Wetland ecosystem services

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WETLAND ECOSYSTEM SERVICES

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ABSTRACT: Wetlands provide important and diverse benefits to people around the world, contributing provisioning, regulating, habitat, and cultural services. Critical regulating services include water-quality improvement, flood abatement and carbon management, while key habitat services are provided by wetland biodiversity. However, about half of global wetland areas have been lost, and the condition of remaining wetlands is declining. In New Zealand more than 90% of wetland area has been removed in the last 150 years, a loss rate among the highest in the world. New Zealand Māori greatly valued wetlands for their spiritual and cultural significance and as important sources of food and other materials closely linked to their identity. The remaining wetlands in New Zealand are under pressure from drainage, nutrient enrichment, invasive plants and animals, and encroachment from urban and agricultural development. In many countries, the degradation of wetlands and associated impairment of ecosystem services can lead to significant loss of human well-being and biodiversity, and negative long-term impacts on economies, communities, and business. Protection and restoration of wetlands are essential for future sustainability of the planet, providing safety nets for emerging issues such as global climate change, food production for an increasing world population, disturbance regulation, clean water, and the overall well-being of society.

Key words: climate regulation, ecological integrity, economic valuation, flood regulation, natural ecosystem, restoration.

INTRODUCTION

Wetlands are among the world's most productive and valuable ecosystems. They provide a wide range of economic, social, environmental and cultural benefits – in recent times classified as ecosystem services (Costanza et al. 1997). These services include maintaining water quality and supply, regulating atmospheric gases, sequestering carbon, protecting shorelines, sustaining unique indigenous biota, and providing cultural, recreational and educational resources (Dise 2009). Despite covering only 1.5% of the Earth's surface, wetlands provide a disproportionately high 40% of global ecosystem services (Zedler and Kercher 2005). They play a fundamental part in local and global water cycles and are at the heart of the connection between water, food, and energy; a challenge for our society in the context of sustainable management. *The Economics of Ecosystems and Biodiversity for water and wetlands* (TEEB 2013) was recently published to help decision-makers prioritise management and protection. The TEEB (2013) study translated the values of ecosystem services into dollar terms (Table 1). For instance, the economic value of inland wetland ecosystem services was estimated at up to US$44,000 per hectare per year. Equivalent values for other wetland biomes were US$79,000 for coastal systems, $215,000 for mangroves and tidal marshes and $1,195,000 for coral reefs. The values, representing a common set of units using benefit transfer, allow comparison across services and ecosystems. On this basis these studies show that of the 10 biomes considered, wetlands have among the highest value per hectare per year (Figure 1), exceeding temperate forests and grasslands.

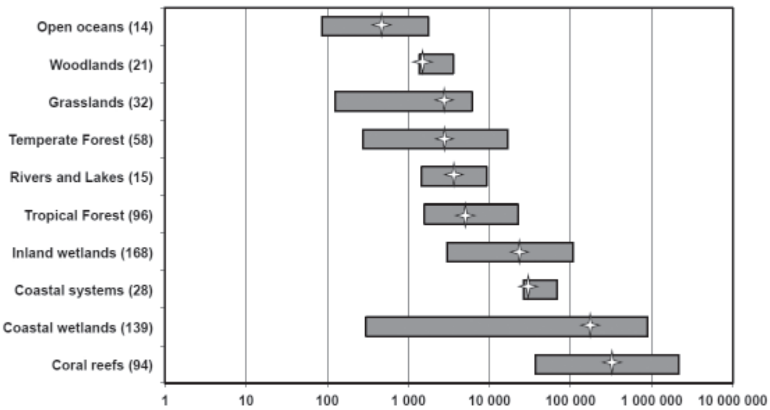

FIGURE 1 Range and average of total monetary value of bundle of ecosystem services per biome: total number in brackets, average as a star (from de Groot et al. (2012), redrawn in TEEB (2013)).

Despite the high value of ecosystem services derived from wetlands, around the world they have been systematically drained and filled to support agriculture, urban expansion, and other developments. In total, about 50% of the world's original wetland area has been lost, ranging from relatively minor losses in boreal countries to extreme losses of >90% in parts of Europe (Mitsch and Gosselink 2000a). Wetlands that remain, whether in the developed or developing world, are under increasing pressure from both direct and indirect human activities; and despite strong regulatory protection in many countries, wetland area and condition continue to decline (National Research Council 2001; TEEB 2013). Many wetlands now require urgent remediation if key functions and associated ecosystem services are to be maintained.

In New Zealand, more than 90% of the original extent of wetlands has been lost in the last 150 years (Gerbeaux 2003; Ausseil et al. 2011b; Figure 2), one of the highest rates and extent of loss in the developed world (Mitsch and Gosselink 2000a). The South Island has 16% of its original wetland area remaining; the more populated and intensively developed North Island has only 4.9% (Ausseil et al. 2011a).

Although legislation identifies protection of wetlands as a matter of national importance (New Zealand Resource Management Act 1991), many wetlands continue to degrade through reduced water availability, eutrophication, and impacts from weeds and pests. The past decade has seen considerable funding injections into wetland restoration projects, for example the Department of Conservation's Arawai Kākāriki Project, and the Biodiversity Advice and Condition Fund, as well as many smaller funding and grants available at regional and local levels (Myers et al. 2013). These funds are targeted mainly at enhancing

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TABLE 1 Monetary valuation of services provided by freshwater wetlands (floodplains, swamps/marshes and peatlands) per hectare per year, and relative importance

	Relative importance (TEEB 2013)	Mean global value (Int[1]$$_{2007}$) (de Groot et al. 2012)	Maximum global value (Int$$_{2007}$) (TEEB 2013)	Manawatu-Wanganui Region (NZ$$_{2006}$) (van den Belt et al. 2009)	New Zealand (NZ$$_{2012}$) (Patterson and Cole 2013)
TOTAL		25,682[2]	44,597	43,320	52,530[3]
Provisioning services		1,659	9,709	17,026	84
Food	⬤	614	2,090	104	
Fresh water supply	⬤	408	5,189	16,814	84
Raw materials	●	425	2,430	108	
Genetic resources	•				
Medicinal resources	•	99			
Ornamental resources	•	114			
Regulating services		17,364	23,018	20,339	45,217
Influence on air quality	•			586	711
Climate regulation	●	488	351		
Moderation of extreme events	⬤	2,986	4,430	16,017	19,530
Regulation of water flows	⬤	5,606	9,369	66	20,500
Waste treatment	●	3,015	4,280	3,670	4,476
Erosion prevention	●	2,607			
Maintenance of soil fertility	⬤	1,713	4,588		
Pollination	•				
Biological control	●	948			
Habitat services		2,455	3,471	971	
Lifecycle maintenance	⬤	1,287	917	971	1,175
Gene pool protection		1,168	2,554		
Cultural		4,203	8,399	4,982	6,054
Aesthetic	●	1,292	3,906	3,896	
Recreation/tourism	●	2,211	3,700	1,086	1,313
Inspiration for culture, art, design	⬤	700	793		4,741
Spiritual experience	⬤				
Cognitive information	⬤				

