Supporting		
Graham *et al*., 2005	Natural and restored marshes	Phosphorus sequestration	Supporting	Restoration	
Groeneveld *et al*., 2007	Abandoned extracted peatlands	*Polytrichum strictum* role in *Sphagnum* return	Supporting		
Hagerthey *et al*., 2008	Subtropical peatland	Nutrient cycle	Supporting		

(continued)

(Appendix continued)

Publication	Peatland type	Target of the study	Ecosystem service (interpreted)	Restoration activity	Response (estimation)
Hajkova *et al.*, 2009	Calcareous fens	Vegetation	Supporting	Mowing, litter removal	Positive
Higgins *et al.*, 2006	Cut-away peatland	Water quality	Regulating	Flooding of cut-away peatlands	
Holden *et al.*, 2004	Drained peatlands	Hydrological processes	Regulating	Conceptual	
Holden, 2005	Global peatlands	Carbon storage	Regulating	Restoration	In some circum-stances negative
Huotari *et al.*, 2007	Cut-away peatland	Biodiversity Vegetation	Supporting	Fertilization	
Jauhiainen *et al.*, 2002	Boreal mires	Vegetation	Supporting	Removal of trees and filling in ditches	Positive
Jauhiainen *et al.*, 2008	Drainage-affected tropical peatland	Greenhouse gases dynamics	Regulating	Hydrological restoration	Neutral
Joy and Pullin, 1997	Cutover raised mire	Biodiversity/large heath butterfly	Supporting		
Keddy *et al.*, 2009	Wetlands including peatlands		All		
Kennedy and Price, 2004	Cutover peatlands	Water storage	Regulating	Theoretical	
Kieckbusch and Schrautzer, 2007	Eutrophic fen	Nitrogen and phosphorus dynamics	Supporting	Rewetting	Negative
Kirkinen *et al.*, 2007	Peatlands of peat fuel utilization	Greenhouse gases emis-sions and sinks	Regulating	After-treatment alterna-tives: afforestation/ restoration	
Kivimäki *et al.*, 2008	Cut-away peatland	Carbon storage	Regulating	Raising water table, planting vascular plants and *Sphagnum*	Positive

(continued)

(Appendix continued)

Publication	Peatland type	Target of the study	Ecosystem service (interpreted)	Restoration activity	Response (estimation)
Konovalchuk and Konovalchuk, 2006	Extracted peatlands	Highbush blueberry	Provisioning		
Laggoun-Defarge *et al*., 2008	Cut-over peatland	Organic matter	Supporting		
Laiho *et al*., 2001	Drained peatlands	Biodiversity: mesofaunal community	Supporting		
Lamers *et al*., 2002	Fens	Biodiversity: plant and animal communities	Supporting		
Lanta and Hazukova, 2005	Cut-over peat bog	Biodiversity: *Betula pubescens*	Supporting		
Large, 2001	Influenced mires	Biodiversity: floristic diversity	Supporting	Spontaneous succession	
La Rose *et al*., 1997	Abandoned peatland	Colonization of *Sphagnum*	Supporting	Ditches blocked	
Lavoie and Rochefort, 1996	Extracted and abandoned peatland	Plants	Supporting	Natural revegetation	Negative
Mälson *et al*., 2008	Boreal rich fen (alkaline fen)	Plant species richness		Rewetting	Positive
Mälson and Rydin, 2007	Drained fens	Biodiversity Vegetation	Supporting	Hydrological restoration Transplantation	
Mälson and Rydin, 2009	Rich fen	Community dynamics	Supporting		
Marinier *et al*., 2004	Harvested peatland	Carbon storage Vegetation	Regulating Supporting	Revegetation with *Eriophorum vaginatum*	Vegetation positive methane negative
Mazerolle and Cormier, 2003	Mined, in preparation to be mined, natural peatlands	Biodiversity *Rana clamitans*	Supporting	Restoration	Positive
Mazerolle *et al*., 2006	Extracted peatland	Faunal and vegetational patterns	Supporting	Restoration	Partially positive

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(Appendix continued)

