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Ecosystem services of wetlands: pathfinder for a new paradigm

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Abstract Ecosystem services are natural assets produced by the environment and utilized by humans – such as clean air, water, food and materials – and contribute to social and cultural well-being. This concept, arguably, has been developed further in wetlands than any other ecosystem. Wetlands were historically important in producing the extensive coal deposits of the Carboniferous period; key steps in human development took place in communities occupying the wetland margins of rivers, lakes and the sea; and wetlands play a key role in the hydrological cycle influencing floods and river droughts. In this paper we examine three pillars that support the wetland research agenda: hydrology, wetland origins and development, and linkages to society. We investigate these through an overview of the evolution of wetland science and assessment of the wide range of topics relating to ecosystem services covered in this Special Issue. We explain the seminal change in how modern society values the benefits of natural ecosystems and highlight the pathfinder role that wetland research has played in the paradigm shift.

Key words wetlands; ecosystem services; hydrological functions; paradigm shift

Services écosystémiques des zones humides: éclaireur pour un nouveau paradigme
Résumé Les services écosystémiques sont des biens naturels produits par l'environnement et utilisés par les humains, comme l'air pur, l'eau, la nourriture et les matériaux, et contribuent au bien-être social et culturel. Ce concept a sans doute été davantage développé dans les zones humides que dans tout autre écosystème. Les zones humides ont été historiquement importantes dans la production des énormes gisements de charbon de la période carbonifère; des étapes clés dans le développement humain ont eu lieu dans des communautés qui occupaient les marges humides des rivières, des lacs et de la mer, et les zones humides jouent un rôle clé dans le cycle hydrologique en influençant les crues et les étiages des rivières. Dans cet article, nous examinons trois piliers qui soutiennent la recherche sur les zones humides: l'hydrologie, les origines et le développement des milieux humides, et les liens avec la société. Nous les étudions à travers un passage en revue de l'évolution de la science des zones humides et une évaluation de la vaste gamme de sujets liés aux services écosystémiques abordés dans ce numéro spécial. Nous expliquons le changement fondamental dans la façon dont la société moderne évalue les bénéfices des écosystèmes naturels, et soulignons le rôle pionnier que la recherche sur les zones humides a joué dans ce changement de paradigme.

Mots clefs zones humides; services écosystémiques; fonctions hydrologiques; changement de paradigme

INTRODUCTION

Ecosystem services are natural assets (Barbier 2011) produced by the environment and utilized by humans, such as clean air, water, food and materials. They contribute to social and cultural well-being (Fischer *et al.* 2009) and have high economic value (Barbier *et al*. 1997, Emerton and Bos 2004, Turner *et al*. 2008). They have been broadly classified as provisioning, regulating, cultural and supporting (Fig. 1, MEA 2005). This concept has much earlier origins in the context of wetland research where it has been embedded in the ideas of ecosystem functioning and resulting human values (Maltby 1986). Management of land and water has focused on enhancing some ecosystem services, such as food production, but this has been often at the expense of degradation of other services, such as those described as regulating, e.g. pollutant removal to improve water quality. This Special Issue of *Hydrological Sciences Journal* investigates the ecosystem services provided by wetlands, with particular emphasis on the trade-off of

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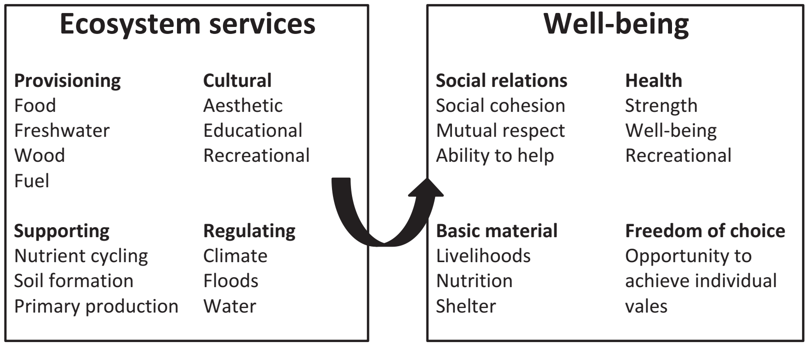

Fig. 1 Ecosystem services and well-being (after MEA 2005).

individual services as these systems have been manipulated either purposely or unintentionally.

In this paper, we examine three pillars that support the wetland research agenda and which are investigated through the wide range of topics covered in this Special Issue: hydrology, wetland origins and development, and linkages to society. We illustrate some of the more intriguing relationships with human development and document significant changes in their perception resulting in a fundamental alteration in their appreciation, use and management over time. This has mirrored a seminal shift in how modern society values the benefits of natural ecosystems and highlights the pathfinder role that wetland research has played in the paradigm shift (Fig. 2).

The dominance of water, at least periodically, is the defining feature of wetlands (Acreman and José 2000). The variation in hydrological regimes, largely determining their structure, processes and

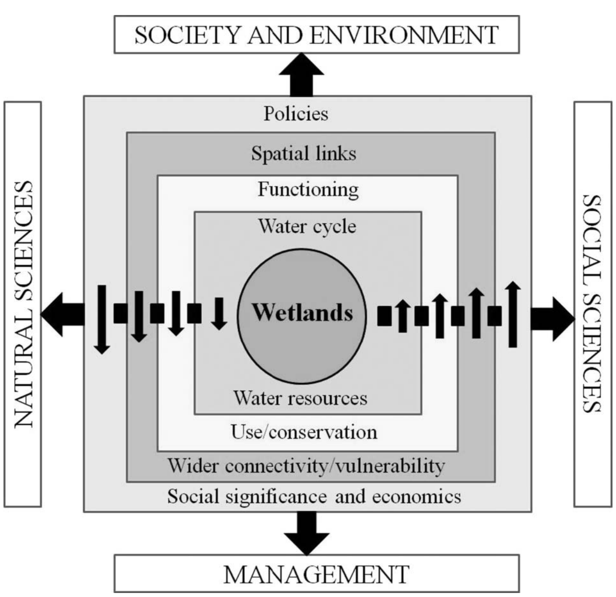

Fig. 2 Wetlands at the centre of concerns of society (after Maltby 2009a).

functioning, results in a wide range of wetland ecosystem types (Maltby 1986, Mitsch and Gosselink 2002, Maltby 2009b). The major types are marshes, swamps and mires (bogs and fens), each demonstrating considerable diversity within the generic category, depending on water quality, dominant vegetation, topography, soils or sediment, and climate (Gore *et al*. 1983). Distinct landscapes, such as floodplains, deltas, peatlands, estuaries and coastal margins, also support a wide variety of wetland types, which often carry distinctive geographical names such as billabong (ox-bow), carr (wet woodland), rhos or culm grassland (wet grassland) and dambo (headwater depressions). There is frequent ambiguity among the scientific community as to what exactly constitutes "wetland", especially in relation to the inclusion or not of rivers and lakes. Wetlands are the only ecosystem type to have a dedicated international convention—The Convention on Wetlands of International Importance, called the Ramsar Convention, after the city in Iran where it was signed in 1971. This has adopted the most inclusive of definitions: "*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres*" (Davis 1993). Coral reefs and caves are also now included specifically within the definition under the Convention.

Whatever the conflicts of opinion, there are at least three features of wetlands that singly or together can be considered diagnostic:

1. the predominant presence and dynamics of water either at or above the surface or within the root-zone;
2. unique soil or sediment conditions that differ from adjacent non-wetland (terrestrial or fully aquatic) areas; and

3. vegetation (and generally animals) specifically adapted to permanently or seasonally wet conditions (see Maltby 2009b for details).