[1] International dollar = US$1. This is a hypothetical unit of currency to standardise monetary values across countries. Figures must be converted using the country's purchasing power parity instead of the exchange rate.
[2] Based on 168 studies, with standard deviation of $36,585, median value of $16,534, minimum value of $3,018 and maximum value of $104,924 (Int$$_{2007}$ ha^{-1} yr^{-1}).
[3] This is based on supporting, regulating, provisioning and cultural values without passive value for comparison purposes.

biodiversity; however, the outcome generally supports sustaining healthy functioning wetlands and delivering a range of wetland ecosystem services.

Although there are many studies quantifying wetland ecosystem services around the world, for example more than 200 case studies were synthesised by Costanza et al. (1997) and Schuyt and Brander (2004), relatively few have been published in New Zealand. Our wetlands are compositionally distinctive with c. 80% of vascular plant species endemic, but functional processes (e.g. decomposition rates and bog development) have been shown to be similar to results found in the Northern Hemisphere (Agnew et al. 1993; Clarkson et al. 2004a, b, in review; Hodges and Rapson 2010). This chapter summarises current knowledge and approaches to quantifying wetland ecosystem services from around the world and, where possible, provides examples and case studies from New Zealand.

What are wetlands?

Wetlands are lands transitional between terrestrial and aquatic systems where an oversupply of water for all or part of the year results in distinct wetland communities. The New Zealand Resource Management Act (1991) defines wetlands as 'permanently or intermittently wet areas, shallow water, and land water margins that support a natural ecosystem of plants and animals adapted to wet conditions'. This definition is similar to others around the world (e.g. Section 404 of the USA Clean Water Act). Many countries use the international Ramsar Convention definition, which is broader and encompasses human-made wetlands and marine areas extending to 6 m below low tide (Ramsar 1982). The focus of this chapter is inland (freshwater) wetlands, i.e. those associated with riverine and lacustrine systems, particularly swamp and marsh, and palustrine wetlands including fen and bog, which together represent the main functional types present in New Zealand (Johnson and Gerbeaux 2004).

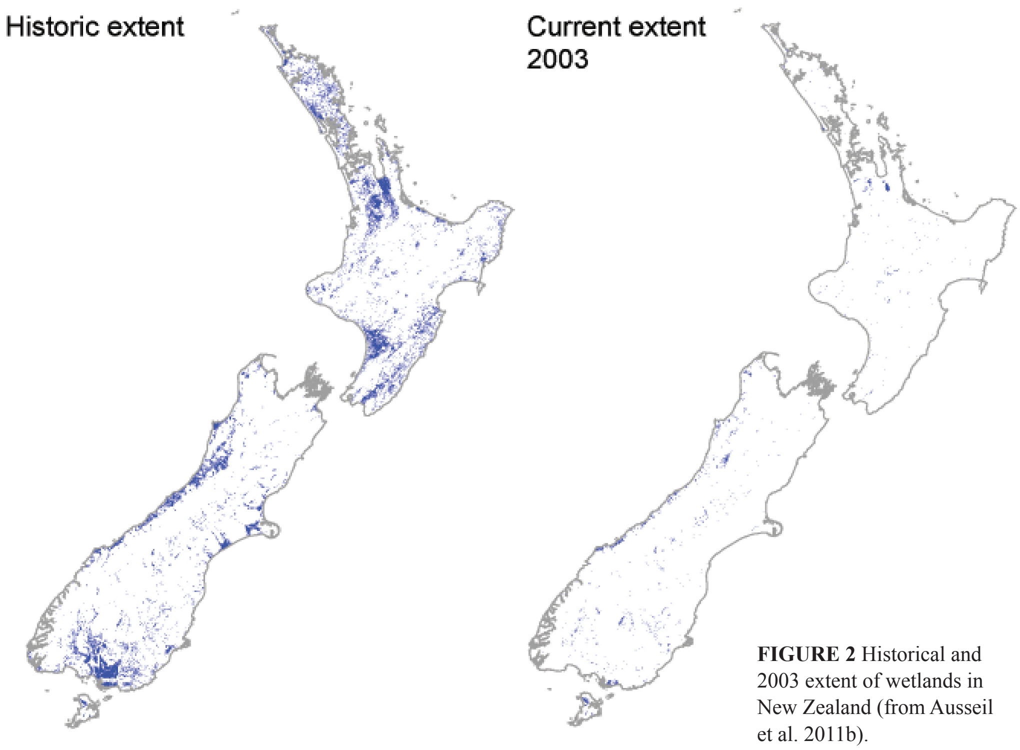

FIGURE 2 Historical and 2003 extent of wetlands in New Zealand (from Ausseil et al. 2011b).

Why are wetlands such important providers of ecosystem services?

Wetlands are able to provide high-value ecosystem services because of their position in the landscape (Zedler 2006) as recipients, conduits, sources, and sinks of biotic and abiotic resources. They occur at the land–water interface, usually in topographically low-lying positions that receive water, sediments, nutrients and propagules washed in from up slope and catchment. Within catchments, wetlands allow sediments and other materials to accumulate and settle, providing cleaner water for fish, wildlife and people. The combination of abundant nutrients and shallow water in receiving wetlands promotes vegetation growth, which in turn affords habitat and food for a wide range of fish, birds and invertebrates. Wetlands also accumulate floodwaters, retaining a portion, slowing flows, and reducing peak water levels, which cumulatively have significant roles in flood abatement.

The near permanent wetness of wetland ecosystems is equally important. Saturated areas have very low levels of oxygen, particularly in the 'soil' where it is accessed by roots and micro-organisms (Sorrell and Gerbeaux 2004). Such anoxic conditions promote changes in critical microbial processes resulting in anaerobic nutrient transformations that make nitrogen available for use by plants (nitrogen fixation) and convert nitrates into harmless gas, thereby improving water quality (denitrification). Having anoxic and aerobic conditions in close proximity is a natural property of shallow water and wetlands (Zedler 2006). The anoxic conditions also promote peat accumulation, locking up carbon, which in turn regulates atmospheric carbon levels and helps cool global climates (Frolking and Roulet 2007).