Publication	Peatland type	Target of the study	Ecosystem service (interpreted)	Restoration activity	Response (estimation)
McNeil and Waddington, 2003	Abandoned block-cut bog	CO_2 exchange *Sphagnum* net primary production	Regulating Supporting		
Mitchell *et al.*, 2002	Cutover bog	Carbon sequestration	Regulating Supporting	Experimental	
Petrone *et al.*, 2001	Restored extracted peatland	Atmospheric exchange of water and CO_2	Regulating	Blockage of ditches and spreading of mulch cover	Negative
Petrone *et al.*, 2004	Restored peatland			Theoretical	
Pigott *et al.*, 1992	Peatland	Amenity	Cultural	Restoration of peatland canal	
Price *et al.*, 1998	Cutover peatland	Energy balance Establishment of *Sphagnum*	Supporting	Artificial microtopography Spreading of straw mulch	
Price and Whitehead, 2004	Abandoned cutover bog	Water storage *Sphagnum* colonisation	Regulating Supporting	Theoretical	
Robertson, 1993	Peatland	Peat-based growing media	Provisioning		
Rochefort *et al.*, 2002	Peat-mined bog	*Sphagnum* growth	Supporting	Flooding	Partly positive
Roulet, 2000	Peatlands	GHG gases	Regulating	Restoration	
Salo, 1999	Peatlands	Wild berries and commercial mushrooms	Provisioning		
Shantz and Price, 2006a	Managed peatland	Hydrology	Supporting	Restoration	
Shantz and Price, 2006b	Abandoned peat extraction sites	Water storage	Regulating		
Silvan *et al.*, 2002	Restored peatland	Gaseous N loss	Supporting	Rewetting, clearcutting	
Silvan *et al.*, 2005	Restored peatland	Nutrient cycling	Supporting	Restoration	Positive
Spieksma, 1999	Cutover raised bog	Discharge	Regulating	Rewetting	No result
Trepel, 2007	Degraded peatlands		Supporting		

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(Appendix continued)

Publication	Peatland type	Target of the study	Ecosystem service (interpreted)	Restoration activity	Response (estimation)
Trepel and Kluge, 2004	Riparian peatlands	Nutrient cycling	Supporting	Theoretical	
Trettin *et al.*, 2006	Forested peatlands	Carbon dynamics CO_2 emissions	Regulating Supporting		
Trinder *et al.*, 2008a	Abandoned cutover peatland	Nutrient cycling	Supporting Regulating	Natural recolonization	
Trinder *et al.*, 2008b	Cutover peatland	Nutrient cycling	Supporting		
Tuittila *et al.*, 1999	Restored cut-away peatland	CO_2 exchange dynamics	Regulating	Rewetting	Positive
Tuittila *et al.*, 2000	Cut-away peatland	CH_4 dynamics	Regulating	Rewetting	Positive
Tuittila *et al.*, 2004	Rewetted cut-away peatland	Carbon sequestration	Regulating	Rewetting, *Sphagnum* reintroduction	Positive
van Dijk *et al.*, 2004	Former agricultural land	Nitrogen cycling	Supporting	Rewetting	
van Duinen *et al.*, 2006	Rewetted and non-rewetted bog remnants	Biodiversity Aquatic invertebrates	Supporting	Rewetting	
van Duinen *et al.*, 2007	Bog remnants	Biodiversity Aquatic invertebrates	Supporting		
van Seters and Price, 2002	Cutover bog	Hydrology and *Sphagnum* regeneration	Supporting	Hydrological change	Positive
Waddington and Day, 2007	Cutover, restored peatland	Methane emission	Regulating	Restoration	Negative
Waddington *et al.*, 2003	Cut-away peat	Carbon sequestration	Regulating	Blocking ditches Spreading of a mulch layer	Negative
Waddington and McNeill, 2002	Abandoned cutover peatland	Carbon loss	Regulating		
Waddington *et al.*, 2009	Peatlands	Carbon storage Peat accumulation	Regulating Supporting	Acrotelm transplant method (acrotelm restoration)	Positive

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(Appendix continued)

Publication	Peatland type	Target of the study	Ecosystem service (interpreted)	Restoration activity	Response (estimation)
Waddington and Price, 2000	Natural, harvested and restored peatland	Water, carbon	Regulating	Various restoration stages	Partially positive
Waddington *et al*., 2001	Natural and post-cutover peatlands	CO_2 production	Regulating	Laboratory incubations	
Waddington *et al*., 2008	cutover and restored peatland	DOC	Supporting	Restoration	Positive
Waddington and Warner, 2001	Natural, restored and naturally regenerated peatlands	Net ecosystem CO_2 exchange	Regulating	Various restoration stages	Positive trend
Waddington *et al*., 2002	Natural and post-cutover peatlands	Carbon storage	Regulating		
Waddington and Price, 2000	Natural, harvested and restored peatlands	Atmospheric exchange of water and carbon	Regulating		Positive trend
Wallage *et al*., 2006	Intact, drained and drain-blocked peat	DOC	Regulating		
Wassen *et al*., 1996	Fens	Water cycle	Regulating		
Wichtmann and Schäfer, 2007	Fens	Biomass utilization	Provisioning	Rewetting/removal of plant biomass	Positive
Wilcox *et al*., 2006	Sedge fen	Water budgets	Regulating	Redirection of waterflows	Positive
Wild *et al*., 2001	Degraded fen/constructed wetland	Phytomass production Nutrient cycling	Provisioning Supporting	Rewetting Cultivation of *Typha*	Positive
Wilson *et al*., 2007	Restored maritime cutaway peatland	CO_2 dynamics	Regulating	Rewetting	Negative
Wosten *et al*., 2008	Intact and degraded peatland		Supporting		

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