Yet, because the effects of hydrological processes and resulting functions extend well beyond the wetland boundary, there are also significant interactions with, and influences on, the wider landscapes of which they are part. The need for connectivity of hydrological processes between different elements of the landscape is especially important in the case of fisheries, as demonstrated by river–lake interactions in Tanzania (Hamerlynck *et al*. 2011, this issue).

Wetlands have been estimated to cover some 6% of the world's land surface (Maltby and Turner 1983). This is probably about half of the extent that existed before human modifications during historical times (Maltby 1986). Original estimates of wetland area and loss were compiled through inventories and maps. More recently, satellite images have been used (http://www.globwetland.org). However, the true extent and loss remains unclear due to complexity of wetlands and natural variations. Wetland loss and degradation has proceeded at least in part due to the poor understanding of their functioning and of their role in providing benefits to people through delivery and maintenance of ecosystem services. This contrasts with their intimate link with human communities in pre-historic times. Wetland loss has occurred either through deliberate or simply inadvertent actions resulting from decisions which have failed to take account of their full worth (Maltby 1991).

The essential linkage to water supplies (Acreman and Miller 2006, McCartney and Acreman 2009) also places wetlands centrally in some of the most contentious and urgent issues governing the most appropriate management of a resource for which there is intense competition and increasing uncertainty due to climate change. Whilst wetland hydrology is a natural science, its relationship to the water cycle is highly relevant to wider societal concerns, such as issues of alternative water resource allocation, water quality and flood risk (Maltby 2009a).

SPECIAL PLACE IN EARTH HISTORY AND HUMAN DEVELOPMENT

On a geological time scale, wetlands created an immense economic resource, but with potentially far-reaching unintended consequences for global climate, as a result of the imbalance in the wetland ecosystem between carbon sequestration and decomposition (Maltby 2010). Within the prehistoric period, they have provided the resources which supported human communities, ranging from the possibility of stimulating hominid evolutionary development to providing the platform for the establishment of early civilisations (Bell 2010). Wetland functioning in terms of food chain support, underpinned by the natural hydrological dynamics, was an essential ingredient to such progression.

Sieffermann (1988) described the modern-day analogues in Central Kalimantan of the tropical peat-swamps of 250 million years ago that produced the extensive coal deposits of the Carboniferous period. Continental shift and a different climate regime moved these vast carbon stores into the higher latitudes of Europe and North America where they would drive the Industrial Revolution of the 19th century (Maltby 2009a). Thus, the fossil forms of carbon sequestration by ancient wetlands had an immense impact on both economic and social development through industrialisation and world trade patterns. Further than this they are also a major source of the sharp rise in CO_2 emissions to the atmosphere with consequences for global warming. Such a relationship is a strong reminder of the importance of biogeochemical coupling between wetlands and the larger global system, and the importance of time, and rate of change, as considerations in environmental management (Maltby 2009a). In this case, the rate of conversion of the carbon store, which is orders of magnitude faster than its accumulation by natural wetland processes, is a cause of potential imbalance with undesirable consequences (Roulett 2000). The modern-day counterpart is the drainage or extraction of peat resulting in oxidation to CO_2 at rates far exceeding its fixation by peat-forming plant communities (Immirzi and Maltby 1992). Ironically, such degradation of peatlands in the modern era reduces the possibility of these ecosystems providing a wider resource for future generations or in future geological time.

A key challenge is to recognize the potential complexity of the wetland heritage in generating benefits at one time, but costs and potentially constraints at another; wealth to some, but hardship, even poverty to others; and competitive advantage in one place, but disadvantages in another (Maltby 1991, 2009a, 2009b).

HUMAN EVOLUTION AND CULTURAL DEVELOPMENT

Wetlands have played a significant role in the evolution of many species, contributing significantly to biodiversity (Gopal 2009). Tourenq *et al*. (2011, this issue) illustrate the link between a unique hydrological system and a unique biodiversity. It is also possible that key steps in human development took place in communities occupying the wetland margins of rivers, lakes and the sea. The "aquatic ape" theory suggests that the fatty acids derived from fish enabled brain capacity to expand to that characteristic of the modern human species (Morgan 1982).

For millennia, prehistoric communities benefited from the natural goods and services of these marginal wetlands, which were the sites of the earliest stages in the development of tool-producing hominids. Dolukhanov (1992) has ascribed the socio-economic development of prehistoric communities to the adaptation to the riverine-lacustrine environment by intensified foraging strategies. The intimate and highly dependent relationship between humans and wetlands in Mesolithic and Neolithic Europe is clear from excavations of numerous post-glacial lake margin settlements (Coles and Coles 1989). The Starr Carr house, recently excavated from the peat-infilled, former post-glacial Lake Pickering in North Yorkshire has been dated at 8500 BC and is the oldest known dwelling in the UK (Wainwright 2010). One aspect that is unknown, however, is the extent to which close proximity to water brought with it discomfort and health problems arising from disease vectors or contamination.

In developed countries, economic development has led to major wetland loss and has meant that people have apparently become less directly dependent on ecosystem services of wetlands over time. The main objectives for retention and management of remaining wetlands are often related to recreation services, and major funds have been dedicated to restoration and conservation, which is considered an affordable choice. This contrasts with the developing world, where many people still depend directly on the natural resources of wetlands and their ecosystem services for their livelihoods, but are, conversely, much more likely to modify wetlands to try and improve their livelihoods. Wetlands are very much viewed as a development opportunity, such as through agriculture, and the idea of protection—even to safeguard ecosystem services—is often viewed as a "luxury" that cannot be afforded. Thus the value that human societies put on wetlands has changed over time.

Whilst dependency was the mainstay of prehistoric communities in Europe, early civilisations were flourishing along the floodplains of major rivers such as the Tigris-Euphrates, Indus, Ganges and Nile (Solomon 2010). This was achieved through hydrological modification using simple water control structures, which stored and diverted water, and improvements in irrigation techniques. This led to less direct dependence on the variable natural annual flood pulse. It transformed the economy and reduced considerably the effort required to secure food. Harnessing and modification of the natural functioning of floodplain wetlands created agricultural wealth and surpluses for trade. Maltby (2009a) reviews how such "hydraulic civilisations" led to a step change in societal development and describes more fully as an example the technological and cultural legacy in the Mesopotamian wetlands, home of the Marsh Arabs.

As a result of periodic inundation, the floodplains of the major rivers of Africa, including the Senegal, Niger, Nile and Zambezi, support wetland ecosystems of exceptional productivity, particularly in comparison with the surrounding arid and semi-arid rangelands where the dry season is long and very arid (Acreman 1996). For centuries, these floodplains have played a central role in the rural economy of the region, providing fertile agricultural land which supports a large human population. They provide, uniquely, two sets of services associated with the distinctive and characteristic alternation between aquatic and terrestrial ecosystem phases (Drijver and Marchand 1985). The flood waters provide a breeding ground for large numbers of fish and bring essential moisture and nutrients to the soil. Water that soaks through the floodplain recharges the underground reservoirs, which supply water to wells beyond the floodplain, as demonstrated for the Senegal valley (Hollis 1996). As the flood waters recede, arable crops are grown, and some soil moisture persists to the dry season providing essential grazing for migrant as well as domestic herds. The floodplains also yield valuable supplies of fish, timber, medicines and other products, and provide crucial habitats for wildlife, especially migratory birds (Acreman and Hollis 1996). Thus wetlands have been particularly crucial for supporting livelihoods of rural poor, and Kumar *et al.* (2011, this issue) provide a conceptual framework for managing together the wetland ecosystem, poverty reduction and sustainable livelihoods.