ECOSYSTEM SERVICES

Wetlands provide a wide range of ecosystem services vital for human well-being. These are discussed below following the classification of TEEB (2010), which relates to the benefits people obtain from ecosystems.

Provisioning services

Wetlands produce an array of vegetation, animal and mineral products that can be harvested for personal and commercial use. Perhaps the most significant of these is fish, the main source of protein for one billion people worldwide, and providing employment and income for at least 150 million people through a fishing industry (Ramsar 2009e). Rice is another important food staple and accounts for one-fifth of total global calorie consumption. Other important food products grown in wetlands include sago and cooking oil (from palms from Africa), sugar, vinegar, alcohol, and fodder (from the Asian nipa palm), and honey (from mangroves). Wetland products also include fuelwood, animal fodder, horticultural peat, traditional medicines, fibres, dyes and tannins.

In New Zealand, wetlands are traditional *mahinga kai* or resource gathering areas (Best 1908; Harmsworth 2002). Early Māori harvested harakeke (NZ flax; *Phormium tenax*) for clothing, mats, kete (baskets) and rope (Wehi and Clarkson 2007), kuta (bamboo spike sedge; *Eleocharis sphacelata*) for weaving and insulation (Kapa and Clarkson 2009), raupō (*Typha orientalis*) for thatching and pollen-based food, dried moss for bedding, poles of mānuka (*Leptospermum scoparium*) for palisades, and culturally important plants for rongoā (medicinal use). As breeding grounds for tuna (eels; *Anguilla* spp.), inanga (whitebait; *Galaxias* spp.) and other fish, as well as sustaining an abundance of birdlife, wetlands were a significant source of food. More recent wetland products include *Sphagnum* moss, a water-retaining horticultural medium for orchids, mostly harvested on the West Coast of the South Island (worth NZ$8.5–18 million per year; Hegg 2004), and horticultural peat, which is mined at five bog sites in New Zealand (de Lacy 2007). In addition, a highly valued honey with significant medicinal properties based on mānuka, a heath shrub species widespread in New Zealand wetlands, is a burgeoning lucrative industry (Stephens et al. 2005).

Regulating services

Wetlands regulate several important ecosystem processes. Three regulating services are globally significant (Greeson et al. 1979), namely water quality improvement, flood abatement, and carbon management. Wetlands purify water (which is why they are often called 'nature's kidneys') through storing nutrients and other pollutants in their soils and vegetation, and trapping sediments (Ramsar 2009c). In particular, nutrients such as phosphorus and nitrogen (as nitrate NO_3^-), commonly associated with agricultural runoff and sewage effluent, are removed or significantly reduced by wetlands (Fisher and Acreman 1999; Tanner and Sukias 2011). Nutrient removal efficiency varies depending on the position of the wetland in the catchment. Those in lower parts of catchments, with large contributing areas, are more efficient at removing nitrogen, while wetlands in upper reaches, below small contributing areas where surface waters are generated, are most effective for removing phosphorus (Tomer et al. 2009). All wetlands help prevent nutrients from reaching toxic levels in groundwater used for drinking purposes and reduce the risk of eutrophication of aquatic ecosystems further downstream.

Wetlands are natural frontline defences against catastrophic weather events, providing a physical barrier to slow the speed and reduce the height and force of floodwaters (Ramsar 2009a, b). The roots of wetland plants bind the shoreline or wetland–water boundary to resist erosion. Wetlands have the capacity to reduce flood peak magnitude by acting as natural reservoirs that can receive volumes of floodwater, and also regulate water flow by slowly releasing flood water to downstream areas (Campbell and Jackson 2004). Where protective wetlands have been lost, flood damage can be significantly worsened, as in Louisiana, USA, in 2005 when Hurricane Katrina caused major loss of life and livelihood. Floodplains are known to be critical in mitigating flood damage, as they store large quantities of water, thereby reducing the risk of flooding downstream (Zedler and Kercher 2005). It has been estimated that 3–7% of a river catchment area in temperate zones should be retained as wetlands to provide adequate flood control and maintain water quality (Mitsch and Gosselink 2000b). In New Zealand, van den Belt et al. (2013) developed a dynamic model to simulate flood protection of the Manawatu River. They suggest that built capital (i.e. man-made river engineering in stopbanks) creates an investment trap in the long-term (i.e. the maintenance costs increase over time). A more cost effective option long term would be to restore the natural wetlands to improve long-term sustainability of the system.

Wetlands play an increasingly recognised role as climate regulators and in sequestering and storing carbon (Frolking and Roulet 2007). Healthy, intact peatlands retain significant amounts of carbon as peat, whereas drainage, peat extraction and burning release it into the atmosphere in the form of greenhouse gases. The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded there is strong scientific agreement that the warming of the Earth's climate since the mid-20th century is caused by rising levels of greenhouse gases due to human activity, including peatland drainage. However, wetlands can function as a climate-change 'safety net' to mitigate climate change impacts provided they are protected, maintained and restored on a global scale (Ramsar 2009h).

In New Zealand, a recently released report on climate change (Office of the Chief Science Advisor 2013) predicts rising sea levels, warmer temperatures, more frequent heavy rains, and lengthy droughts by 2050. Impacts are likely to be greatest in vulnerable areas such as those already prone to flooding or drought, and 1-in-100-year floods will become 1-in-50-year occurrences by the end of the century. The most flood prone sites often coincide with historical wetland sites, as evidenced by the extensive flooding in the Bay of Plenty in 2004 (Figure 3; Gerbeaux 2005).

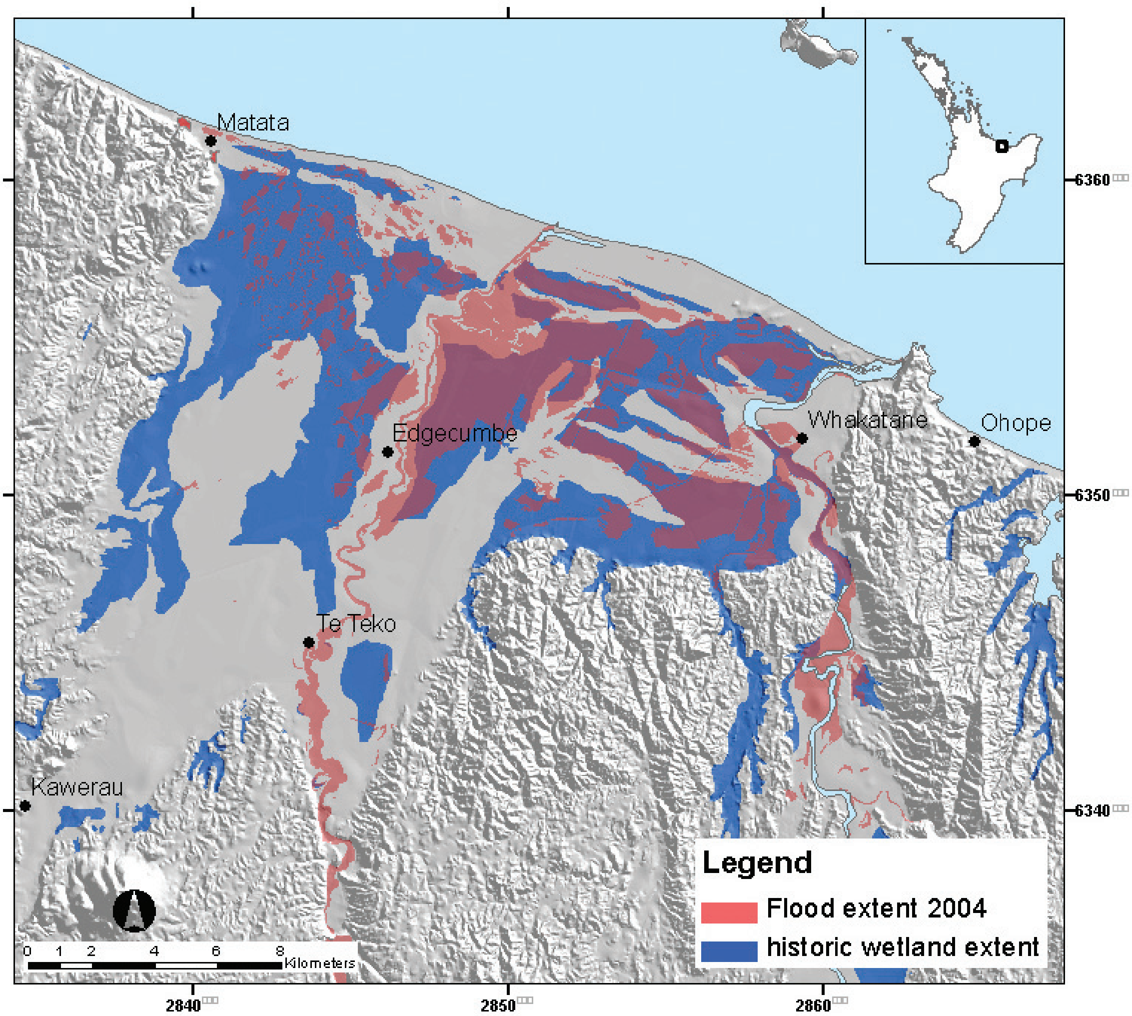

FIGURE 3 Extent of 2004 flooding in Bay of Plenty, New Zealand, compared with historical wetland areas (from Gerbeaux 2005).

Habitat services (or 'supporting services')

Habitat services, for example lifecycle maintenance (nursery service) and gene pool protection, are necessary for sustaining vital ecosystem functions and the production of all other ecosystem services. They differ from provisioning, regulating, and cultural services in that their impacts on people and societies are often indirect or occur over long time frames, whereas changes in other categories have relatively direct and short-term impacts (TEEB 2013).

Although wetlands cover a relatively small area of the Earth's surface, they are strongholds of biodiversity. Many are extremely rich in flora and fauna, several have endemic species, and virtually all contain species confined to wetlands. However, as a result of ongoing land conversion and excessive water abstraction, wetland species are declining faster than those from other ecosystems (Ramsar 2009d). In New Zealand, wetlands are one of the most nationally threatened and degraded ecosystem types (Ausseil et al. 2011b). Covering only 250 000 hectares (0.93% of New Zealand's land area), they support a disproportionately high number of threatened plants and animals, including 67% of freshwater and estuarine fish species (Allibone et al. 2010) and 13% of nationally threatened plant species (de Lange et al. 2009). In some regions (e.g. Canterbury), a larger proportion of threatened plants is associated with wetlands compared with many other habitats. Wetland biodiversity throughout the world supports many economic activities, providing people with countless products that are harvested, bought, sold, and bartered. Safeguarding the variety of life in different types of wetlands across the globe is therefore a vital part of humanity's insurance policy for a sustainable future (Ramsar 2009d).

Cultural services

Wetlands deliver significant non-material benefits such as cultural, spiritual, aesthetic, and educational values. They also provide opportunities for recreation and tourism. The wetland landscapes and wildlife we value today typically result from complex interactions between people and nature over centuries. Once these intimate linkages are damaged or destroyed, it is rarely possible to restore or recreate them. Wetlands also attract diverse recreational and ecotourism activities, generating significant incomes that benefit local communities and national economies (Ramsar 2009g), which is particularly true in New Zealand. Closely allied to the benefits of wetlands for recreation and well-being is their educational value. Catering for a variety of needs, from conventional school-group visits to engagement of the wider community, an expanding network of wetland education centres is being established around the world (Ramsar 2009g). Numerous such centres have been developed in New Zealand (e.g. at Miranda in the Waikato, Mangarakau Wetland in Tasman, Travis Wetland in Canterbury, and Sinclair Wetlands in Otago). Additionally, the active involvement of the community in restoration projects is increasing, providing Green Prescription health benefits (http://www.health.govt.nz/your-health/healthy-living/food-and-physical-activity/green-prescriptions, accessed 2013) along with the more obvious social, educational and biodiversity rewards (Figure 4).

Wetlands, particularly peat bogs, are important for providing a historical legacy by preserving remains of great archaeological significance (Ramsar 2009f). The cold, water-logged and oxygen-free conditions protect organic materials from decomposing by inhibiting the growth of bacteria. Perhaps the most fascinating archaeological remains are the well-preserved Iron Age bog bodies from north-west Europe (e.g. Tollund Man from Denmark) and the United Kingdom (Lindow Man ('Pete Marsh') from England) (http://bogbodies.wikispaces.com/Bog+Bodies+of+Iron+Age+Europe#Bog Bodies). These human remains provide detailed evidence on the physical features, clothing, diet and culture of bog people societies that existed more than 2000 years ago. The study of other archaeological remains such as pollen grains and macrofossils preserved in the peat has enabled detailed reconstruction of past vegetation and climate to be developed (e.g. McGlone and Topping 1977; McGlone and Wilmshurst 1999; McGlone 2009). In New Zealand, podocarp forests that existed c. 2000 years ago, buried and preserved in wetlands by the Taupo eruption, have yielded wood, invertebrates, foliage, and branches with attached seeds, which have enabled forest 'reconstructions' and pinpointed a late summer – early autumn timing for the eruption (Clarkson et al. 1988, 1992, 1995). In total, 177 wetland archaeological sites have been inventoried in New Zealand (Gumbley et al. 2005).