The benefits of wetlands were presumably fully appreciated by earlier human cultures and certainly by traditional users of wetlands (such as wildfowlers, reed-harvesters, fishermen). However, malaria was endemic in many European countries and still is in many tropical countries, which often encouraged the seasonal use of wetlands, when resources were most plentiful, with permanent homes on higher, drier and mosquito-free ground. The benefit of wetlands were either ignored or dismissed as less significant by more powerful sectoral interest groups, and conversion was justified by promoting wetlands as unhealthy and disease-ridden (Maltby 1986).

Drainage of the English Fens to create rich farmland (Darby 1983) and establishment of agricultural polders in The Netherlands, where previously there had been sea and coastal marsh (Idema *et al*. 1998), were generally hailed as remarkable and desirable engineering achievements. For centuries "*the drainage of wetlands has been seen as a progressive, public-spirited endeavour, the very antithesis of vandalism*" (Baldock 1984). Yet, there was often local opposition—for example, the "Fen Tigers", people whose livelihoods were threatened by the ecological changes resulting from agricultural conversion. Facilitated by technological development and changing economic circumstances, the transformation of wetlands has led to the provision of other wetland services, such as food production from arable farmland, and non-services, such as residential or industrial use. This has necessitated fundamental hydrological alteration which carries a risk if modification is insufficient to deal with extreme events or the effects of unanticipated climate change. In effect, it reduces resilience in the landscape. Further, the properties of the wetland that make them attractive in the first place for alternative use may depend on maintenance of a certain hydrological regime. Without it, their value may decline or unanticipated consequences increase. The potential impact of drainage of organic soils on the world carbon cycle was recognized more than 30 years ago, primarily through research in Latvia (Glazacheva 1975), Estonia (Hommik and Madissoon (1975), Belorussia (Klueva 1975), and Sweden and Finland (Johansson and Seuna 1994), which demonstrated the "*significant alterations to the hydrological cycle of wetland drainage*" (Armentano 1980). Large agricultural areas reclaimed in the past century, south of the Venice Lagoon, Italy, have experienced significant land subsidence due to oxidation of peat organic soils (Gambolati *et al*. 2006). Such is the case, in the UK, of the Fens, in which the fertile peat has rapidly declined due to oxidation in a non-waterlogged environment. The Holme Post shows a loss of 5 m of peat in the East Anglian fens since 1858 (Waltham 2000). This exposes much less fertile inorganic substrates, requiring artificial fertilizer to support agriculture, but increasing the risk of groundwater as well as surface water contamination. The former regulatory services of the wetland have declined and the increase in provisioning services has persisted for a finite time only before requiring significant external subsidies, resulting in growing costs from pollution.

Despite increasing recognition of the adverse consequences, wetland alteration has continued worldwide. Well publicized examples include the shrinkage of Lake Chad in Africa (Coe and Foley 2001) and Central Asia's Aral Sea (Roggieri 2009), desertification of the marshlands of southern Iraq (Maltby 1994, Partow 2001), drainage of the peatlands of central Kalimantan (Morrogh-Bernard *et al*. 2002), and eutrophication of the Florida Everglades (Kadlec 2009). Such wetland degradation is often an indicator of adverse change in the catchment supplying the wetland. The changes in ecosystem services that occur as a result of drainage and alternative management are illustrated for the Hula Wetlands, Israel (Cohen-Shacham *et al*. 2011, this issue). Stratford *et al*. (2011, this issue) have developed a single tool for assessing the vulnerability of wetland ecosystem services to a range of such impacts.

RECOGNITION OF WETLAND VALUES

Initial scientific interest in wetlands focused rather narrowly on their description, origins of formation and ecological relationships. Research emphasized the individuality of separately-defined ecosystems in the landscape, such as bog *versus* fen or marsh *versus* swamp, instead of recognizing the over-arching importance of variation in the hydrological regime determining the range of wetland-forming conditions. Early studies were restricted to either their natural science or their part in the human economy (e.g. Good *et al.* 1978, Godwin 1981, Scudder and Conelly 1985); the two were rarely linked. Maltby (2009a) summarized from earlier analyses of the literature five features that have broken down this dichotomy and which have resulted in a paradigm shift, with wetlands assuming greater prominence on the scientific and political agenda in recent years:

1. An increasing scientific research focus on wetlands linked with the environment and conservation movements.
2. Raised awareness of the socio-economic significance of wetland functioning and delivery of ecosystem services.
3. Wider recognition of the far-reaching consequences of wetland degradation and loss, especially in relation to climate change.
4. Opportunities for wetlands, particularly in the developing world to deliver improvements in the welfare and livelihoods of local people through integrated development and poverty alleviation initiatives.
5. Progressive recognition of the potential or actual role of wetlands within various policy frameworks, including specific legislative instruments to deliver the wider objectives of sustainable development.

Especially since the 1970s, there has been greater emphasis of wetlands generically as a rich natural resource offering a wide range of goods and services that stem from how they function in the landscape. In particular, research in the USA began to highlight the "functions and values" of wetlands (e.g. Horwitz 1978, Greeson and Clark 1980, Adamus and Stockwell 1983, Tiner 1984, Sather and Smith 1984). Whilst leading to some confusion through this mix, and publishing lists initially that did not caution sufficiently that not all wetlands performed all functions (Maltby *et al.* 1996, Maltby 2009a), and that some performed contrary functions (Bullock and Acreman 2003), this emphasis underpinned a new policy direction not only for the USA, but which would be influential globally.

Continuing to move beyond the individual site or ecosystem type, the vital role of wetland habitats and their connectivity across national boundaries and continents for conservation of populations of migratory birds was the essential driver for the Convention on Wetlands of International Importance Especially as Waterfowl Habitat—known by the initial title of the Ramsar Convention. The rationale of protecting not just individual wetlands, but whole networks, was a major step forward in recognizing the need to safeguard breeding, over-wintering, resting and feeding sites that made up often complex life cycles. The undoubted success in raising the profile of wetlands internationally also attracted criticism from developing nations, reluctant to join the Convention on the basis that it failed their alternative priorities, such as poverty alleviation, due to lack of economic development and burdens of debt. With sensitivity to the inherent bias towards the interests of richer nations, there was a dramatic change in the character of the Convention at the 1987 Conference of Parties in Regina, Canada. This took the form of a revision of the criteria for designation of a Wetland of International Importance to reflect more the wider functional role of wetlands, and also the elaboration of the "wise use" requirement to put more emphasis on the link to sustainable development (Maltby 1991, 2009a). The wise use concept was particularly important for recognizing the value to local communities of exploiting wetland resources and services, provided that this was sustainable and did not degrade the wetland. It also recognized the fact that many traditional management practices shaped and enhanced the character of wetlands, rather than wetlands being in need of complete protection that excluded people. There is now a comprehensive conceptual framework for the wise use of wetlands and the maintenance of their ecological character (i.e. "the structure and inter-relationships between the biological, chemical, and physical components of the wetland", Ramsar Handbook 1). This complements the other Convention volumes dealing with water management. Thus, whilst the bird lobby had succeeded from the 1960s in raising the profile of wetlands internationally, it was the translation of their functional importance, contributing for example to flood control, water quality and fisheries, that attracted the broader international commitment. Since Regina, key new members joining the Convention have included Botswana, Brazil, Cameroon, Chad, China, Cuba, Congo, Tanzania, Zambia and Iraq; the total number of contracting parties is now 160 and includes 1923 sites covering more than 187 million hectares (Ramsar Secretariat 2011).