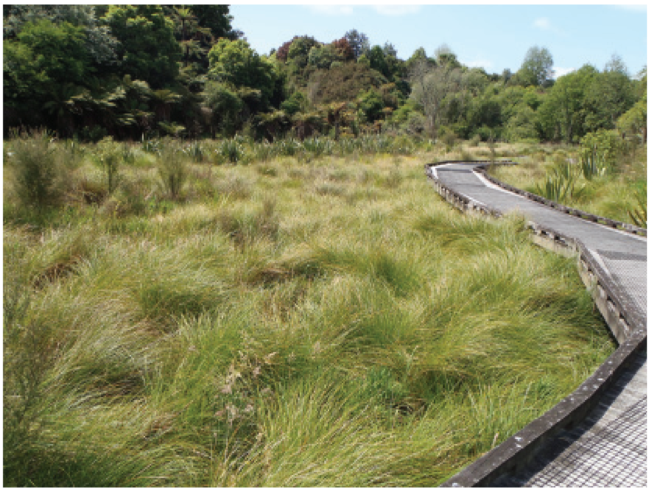

FIGURE 4 Mangaiti Gully, a city council community wetland restoration project in Hamilton City, North Island, New Zealand.

New Zealand Māori greatly value wetlands for their spiritual significance. They regard wetlands and associated inland waterways as taonga (treasures, of significant value) closely linked to their identity as tangata whenua (people of the land). Many wetlands have historical and cultural importance, and some include wahi tapu (sacred places) (Harmsworth 2002). Early Māori also used wetlands to hide their precious taonga, for preserving timber artefacts and waka (canoe), and as a safe haven in times of war (Gumbley et al. 2005). Common Māori words for describing a wetland include *repo* (swamp, bog, marsh) and *ngaere* (swamp, wetland) (Harmsworth 2002).

CASE STUDIES

Introduction

An economic evaluation of the value of New Zealand ecosystems (Cole and Patterson 1997; Patterson and Cole 1999, 2013), based on Costanza et al.'s (1997) landmark valuation study of global ecosystems, estimated that inland (freshwater) wetlands delivered a total value ($\$_{2012}$) of NZ$5,122 million per year. Even though wetlands cover less than 1% of New Zealand's land area, they generate 13% of the direct (i.e. commodities) and indirect use value (i.e. from supporting or protecting direct value) derived from land-based ecosystems. Although the most important ecosystem service was water regulation (storage and retention), estimated at NZ$3,403 million, Patterson and Cole (2013) noted that this may be an overestimate for the New Zealand situation as we have relatively abundant water supply. Disturbance regulation was the next most important ecosystem service, valued at NZ$3,242 million, and included storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability. Cultural services (aesthetic, education, scientific values) were also high at NZ$787 million, followed by waste treatment at NZ$743 million. As wetlands cover only a small portion of New Zealand, Patterson and Cole (2013) calculated a very high ecosystem service delivery of NZ$52,530 $ha^{-1} yr^{-1}$ ($\$_{2012}$; gross direct and indirect use-value[1]) (Table 1). In a local study, van den Belt et al. (2009) updated the values of ecosystems in the Manawatu-Wanganui Region (Table 1). Direct and indirect values were assessed, excluding non-use value (existence or passive) for lack of data. Wetlands had the highest annual per-hectare value (NZ$\$_{2006}$) by far ($43,320), mainly due to their indirect value (in comparison, dairy was $1,796[1,2], sheep and beef $719, native forest $2,065, and horticulture $19,001). In proportion, wetland service values from freshwater supply and moderation of extreme events in the region were much higher than global figures (de Groot et al. 2012; TEEB 2013). However, several data, methodological and theoretical issues remain to be resolved (van den Belt et al. 2009; Patterson and Cole 2013) Nevertheless, monetary valuation of ecosystem services intends to make both direct and indirect use value visible to policymakers and the general public. For instance, indirect value was shown to account for 80% of the total value of ecosystem services in the Manawatu-Wanganui Region (van den Belt et al. 2009).

As there is increasing interest among decision-makers and managers in valuing natural capital, we include below two case studies for contrasting wetland types illustrating the range of ecosystem services present in New Zealand wetlands.

Whangamarino Wetland

Whangamarino Wetland probably provides the most detailed economic evaluation of a New Zealand wetland to date (Waugh 2007). This is a large complex of bog, fen, swamp and open water associated with rivers and streams draining via the Whangamarino River into the lower Waikato River, midway between Hamilton and Auckland (Figure 5). It covers an area of 7290 hectares, a 5690-hectare portion of which is administered (since 1989) by the Department of Conservation and designated as an internationally significant Ramsar site (Department of Conservation 2007). The wetland supports a wide range of economic values, both use (direct use of a wetland's goods) and non-use (existence or passive value), totalling US$\$_{2003}$9.9 million per year (Kirkland 1988 in Schuyt and Brander 2004). Of this, more than $7.2 million was categorised as non-use preservation value in recognition of society's willingness to pay for its conservation and sustainable management.

FIGURE 5 Aerial view of Whangamarino Wetland, North Island, New Zealand. (Photo: Shonagh Lindsay)

The wetland complex has a high diversity of habitats and species. It is home to several threatened plant species including the swamp helmet orchid *Anzybas carseii*, which is found only at Whangamarino, as well as the more widely distributed water milfoil *Myriophyllum robustum*, fern *Cyclosorus interruptus*, bladderwort *Utricularia delicatula*, clubmoss *Lycopodiella serpentina*, and liverwort *Goebelobryum unguiculatum*. Whangamarino provides habitat for one-fifth of New Zealand's population of Australasian bittern (*Botaurus poiciloptilus*), as well as other threatened birds such as the grey teal (*Anas gibberfrons*), spotless crake (*Porzana tauensis plumbea*) and North Island fernbird (*Bowdleria punctata vealeae*). The wetland contains a key population of the threatened black mudfish (*Neochanna diversus*), which survive dry periods by burying themselves in moist mud or under logs until the water returns. In 1994, construction of a rock rubble weir was commissioned on the Whangamarino River to increase minimum water levels and reinstate a 'wet/dry' seasonal cycle (Department of Conservation http://doc.govt.nz/conservation/land-and-freshwater/wetlands/wetlands-by-region/waikato/whangamarino/ramsar-site/ accessed 2013). This became fully functional in 2011 and now provides improved hydrological regimes to over 2000 hectares of wetland.