The transformation of emphasis at Regina was five years ahead of the Earth Summit in Rio in 1992, which brought to global prominence the concept that natural ecosystems are vital for human life. Whilst this was already well known by earlier generations, Rio succeeded in codifying the recognition of the importance of nature. Manifest through the Convention on Biological Diversity (CBD), the balanced objectives of conservation, sustainable development and equitable sharing of the benefits of genetic resources were proposed to be realized by means of the "ecosystem approach". The ecosystem approach was adopted as the methodological framework for meeting the key objectives of this important global convention. Its definition under the CBD has a clear hydrological component: "*. . . the integrated management of land, water and living resources to achieve sustainable management in an equitable way*." In parallel, water managers were developing ideas of Integrated Water Resource Management (IWRM—see Global Water Partnership http://www.gwp.org/), and catchment managers the notion of Integrated River Basin management (IRBM), which have many fundamental concepts in common, such as working at a landscape (normally river basin) scale, involving diverse scientific disciplines from engineering, through life and environmental sciences to sociology and economics, and ensuring participation of stakeholders from local communities to national governments and international bodies. Many developing countries are endorsing IWRM approaches, and changing policies etc. to incorporate the principles. However, few have the resources to implement them well, and so, given the constraints they face, this generally reflects an aspiration rather than a realistic approach to water resources management. The European Water Framework Directive incorporates this type of thinking, and de la Hera *et al.* (2011, this issue) have developed a wetland typology to support river basin management plans for the implementation of the Directive. The cross-cutting features of wetlands place them centrally in the implementation of the ecosystem approach and they feature prominently in case study examples worldwide (Smith and Maltby 2003, Maltby 2006).

Explanation of the links from wetland ecosystem processes to functioning as part of a natural environment domain and, thence, through socio-cultural and economic networks to human values (Maltby *et al*. 1994) established a rationale to underpin the scientific relationships between ecosystem structure and functioning and the delivery of ecosystem services. Hydrological processes and functioning are key drivers of the many physical and biochemical interactions within ecosystems which in turn control the performance of the services beneficial to humans.

The Millennium Ecosystem Assessment formalized the concept and definitions of ecosystem services, the recognition of which is a vital element in the practical "operationalisation" of the Ecosystem Approach. Acreman and Mountford (2009) provide a link between processes, functions and services (Table 1) with examples from wetlands, whilst Maltby (2009b) developed an innovative methodological approach to predict the likelihood of particular wetland functions and resulting service delivery.

Table 1 Wetland processes, functions and services (after Acreman and Mountford 2009).

Processes	Functions	Services
Denitrification and other transformations of nutrients in plant cells	Uptake from water and use of nutrients by plants	Improvement in water quality through reduced nutrient
Downward movement of water by gravity from the wetland into underlying strata	Recharge of aquifers	Augmentation of groundwater resources available for human use
Movement of water from rivers during high flows to inundate a floodplain surface, fill depressions and saturate the soil	Flood water storage	Reduction in downstream flood risk
Production of peat from dead plant material in anaerobic conditions	Carbon storage	Reduction in greenhouse gases

Vilardy *et al.* (2011, this issue) and Singh *et al.* (2011, this issue) provide examples of the links between hydrology, ecosystem services and human well-being. Campos *et al.* (2011, this issue) found that there were no significant differences between swamps and marshes in their ability in water retention and carbon sequestration. The provision of ecosystem services may depend on the particular ecological state of the aquatic system, and Gomez-Baggethun *et al.* (2011, this issue) indicate how changes can occur depending on the alternative stable states in Donana Marsh, Spain. Changes in state do not necessarily mean the complete destruction of a wetland. In certain circumstances, maintaining fixed ecological character may not be appropriate; this is a societal choice.

Integrated catchment management involves putting in place a series of linked actions that together deliver the goods and services required by mankind, including: land for farming, housing and industry; supplies of freshwater for public use, irrigation and power generation; protection from floods; and a healthy environment for recreation. River basin authorities are increasingly recognizing the maintenance of natural resources and functions of ecosystems, such as wetlands, as a key strategy for sustainable development (UNEP/WI 1997). The

Ramsar Convention provides guidance on integrating wetlands into river basin management (Ramsar Secretariat 1999). Clear recognition of the important links between the hydrological functioning of wetlands and human well-being emerged from studies of the Charles River watershed, Massachusetts, USA (Sather and Smith 1985, Doyle 1987) and the effects of closure of the Aswan High Dam. The United States Corps of Engineers demonstrated the financial benefits of using natural wetlands for flood control in the Charles River catchment. This was further elaborated for Europe under the ECOFLOOD project (Blackwell and Maltby 2006). It was estimated that flood damage would increase by at least US$ 3 million per year if 40% of the wetland area were removed, rising to US$ 17 million if all were lost. An annual value of over US$ 1 million was placed on the retained wetlands. It was financially advantageous to retain wetlands rather than build new engineering structures to achieve flood control, and the Corps of Engineers finished in 1984 the acquisition of the wetlands "at fair market value" (Doyle 1987). The recent work by McCartney *et al.* (2011, this issue) has shown that the GaMampa wetland of South Africa has a value of more than US$ 80 000, even though it comprises less than 1% of its catchment. Lack of understanding of the economic value of the services provided by wetlands inevitably leads to poor policy decisions (Verma and Negandhi 2011, this issue).

Closure of the Aswan High Dam in 1965, and the consequent alteration in hydrology, sediment and nutrient dynamics, caused a dramatic decline in the sardine and shrimp fishery in the eastern Mediterranean causing the closure of canning factories and substantial economic losses (El-Sayed and van Dijken 1995). However, the dam was beneficial to the general economic development of Egypt and a new fishery (of a different type) has been created in Lake Nasser. This provides a good example of trade-off and distributional effects (i.e. who benefits and who loses as a consequence of development. Despite the strength of evidence, Barbier (2011, this issue) contends that wetland services are nearly always underdeveloped and non-marketed. There is thus a particular need to make more explicit valuations to determine the trade-offs between converting or exploiting wetlands and any resulting loss of services. Rouquette *et al.* (2011, this issue) discuss this in relation to the switch in Western Europe from floodplain management for agriculture to the provision of wider services. A detailed analysis of trade-offs in ecosystem services according to different management regimes has been carried out by Acreman *et al.* (2011, this issue) for the Somerset Levels and Moors, UK. It reveals both synergies and conflicts that inevitably make decision-making in optimal water management complex and subject to different stakeholder pressures and influence.

LINKS TO SUSTAINABLE DEVELOPMENT

Delivery of water to sustain wetland functioning is a key element in maintaining or enhancing the services from wetlands. Management for the long term is essential and may require institutional support, such as through legal instruments (Sullivan and Fisher 2011, this issue).

In many parts of Africa, water is the limiting resource and development options need to be considered in terms of the most beneficial use of water. Barbier *et al.* (1991) demonstrated that the net economic benefits of ecosystem services (fishing, agriculture and fuel wood) from the Hadejia-Nguru wetlands in Nigeria were US$ 32 per 1000 m^3 of water, whereas returns from crops grown on the Kano River project (to which water upstream of the wetlands is now diverted) were only US$ 0.15 per 1000 m^3. Barbier and Thompson (1998) concluded that the additional value of production from large-scale irrigation schemes does not replace the lost production attributable to the downstream wetlands. Furthermore this valuation did not include other services of the wetlands, such as groundwater recharge, biological diversity and cultural heritage. Recharging of groundwater has long been recognized as an important function of wetlands and Hollis *et al.* (1993) concluded that recharge in the Hadejia and Jama'are river basins of northern Nigeria occurs primarily during flood flows, since the floodplain provides a large surface area and the river bed is often impermeable. Changes in the recharge function result in welfare losses for wetland populations (Acharya 1998). Recently constructed dams have reduced the area inundated, but insufficient monitoring of groundwater levels is being undertaken to assess the impact, at a time when development agencies are sponsoring agricultural development by pumping of water from aquifers beneath the floodplain, which may not be sustainable (Acreman 1996).