The main use values recognised for Whangamarino Wetland are flood control, gamebird hunting, recreation, commercial fishing of eels (tuna), and carbon storage. Of increasing economic significance is the wetland's role as part of the substantial flood control scheme on the lower Waikato River (Waugh 2007), which lowered regional water levels. The scheme reproduces the natural water storage function of Whangamarino Wetland and adjoining Lake Waikare, but in a more controlled way, to depress flood peaks in the Waikato River (Department of Conservation 2007). Water storage in the wetland has reduced public works costs (e.g. stopbank construction), and damage to farmland during the 10 flood events that occurred between 1995 and 1998, saving an estimated NZ$5.2 million in flood control costs during a single 1-in-100-year flood event in 1998 (Waugh 2007).

Gamebird hunting is another important use of Whangamarino Wetland, particularly in the c.1600 hectares under private tenure. The wetland is visited by most New Zealand gamebird species at least seasonally and these include mallard (*Anas platyrhynchos*), grey duck (*Anas superciliosa superciliosa*), New Zealand shoveller (*Anas rhynchotis variegata*), pūkeko (*Porphyrio porphyrio*), black swan (*Cygnus atratus*), paradise shelduck (*Tadorna variegata*), and Canada goose (*Branta canadensis*). The Gamebird Habitat Trust raises more than NZ$60,000 per year from gamebird habitat stamp fees at $2 per hunting licence to support restoration of wetland sites, including Whangamarino (Department of Conservation 2007).

Torehape Bog

Torehape Bog on the Hauraki Plains, North Island, provides a rare example of an attempt to harvest peat sustainably for the horticultural industry without compromising biodiversity values. The overall project is a partnership between mining companies, research scientists, land managers, regulatory authorities, NGOs, and community groups.

Torehape comprises 180 hectares of privately owned bog, which is currently being mined for horticultural peat, adjoining 350 hectares of Wetland Management Reserve administered by the Department of Conservation. The restiad raised bog is dominated by *Sporadanthus ferrugineus*, and is a rare and threatened ecosystem (Williams et al. 2008) reduced to three natural sites in the Waikato Region. Gamman Mining has resource consent to mine the top metre of a 4–6 metre depth of peat on private land, and are required to restore the bare surface to original bog vegetation. Torehape Peat Mine produced c. 60 000 cubic metres in 2013 (down from a peak of 80 000 m^3 yr^{-1} in the 1990s), which equates to c. NZ$3.4 million annually (R. Gamman, pers. comm., 2013). The peat is used for potting mixes, compost, mushroom-growing media, organic fertilisers, and soil conditioners.

A patch approach to restoration (Figure 6) has been developed following peat harvesting whereby small 'islands' of milled peat scattered over the mine surface are seeded with early successional mānuka. The developing mānuka shrubland functions as a nurse, providing suitable environmental conditions for seeds and propagules of later successional bog species (*Sporadanthus, Empodisma robustum, Sphagnum cristatum*) that are blown in from the adjoining intact peatland.

Non-use values of Torehape Mine relate to the status of the site as a threatened ecosystem type, and its habitat values for threatened plants such as *Sporadanthus*, *Calochilis robertsonii* and *Dianella haematica*, birds such as the Australasian bittern and North Island fernbird, and the stem borer caterpillar 'Fred the Thread' (*Houdinia flexilissima*).

The restoration project has provided plant and invertebrate source material, and techniques for the successful establishment of three new populations of restiad bog at sites where the bog type originally occurred (Lake Serpentine, Lake Komakorau, Waiwhakareke Natural Heritage Park). These populations are important for educational purposes, with the Lake Serpentine one being showcased within a predator-proof fence as part of the proposed National Wetland Trust interpretation centre (http://www.wetlandtrust.org.nz/centre.html, accessed 4 September 2013).

WETLAND CARBON STOCKS

Wetlands have the highest carbon density among terrestrial ecosystems and contain 20–25% of the world's organic soil carbon (Gorham 1991). They are the dominant natural source of methane emissions (Kayranli et al. 2010), but can also sequester carbon as anaerobic conditions prevent decomposition of organic matter. Their contribution as a source and sink of carbon is a major issue in evaluating climate change impacts (UNFCCC 1997). When overall carbon dynamics of these systems are considered, wetland ecosystems compare favourably with other terrestrial habitats (Anderson-Teixeira and DeLucia 2011). Freshwater wetlands can be broadly divided into peatlands and mineral soil wetlands – known as freshwater mineral soil (FWMS) wetlands (Bridgham et al. 2006). In peatlands, carbon is mainly sequestered through organic matter production and accumulation, which outweighs organic matter decomposition in anaerobic soil conditions (Grover et al. 2012). In FWMS wetlands, carbon