The maintenance of naturally flooded conditions may also be an essential requirement to avoid severe environmental degradation. Such is the case in avoiding the oxidation of potential and acid sulphate soil materials (PASS) resulting from drainage schemes, upstream river regulation or local engineering works. Of particular significance is the Mekong Delta, which contains an estimated 2×10^6 ha of PASS. The drawdown of water associated with conversion of *Melaleuca*-dominated wetland forest to rice paddy may increase acidity of surface waters to below pH 2.0 with serious implications for rice yields, fisheries and human health (Maltby 1996, 2006, Safford *et al.* 2009). The annual flood pulse in the Tonle Sap wetland in Cambodia supports great biodiversity and major fisheries (Kimmu *et al*. 2006). Pioneering work by Ni (2000) has shown the multiple benefits of the traditional *Melaleuca* wetland ecosystem and, more importantly, how re-establishment of wetland hydrological flows in close association with rice paddy can counteract adverse levels of acidity, improve rice yields and enhance sustainability.

SOME KEY MILESTONES

During the past 40 years, there has been a series of key milestones in the evolution of wetland science and policies.

A dedicated international Convention

The Ramsar Convention has been highly adaptive since its original adoption in 1971. It has moved significantly from its origins in the bird conservation lobby to a much broader remit linked to the wider benefits of wetland conservation and management to people. A wetland qualifies for the designation of "international importance" if it meets criteria related to functioning, such as hydrology, ecology and support of human as well as wildlife populations. Fulfilling "wise use" requires the understanding of the hydrological fundamentals which retain ecological character and set the parameters for sustainable use.

Regulatory frameworks in North America and elsewhere

Wetland functions are given particular emphasis under United States Federal Law through implementation of the 404 Program authorized under section 404 of the Clean Water Act (33 US Code 1344). Activity likely to impact on wetlands requires a permit and no permit will be granted which involves alteration of wetlands identified as performing functions important to the public interest. The need to assess wetlands in the context of the permitting process coupled with a "no net wetland loss" policy underpins the development of functional assessment methodologies in the USA (Smith *et al.* 1995, Brinson 1996, 2009). Canadian policy on wetlands has also emphasized an approach that highlights their functional importance. As early as 1991, the objective was to "promote the conservation of Canada's wetlands to sustain their ecological and socio-economic functions, now and in the future" (Government of Canada 1991). The policy goals are very much in line with the wise use requirements of the Ramsar Convention and include maintenance of functions and values, as well as recognizing wetland functions in resource planning, management and economic decision making (Maltby 2009a). It is noteworthy that the Canadian Policy model has been influential elsewhere in framing a wetland policy, notably in the case of Uganda (Republic of Uganda 1995).

Further elaboration of the Functional Approach in Europe

"*A functional approach to wetland assessment is one that acknowledges that wetlands can perform work at a variety of scales in the landscape, which may result in significant direct and indirect benefits to people, wildlife and the environment*" (Maltby 2009b). The development of a European methodological procedure for the assessment of wetland functions has paralleled that in the USA (Maltby *et al.* 1994). The key differences from the USA context are manifest at the detailed operational level, e.g. lack of a regulatory programme in Europe, with a strong element of human intervention through frequent direct wetland management, including formal conservation strategies in Europe and extreme geographical diversity coupled with often small size of individual wetlands. A major interdisciplinary research initiative resulted in the development of Function Assessment Procedures (FAPs), which also provide insight into the delivery of ecosystem services (Maltby 2009b). The FAPs focus on river marginal and lake marginal wetlands and differ from US methodologies primarily through their scale of application and link to an underlying empirical science base. The fundamental unit of assessment is the hydro-geomorphic unit (HGMU) defined as an "*area of homogeneous geomorphology, hydrology and/or hydrogeology and under normal conditions, homogeneous soil/sediment*" (Maltby *et al.* 1998). Hydrological functions assessed include floodwater detention, groundwater recharge / discharge and sediment retention. Other functions assessed are biogeochemical and ecological. Full details are given by Maltby (2009b). One of the important implications of this approach is that it provides a means of assessing the many undesignated or non-formally protected wetlands that often occur in association with farmland or other land uses. These may play a pivotal role in the delivery of important ecosystem services in some landscapes (Blackwell and Pilgrim 2011, this issue). In comparison, Okruszko *et al.* (2011, this issue) present an overview of ecosystem services of European protected wetlands and examine the implications of hydrological alterations caused by future climate and socio-economic changes.

INNOVATIONS

Recent policy changes in some countries have recognized an unprecedented level of significance of wetlands. Notable is the importance of major wetlands in Australia identified through the Water Act (2007) and the emerging plan of the Murray-Darling Basin (MDBA 2010). Some 18 significant wetlands are recognized as "environmental assets", which require guaranteed water flows for maintenance. Historically, the necessary environmental flows have been deficient not least because of diversion to agricultural (primarily) irrigation use. The Australian Government has embarked on a major programme of purchasing the irrigation licences from farmers willing to sell, and has also made funds available for improved infrastructure to make better use of water resources, in particular to achieve increased environmental flows for the major wetlands of the Basin. The guide to the proposed Murray-Darling Basin Plan, however, has met with considerable opposition, especially from rural communities, and resolution of the conflicting demands is still awaited.

The recognition of the ecosystem services of wetlands led to appreciation of their economic value (Barbier *et al.* 1997, Turner *et al.* 2008) and a progressive willingness to pay to maintain them (Smith *et al*. 2006). For example, the Catskills and Delaware river basins cover some 4000 km^2 and provide 90% of the drinking water supply to New York City's 9 million residents. Historically, these catchments have supplied high-quality water, but, in the 1980s, concerns about pollution increased. In 1989, the US Environmental Protection Agency initiated a requirement that all surface drinking water supplies had to be treated by filtration, unless it could be demonstrated that existing treatment processes or natural river basin services were sufficient to provide safe water. In 1992, the City of New York decided to invest in protecting the river basin area rather than build new water filtration facilities, which would have cost US$ 6–8 billion to build and US$ 300 million annually to operate (Smith *et al.* 2006). The costs of investing in basin management to maintain and restore natural filtration are much lower. Investment of US$ 1–1.5 billion over 10 years was financed by a 9% tax increase on New York City water bills; a new filtration plant would have required a two-fold increase in water bills. The City has also provided US$ 40 million in compensation to cover the additional costs of dairy farmers and foresters who adopted best management practices.

In many cases, ecological restoration has been attempted to recover the benefits of wetland ecosystems. From the mid-1990s, the scale of the schemes was greatly increased. The justification for these landscape-scale restoration schemes was: (a) to safeguard existing wetland fragments through creating buffer zones around them; (b) to achieve a critical extent of wetland for species that require large areas; (c) to link wetland fragments to allow dispersal of species; (d) to achieve carbon sequestration through vegetation growth and peat formation; and (e) to meet fundamentally the goals of the Convention on Biological Diversity at national scales for habitat restoration (Acreman and Mountford 2009). In Europe, the first major schemes were in The Netherlands, e.g. Oostvaarders Plassen and Lauwersmeer, both exceeding 5000 ha (Kampf 2000). Over the past two millennia, the Fenlands of eastern England have changed from a natural wetland of fens, swamp, carr and open water to an almost entirely pump-drained intensive arable landscape, such that, by 1900, only 0.1% of the original fen habitat resource survived (Colston 2003). From the early 1990s, a "Wet Fens for the Future" programme stimulated wetland restoration. The largest scheme (37 000 ha) is the Great Fen Project; it incorporates remaining "island" wetlands at Holme and Woodwalton National Nature Reserves (Gerrard 2004) and intervening arable land. Restoration objectives focus on functional integrity and resistance to invasion by new species (Hughes *et al.* 2005), which requires an appropriate hydrological regime. Initial focus was therefore on the feasibility of sufficient water availability to meet the requirements of wetland plant communities (Wheeler *et al.* 2004) under current and future climates and the potential for hydrological functions, such as flood water storage. Results of hydrological modelling (Mountford *et al*. 2002) showed that wetland restoration of the majority of the scheme area would require storage of around 3×10^6 m^3 of the winter excess water to meet summer demand for 17 000 ha restoration one year in two. Winter discharge from the Great Fen area exceeded 3×10^6 m^3 during 32 of the 38 years of record available. However, it was estimated that storage of 8×10^6 m^3 would be needed to cope under the 2050 climate (with reduced summer rainfall) predicted by the Hadley Centre HadCM2 model (UK Climate Impacts Programme 1998). Considerable savings are anticipated as currently flood water is pumped mechanically from the area.

Restoration of the Mesopotamian marshes poses one of the world's greatest hydrological and socio-political challenges. The historical snowmelt flood pulse of the Tigris and Euphrates rivers fed a wetland area of some 25 000 km^2 until the 1970s (Maltby 1994, Partow 2001). The range of marshland types generated by variation in hydro-period provided vital services, not only to the unique Marsh Arab (Madan) culture, but also more widely (Table 2). Some 90% of the wetland area had been lost by 2000, increasing to 93% by 2003, as a result of upstream and in-country engineering works which are well documented (Maltby 1994, Partow 2001). The loss of marsh ecosystems has "*raised concerns over depletion of important bird populations, extinction of endemic rare animal and fish species . . . Increased frequency of dust storms and the effects on regional climate and loss of fish nursery grounds . . . which extend well beyond the boundaries of the freshwater wetlands*" (Maltby 2005). Initially uncoordinated, but subsequently government supported, re-flooding of the marshes started in 2003. In Spring 2005, UNEP reported 50% recovery. Field surveys have documented a surprising degree of biodiversity recovery (Richardson and Hussein 2006, Abed 2007). It is not clear what will be the final extent of restored wetland. This is dependent *inter alia* on the priority use of water resources upstream in Iraq, as well as bilateral/ multilateral discussions with neighbouring countries, especially Turkey and Iran who are drawing down water which otherwise could support restoration. Unfortunately, the ability of restored marshes to generate a wide range of human benefits is not always realized let alone quantified (Maltby 2009a). Restoration must compete with other priorities of a fledgling government. Security, urban and agricultural water supply, power generation, health and economic development all currently attract greater attention of government time.

Table 2 Importance of the Mesopotamian Marshlands (after Maltby 1994).

Unique human community supported by natural resources
Productive traditional agriculture
Sustainable utilisation of wetland and adjacent land
Buffalo and cattle
Fishing and birds
Reeds and other plants
Cultivation
Integrated transport
Habitat for important populations and species
Intercontinental migration
Regional biodiversity
Rare and endemic species
Globally threatened birds, mammals, invertebrates
Cyprinid marsh species of high evolutionary significance
Linkage to Gulf
Hydrological interface between catchment and marine ecosystem; Discharge; Water quality (nutrients, salinity, contaminants); Sediment; Temperature continuum for movement of economically important fish/shrimp e.g.
– *Metapenaeus affinis*
– Pomphret
– Saboor
Microclimate
Environmental reconstruction
Peat/sedimentary deposits

STRENGTH OF THE SCIENTIFIC EVIDENCE

Whilst there have been considerable recent advances in knowledge, there are still many commonly-held views about the functioning of wetlands and provision of resulting services that do not necessarily have the support of a sufficiently robust evidence base. This is due at least in part to the inherent variability of wetland ecosystems and the limited scope of hydrological research. We have selected just a few examples to question the verifiable evidence against the anecdotal viewpoint which may be more prevalent.

Wetlands and floods

In many analyses of ecosystem services of wetlands, their role in the hydrological cycle has been highlighted. Wetlands are often said to "act like a sponge", soaking-up water during wet periods and releasing it during dry periods (e.g. Bucher *et al.* 1993). The basic references on the hydrological functions of wetlands are summaries of studies collated in the USA in the 1980s (Adamus and Stockwell 1983, Bardecki 1984, Carter, 1986). These summaries have been used by organizations, such as IUCN—the World Conservation Union (Dugan 1990), Wetlands

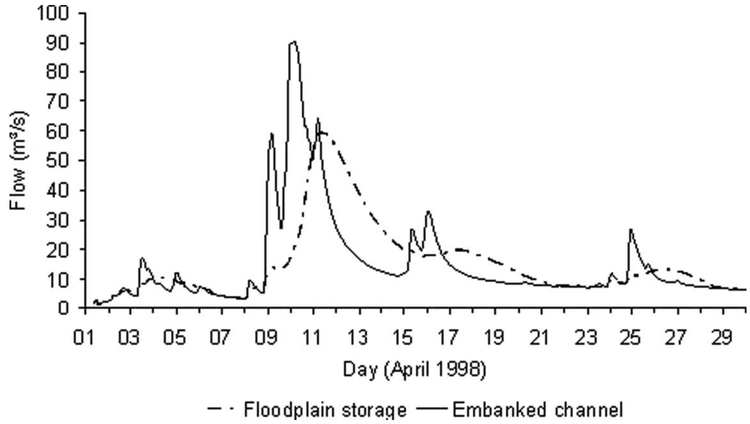

Fig. 3 Observed flows on the River Cherwell (dashed line) compared with modelled flows removing floodplain storage by embanking the river (solid line) (after Acreman *et al*. 2003).

International (Davies and Claridge 1993) and the Ramsar Convention on Wetlands of International Importance (Davis 1993). In a literature review of the hydrological functions of wetlands, Bullock and Acreman (2003) found that most (23 of 28) studies show that floodplain wetlands reduce or delay floods, with examples from all regions of the world. For example, a modelling study of the River Cherwell in Oxfordshire, UK (Acreman *et al*. 2003) showed that separation of floodplains from the river by embankments increases the peak flows downstream by up to 150% (Fig. 3). Floodplain water storage is largely on the surface; thus the wetland is not strictly acting like a sponge.

For wetlands to "soak-up" water internally within their soils, there would need to be some storage capacity, i.e. the soil would need to be dry. Many wetlands have a hydro-period that includes drier and wetter phases. Campos *et al.* (2011) show that forested wetlands and marshes along the Gulf of Mexico take-up water from June to October, as water levels rise by up to 1.2 m. Whether this reduces floods depends on when flood-producing rainfall occurs; if a wetland is already saturated, it offers no or limited flood storage (Acreman *et al*. 2007). Indeed, areas of saturated soils in headwater areas are defined as runoff contributing areas by hydro-geomorphologists (e.g. Hewlett and Hibbert 1967).This relationship forms the basis of rainfall–runoff models used by hydrologists, such as TOPMODEL (Beven and Kirkby 1979). Runoff from these areas tends to be overland and runoff speed is faster across bare soils than though vegetation (Holden and Burt 2003). Runoff speed is also faster if water can travel through drains or natural pipes in the soil. Thus, wetland restoration can reduce floods downstream by re-vegetating bare wetlands (Bonn *et al*. 2009), or blocking of "grips", drainage ditches in peatland (Wilson *et al.* 2010). Because of this complex relationship between wetland water regimes and hydrology of the wider catchment, care must be taken when extrapolating findings from one wetland study to produce generic guidance on wetland functions and services.