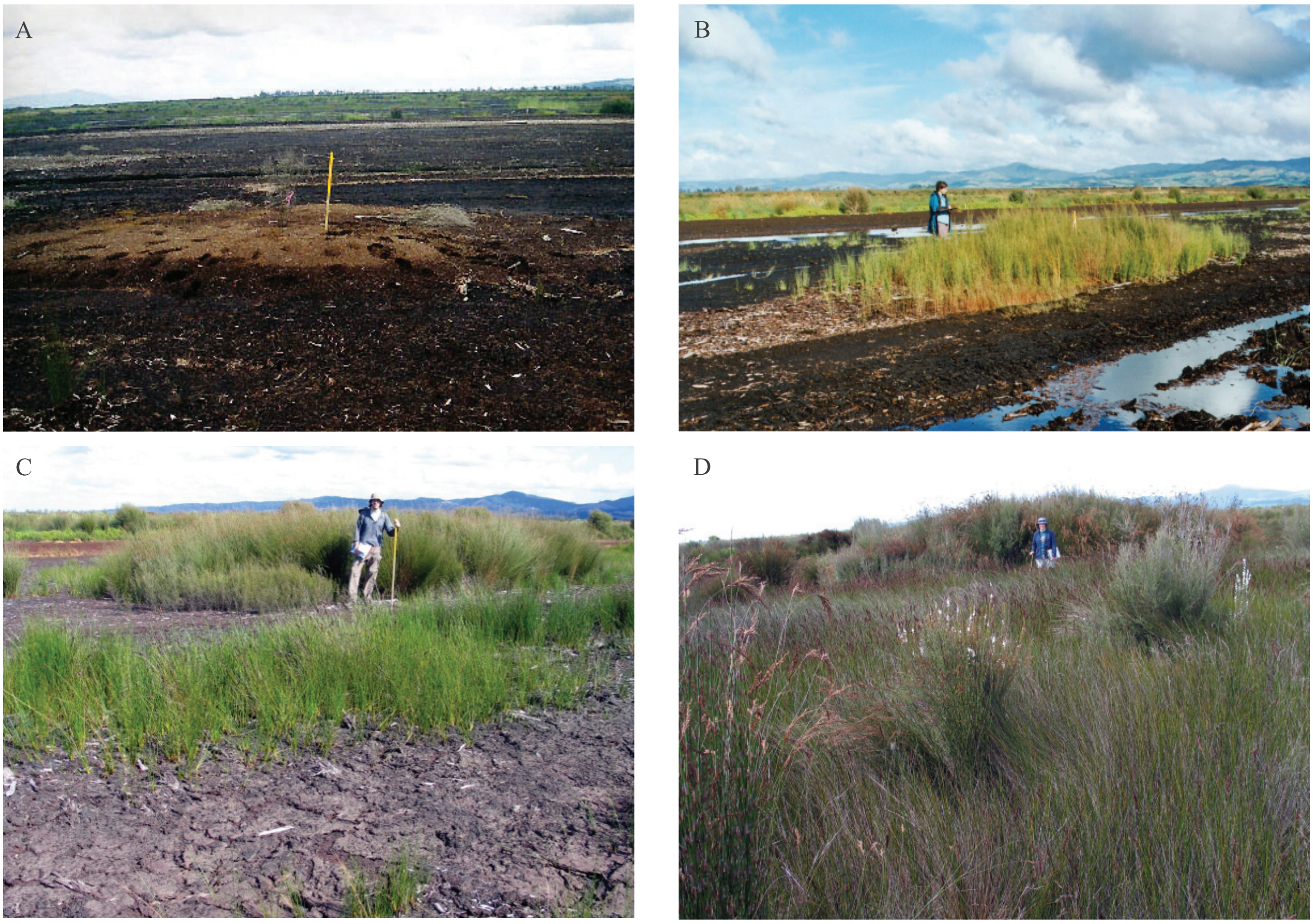

FIGURE 6 Patch approach to restoration whereby the islands provide a seed source for surrounding bare mined surface: A, 0 years (set-up with milled peat and mānuka branches laden with seed capsules); B, after 1.5 years (mānuka (*Leptospermum scoparium*) has established); C, after 3.4 years (*Sporadanthus* has established around islands, *Baumea teretifolia* on mine surface); D, after 6 years (revegetated, *Sporadanthus* flowering left foreground).

sequestration occurs through sediment deposition from upstream as well as on-site plant production; together these outweigh the decomposition rates (Bridgham et al. 2006). Net carbon release versus carbon sequestration changes over time (Mitra et al. 2005; Kayranli et al. 2010). On a longer-term scale (>500 years) and on a global scale, carbon sequestration from wetlands has been shown to be greater than carbon release, creating a net cooling effect (Whiting and Chanton 2001; Frolking and Roulet 2007). Land-use change has had a major impact on wetland carbon storage and dynamics. Wetland drainage and subsequent conversion to agriculture or forestry results in substantially increased decomposition rates of organic matter previously stored under anaerobic conditions, and significant amounts of carbon released into the atmosphere (Mitra et al. 2005). The rates of organic matter decomposition from wetlands converted to other land uses also vary with wetland and peat types (Zauft et al. 2010). Peatlands converted to other land uses show higher decomposition rates and therefore higher carbon loss compared with FWMS wetlands, which may lose negligible amounts of carbon as a result of land-use change, as reported for the wetlands of North America (Bridgham et al. 2006).

Ausseil et al. (in prep.) summarises information on carbon stocks in New Zealand garnered from field survey. It is estimated that 36 Tg of carbon is stored in the upper 30 cm of wetland soils, rising to 164 Tg if the full peat profile is considered. Carbon densities range between around 1,600 tC ha^{-1} under organic soils and around 200 tC ha^{-1} under FWMS soils. These values are comparable with freshwater wetlands in the US and Canada. Draining for agricultural use increased mineralisation and caused an increase in net carbon emission. Emission estimates vary greatly, from 1 tC $ha^{-1}yr^{-1}$ at a New Zealand site (Nieveen et al. 2005) to 30 tC $ha^{-1}yr^{-1}$ in Scandinavia (Kasimir-Klemedtsson et al. 1997).

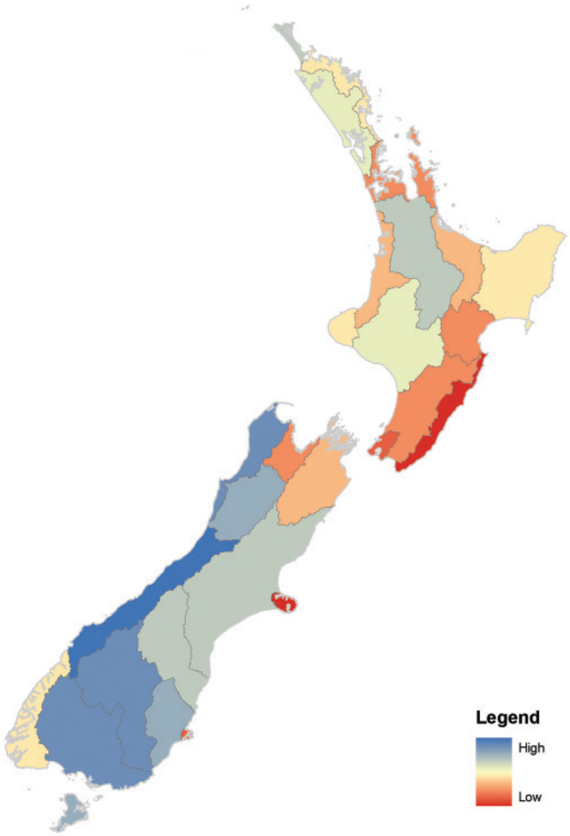

FIGURE 7 Wetland habitat provision index for New Zealand per biogeographic unit (from Ausseil et al. 2011b).

WETLAND ECOLOGICAL INTEGRITY

Freshwater wetlands in New Zealand have been severely degraded by anthropogenic activities since pre-European settlement. As they are ecotones that support both terrestrial and aquatic biota, they can be affected by a range of human disturbances, including alterations of nutrient supply, changes in hydrology, sedimentation, fire, vegetation clearance, soil disturbance, weed invasions (aquatic and terrestrial), and animal pest invasions (e.g. livestock grazing, pest fish, mustelids, or rodents) (Clarkson et al. 2004c). Human disturbances can change biological community structure, composition, and function, thereby altering ecological processes. Degradation of this suite of ecological features is described as a decline in ecological integrity, which then affects functions and services. Ausseil et al. (2011a) developed six measures of anthropogenic pressures known to impact wetland ecological integrity: naturalness of the upper catchment cover; artificial impervious cover; nutrient enrichment; introduced fish; woody weeds; and drainage. These measures were chosen because they covered the major threats known to damage wetlands (Brinson and Malvarez 2002; Clarkson et al. 2004c; Sorrell et al. 2004), and could be measured consistently using geographic information system (GIS) indicators at national level. Transfer functions were then applied to reflect possible impacts on ecological integrity. The potential impacts were then integrated into a single index of ecological integrity to quantify potential human disturbance. The index ranged from 1 (pristine) to 0, where 0 indicates complete loss of biodiversity and associated ecological function.