Wetlands and groundwater

Many wetlands exist because of underlying impermeable layers that prevent vertical movement of water. However, other wetlands are hydrologically connected to underlying aquifers (Acreman and Miller 2002). For example, the Azraq Oasis in Jordon (Fariz and Hatough-Bouran 1998) is fed by upward moving groundwater (discharge). In contrast, during inundation of the floodplain wetlands of the Senegal River valley, water moves downwards to the underlying aquifer (recharge) (Hollis 1996). Alteration of catchment hydrology, including abstractions from surface water and groundwater, impoundment or diversion of rivers and land-use change, can all have a significant impact on wetlands and the functions they perform. For example, the Las Tablas de Daimiel wetland in Spain (Llamas 1989) was historically groundwater-fed, by water moving upwards from the underlying aquifer. From 1972, irrigated agriculture expanded rapidly with EU subsidies and through intensive use of groundwater from 16 000 wells (Acreman 2001). During long periods of low rainfall, groundwater levels declined by 20–30 m (Bromley *et al.* 1996) stopping groundwater discharge and causing degradation of the wetlands. Any water that reached the wetland percolated downwards into the depleted aquifer (Fornés and Llamas 2001), reversing the function of the wetland to that of a groundwater recharge site. Local farmers considered reduced evaporation (from a smaller wetland) and increased recharge as a beneficial change in ecosystem function, yielding more groundwater for abstraction.

Wetlands and water quality

There is a substantial literature relating to the role of wetlands in the protection and/or enhancement of water quality (Maltby 2009b). For example, the Nakivubo papyrus swamp in Uganda receives semi-treated sewage effluent and highly polluted storm water from Kampala. During the passage of the effluent through the wetland, sewage is absorbed and the concentrations of pollutants are considerably reduced, such that water can be abstracted nearby for public water supply (IUCN 2003). This function has led to their use as buffer zones, particularly in the prevention of contaminants from agriculture and sometimes urban or industrial sources reaching main streams or lakes. The degree to which this service and the resulting purification of water occur depends not only on hydrology but also on size, location, vegetation and soil type (Leeds-Harrison *et al.* 1996, Dosskey *et al*. 1997), as well as the nature of the source impacts. Processes including denitrification, plant uptake, absorption and sediment retention enable the removal or storage of nutrients, heavy metals biocides and sediment (Blackwell and Maltby 1998, Blackwell *et al.* 1999). Hydrological conditions control these processes and the precise functioning of the wetland buffer (Maltby 2009b). Convention has generally advocated the position of buffer zones as riparian strips alongside rivers and streams to counteract the contaminating effect of runoff (e.g. Cooper 1990, Haycock and Burt 1993). Whilst such positioning can be highly effective in removing pollutants from diffuse sources such as shallow groundwater or sheet-flow runoff, they may be completely bypassed when hydrological flows are intercepted by ditches or drains. This is particularly common in the European agricultural landscape (Goudie 1986). The most effective location of the wetland buffer may actually be along the alignment of such ditches, and downslope, generally at right angles to the river or stream course (Blackwell and Maltby 1998). In a study site on the River Torridge, UK, it was found that the wetter overflow zones associated with drainage ditches regularly removed more than 90% of the nitrate from adjacent agricultural land (Blackwell 1997). This emphasizes the importance of hydrological pathways in the landscape as a factor to determine the most efficient pattern and management of wetland buffer zones.

Peatlands and carbon sequestration

Interest in the capacity of peatlands to help mitigate climate change through carbon sequestration has stimulated significant questions regarding the status of current peat resources and the possibility of new formation (Immirzi and Maltby 1983, Maltby 2010). The answers are particularly relevant to the management of upland ecosystems in the UK. This is the case with the potential benefits associated with the blocking of ditches (grips) in the peat to help restore hydrological integrity previously disrupted by drainage. It is still uncertain whether such management actions to increase waterlogging are sufficient to reverse the carbon balance in favour of increased storage. (e.g. Worral *et al.* 2003, Worral and Evans 2009). Other factors, such as burning and grazing, are important in determining the stability of the existing carbon store. Of overriding importance, however, is whether the current (or immediate future) climatic conditions are sufficient in combination with the local factors such as topography, substrate conditions, vegetation, acidity and nutrient status to enable new peat formation. Despite considerable on-going research, there is still uncertainty regarding the existence of the necessary climate template, at least in the UK, for the net accumulation of new peat. It does not detract, however, from the argument to maintain or restore hydrological conditions so as to minimize any further losses of existing carbon store in peatlands.

Trade-off

The issue of trade-off arises when wetlands are modified from their “natural” state. This usually involves hydrological change. The management decision then becomes influenced by policy priorities or particular stakeholder influence. Dilemmas are inevitable. An example highlighted as illustration in the UK National Ecosystem Assessment (2011) is that of using wetlands for water quality protection/improvement with resulting increase in generation of nitrous oxide, a potent greenhouse gas. Based on the possible implications of trade-offs, a compatibility matrix (Table 3) has been developed for particular ecosystem services in upland peatland (Maltby 2010). Acreman *et al.* (2011) examined trade-offs

Table 3 Compatibility matrix for management of ecosystem services in upland peatlands (after Maltby 2010).

Affected ecosystem service	Managed ecosystem service:							
	Carbon storage/ sequestration	Water quality	Flood risk reduction	Crops/ livestock/ game production	Habitat/ species	Palaeo-environmental information	Traditional recreation	Landscape (especially wilderness)
Carbon storage/ sequestration		+	+	–[b]	+	+	–[c]	+
Water quality	+[a]		+	–[d]	+	+	–[c]	+
Flood risk reduction	+	+			+	+	–[c]	+
Crops/ livestock/ game production	–[d]	–[d]	–[d]	–[d]	–[d]	–[d]	No effect	+
Habitat/ species	+	+	+	–[d]		+	–[c]	+
Palaeo-environmental information	+	+	+	–[d]	+		No effect	+
Traditional recreation	–	–	–	–[d]	–	–		No effect
Landscape (especially wilderness)	+	+	+	–[d]	+	No effect	+	

[a]not necessarily for colour; [b]storage may be maintained depending on level of impact; [c]certain low-impact amenity access may be compatible; [d]except game.

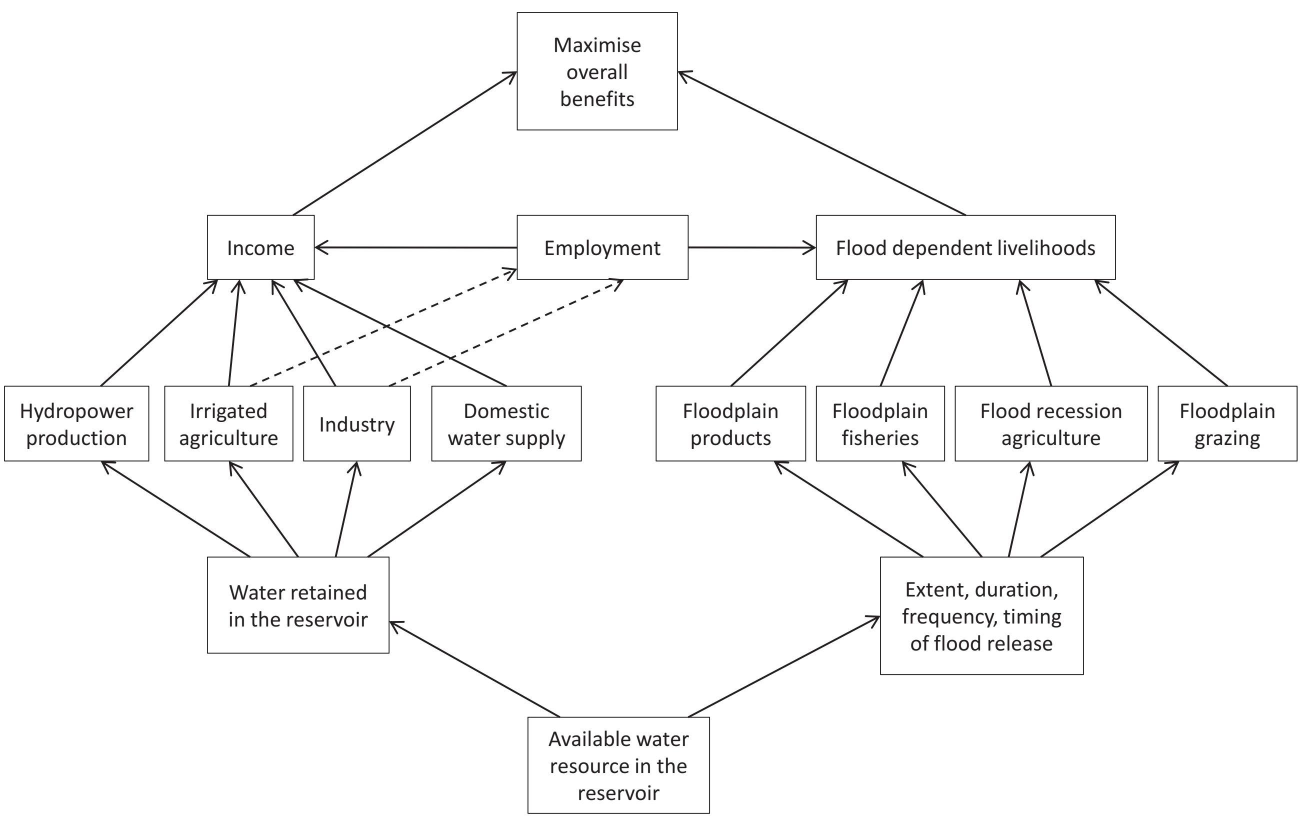

Fig. 4 Trade-off considerations in making decisions about managed flood releases from reservoirs to conserve downstream floodplain wetlands (after Acreman and McCartney 2002).

in ecosystem services in the Somerset Levels and Moors, UK. Results show that high water levels reduce carbon dioxide emission and increase bird habitat and hay production, whilst lower water levels improve grazing quality, reduce floods and reduce methane emissions. Management decisions on wetlands are thus a trade-off of ecosystem services as demonstrated for flood releases from reservoirs (Fig. 4) to conserve downstream floodplain wetlands (Acreman and McCartney 2002).

More evidence-based assessments for different wetland types and locations will be necessary to strengthen the basis for decision making regarding other use and management. Further development and testing of the functional approach to assess the extent to which a wetland or part of a wetland can actually deliver a particular individual, or combination of service(s) will be a key step in strengthening the evidence box. It will be essential to link the natural science evidence with outcomes expressed in both social and economic terms, to enable fully informed societal decisions on the optimal (wisest) use of wetland resources.

There are still many gaps in our technical understanding, methodological techniques and locational knowledge that need filling. Notably we will need to understand much more about the effects of land-use change on wetland functioning, the interactions among ecosystem processes and the influence of environment, especially climate change, on functioning and service provision. There is still limited knowledge of the location and distribution of small wetlands in the landscape, or of the amount of wetland required to support a specific quantity or quality of ecosystem service.

INFLUENCING POLICY

Wetlands have played an important role in influencing government and international policy. These include those seeking subsidies to drain them or convert them to forest (e.g. UK incentives leading to planting of blanket bogs of Caithness and Sutherland, Maltby 2010), as well as those seeking their protection and sustainable management (e.g. EU environmental policy, Water Framework Directive, Ramsar Convention).

The growing ecosystem service evidence base, outlined in a growing number of over-arching assessments, and further demonstrated in this Special Issue, provides a platform for an even stronger focus on the potential importance of wetlands within the policy mix. Yet, a major constraint lies in the fact that there is a wide range of services provided with a major range in performance depending on wetland type and cutting across contrasting policy sectors. There are few countries with a distinct wetland policy. Europe is noteworthy in lacking a Wetlands Directive even though it has developed a holistic policy for water through the Water Framework Directive (WFD) The WFD is lacking in its consideration of non-designated wetlands despite the fact that their management in the landscape is highly relevant to many of the measures required to deliver the ambitions of the Directive.

Two recent initiatives, one global, the other national, can contribute to raising the profile of wetlands and their hydrological management as a lynchpin for a sustainable environment. The Economics of Ecosystems and Biodiversity (TEEB) project (Kumar 2010) has demonstrated the real value of natural capital including wetlands. In the UK the National Ecosystem Assessment (NEA, WCMC 2011) has raised awareness of the services provided by specific priority habitats such as wetlands and their connections with human well-being. Such initiatives further reinforce the case for a more coherent approach to wetlands. Hydrology is key and the hydrological cycle links land and water across different landscapes and economic sectors. The inappropriate distribution of the costs and benefits associated with water management can only be rectified by more holistic and integrated approaches to the natural environment and socio-economic sectors.

THE WAY AHEAD

The rationale and strategy for wetland protection and management has relied for a long time on the strength and significance of the conservation (and especially the bird) lobby. This will no doubt continue to be important. However, in the face of unprecedented increases in world food and other commodity prices, the growing concern in meeting basic human needs, such as clean water, relief from poverty and safety from environmental hazards, there is need for a complimentary human-centric approach that takes account of aspects seen as more directly related to wider aspects of livelihoods and human well-being. Such a new paradigm would attempt to couple the often contradictory policy areas by focusing the hydrological management and associated management of wetlands on outcomes rather than ecological or other typologies. Such outcomes could be structured around ecosystem services, e.g. cleaner water, reduced flooding, slower climate change, improved human health. Economic analysis should be used to examine the efficiency of spend/costs associated with wetland management compared with the expenditure across different sectors, not always working in the same direction. This paper has illustrated some historic examples where the cost of maintaining wetland hydrology was by far the least expensive option in meeting a desired outcome.

The successful implementation of a new approach will require widespread buy-in from vested interests, especially farming communities. Innovative tools can assist in this—notably payments for ecosystem services which can go a long way in rectifying the imbalances between costs and beneficiaries from those services (e.g. Kumar *et al.* 2011). A unifying Wetland Policy, complementing existing legislations would go a long way in achieving greater coherence to the complexity of different policies impacting on land and water management. It would move away from the "silo" of protected areas alone to emphasize the importance of the greater wetland resource which exists outside formal designation. The designated iconic sites can still serve as the standard bearers of our vital natural environment, but the broader view is likely to generate greater resonance amongst the wider public and the political process that is wrestling with the enduring impact of the result of global financial crisis.

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