Using this approach, ecological integrity in over 60% of wetlands was measured at less than 0.5. These results indicate high levels of human-induced disturbance pressure and probable substantial biodiversity loss. Values reflect general patterns of agricultural and urban development with the lowest measures found in biogeographic units characterised by warm, flat, fertile land favoured for agricultural development. For example, the Waikato Region is dominated by intensive agriculture and contains wetlands with a mean ecological integrity of 0.35. In contrast, wetlands in Fiordland or Stewart Island that are predominantly managed as national parks have typically high ecological integrity indices at over 0.9. Ausseil et al. (2011b) have combined ecological integrity with historical extent to develop a habitat provision index for wetlands. The degree of habitat provision varies per biogeographic unit in New Zealand (Figure 7). Low values represent units where wetland areas either are small, depleted or have been degraded.

The ecological condition of wetlands can also be assessed in the field using the Wetland Condition Index (WCI), a semi-quantitative metric developed for state of the environment monitoring (Clarkson et al. 2004c). Five ecological indicators are compared and scored against an assumed natural state (as at c. 1840): hydrological integrity; physiochemical parameters; ecosystem intactness; browsing, predation and harvesting (animal impacts); and dominance of native plants. The total score is out of 25; the higher the score, the better the ecological condition. Wetlands in developed, agricultural catchments have significantly lower WCI than wetlands in indigenous-dominated catchments (n = 72, P < 0.001; Figure 8). The WCI measures actual change (state) compared with predicted change, using the GIS-based wetland ecological integrity metric but requires field visits to individual wetlands, whereas the GIS approach provides full national coverage. Comparison of scores of significant wetlands

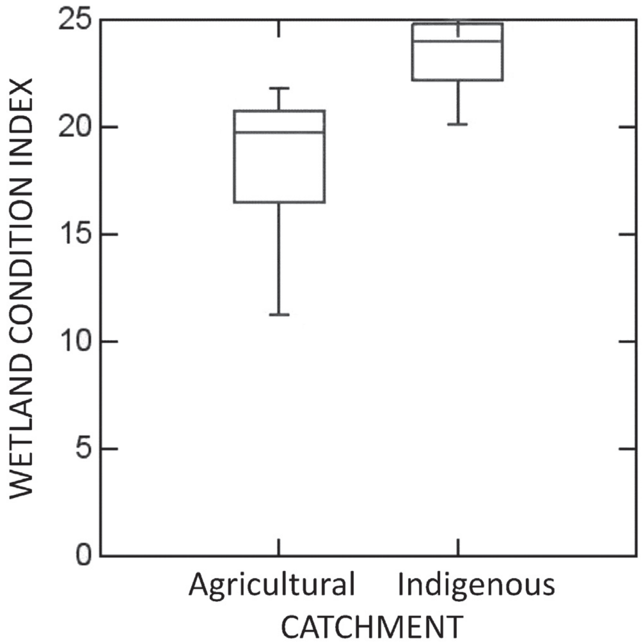

FIGURE 8 Box-plot summary of medians and upper and lower quartiles of Wetland Condition Index of New Zealand wetlands within indigenous and agricultural catchments. Source: New Zealand Wetland Database (BR Clarkson unpubl. data).

at the regional scale (e.g. West Coast) indicates the measures are highly correlated. Ongoing field checking of wetlands in targeted regions (e.g. Southland and Auckland) is currently underway to refine and verify the data in Ausseil et al. (2011a) to increase the usability of the GIS approach.

RESTORATION

The Whangamarino and Torehape case studies above have demonstrated the values associated with restoring wetlands. Restoration of degraded wetlands around the world is vital to maintain biodiversity and associated ecosystem services. In a study in the Mississippi Valley, for instance, the value of restoring forested wetland was assessed on three ecosystem services (greenhouse gas mitigation, nitrogen mitigation, and waterfowl habitat), showing that a return in restoration investment could be achieved in 2 years (Jenkins et al. 2010). The success of wetland restoration, however, is variable. Wetlands, particularly the late-successional fens and bogs, are complex and difficult to restore. In general, once disturbed, ecosystem recovery is slow or trends towards alternative states that differ from reference sites and may require costly intervention. In a global analysis of wetland restoration projects, large wetland areas (>100 ha) and wetlands restored in warm (temperate and tropical) climates recovered more rapidly than smaller wetlands and wetlands restored in cold climates (Moreno-Mateos et al. 2012). Balmford et al. (2002) concluded many wetlands have been modified for short-term private benefits, for example intensive agriculture or shrimp farming, that do not factor in extensive losses of social and other benefits. The authors present a strong economic case for retaining natural wetland habitats because, in all studies analysed, developed wetlands have a much lower dollar value than that of natural wetlands.

In New Zealand, most of the wetlands that have survived the human settlement phase are modified to some degree, particularly those remnants in agricultural landscapes or urban environments. As awareness of wetland values spreads, the demand for technical resources has increased (e.g. Peters and Clarkson 2010; Denyer and Peters 2012). The number of private individuals, community groups, iwi, and organisations restoring wetlands is rapidly increasing. General public recognition of wetland values is also expanding, for example, a survey of Hawke's Bay households indicated the net non-market value of a restoration programme at Pekapeka Swamp to be NZ$5–$18 million (Ndebele 2009). Regional councils also have a mandate to protect wetlands and have developed environmental fund initiatives (Waikato Regional Council: http://www.waikatoregion.govt.nz/Environment/Natural-resources/Water/Freshwater-wetlands/) and plans to strengthen protection of remaining wetlands (Lambie 2008; Otago Regional Council 2012). However, we cannot be complacent, as wetlands continue to degrade and disappear and many require active management to enhance their long-term viability. Only continuing awareness of wetland threats and ongoing commitment of funds for protection and restoration will ensure the multiple values of our wetlands are preserved for future generations.

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Endnotes

[1] Patterson and Cole (2013) distinguish gross value (including supporting value) from net value (without supporting value) to avoid double-counting.

[2] Based on more recent calculations using a unit price for milk solids of NZ$6 and a pastoral pressure of 3.5 cows per hectare with each cow producing 400 kg of milk solids per season, the figure would increase to NZ$8,400 in 2013.