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Temperate freshwater wetlands: types, status, and threats

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SUMMARY

This review examines the status of temperate-zone freshwater wetlands and makes projections of how changes over the 2025 time horizon might affect their biodiversity. The six geographic regions addressed are temperate areas of North America, South America, northern Europe, northern Mediterranean, temperate Russia, Mongolia, north-east China, Korea and Japan, and southern Australia and New Zealand. Information from the recent technical literature, general accounts in books, and some first-hand experience provided the basis for describing major wetland types, their status and major threats. Loss of biodiversity is a consequence both of a reduction in area and deterioration in condition. The information base for either change is highly variable geographically. Many countries lack accurate inventories, and for those with inventories, classifications differ, thus making comparisons difficult. Factors responsible for losses and degradation include diversions and damming of river flows, disconnecting floodplain wetlands from flood flows, eutrophication, contamination, grazing, harvests of plants and animals, global warming, invasions of exotics, and the practices of filling, dyking and draining. In humid regions, drainage of depressions and flats has eliminated large areas of wetlands. In arid regions, irrigated agriculture directly competes with wetlands for water. Eutrophication is widespread, which, together with effects of invasive species, reduces biotic complexity. In northern Europe and the northern Mediterranean, losses have been ongoing for hundreds of years, while losses in North America accelerated during the 1950s through to the 1970s. In contrast, areas such as China appear to be on the cusp of expanding drainage projects and building impoundments that will eliminate and degrade freshwater wetlands. Generalizations and trends gleaned from this paper should be considered only as a starting point for developing world-scale data sets. One trend is that the more industrialized countries are likely to conserve their already impacted, remaining wetlands, while nations with less industrialization are now experiencing accelerated losses, and may continue to do so for the next several decades. Another observation is that countries with both protection and restoration programmes do not necessarily enjoy a net increase in area and improvement in condition. Consequently, both reductions in the rates of wetland loss and increases in the rates of restoration are needed in tandem to achieve overall improvements in wetland area and condition.

Keywords: wetland loss, wetland inventories, biodiversity, hydrologic alterations, eutrophication, restoration

INTRODUCTION: GEOGRAPHIC COVERAGE AND WETLAND TYPES

Temperate freshwater wetlands include a large variety of types in the major geographic regions of the globe (Fig. 1). Their geomorphic settings range from portions of alluvial wetlands that are closely connected with river channels to isolated depressions that are largely driven by groundwater and not connected to other aquatic systems. Wetlands are known for providing critical habitat for many species (Keddy 2000; Bedford *et al*. 2001). At the same time, wetlands are strongly influenced by human activities, in part because they occur where societies choose to live, such as ports on rivers and lakeshores, or where society relies on the production of food and fibre, such as nutrient-rich soils for agriculture and silviculture. Some of the greatest threats to local biodiversity are the result of these conflicting land uses.

This review evaluates the available literature on temperate freshwater wetlands with particular emphasis on the influence of human activities on wetland condition and area, both of which are relevant to the capacity of wetlands to support native assemblages of flora and fauna (e.g. biodiversity). Where the term biodiversity is used, it is intended to encompass (1) areas that incorporate the range of natural variation, including seral stages, (2) viable populations of all native species, both in abundance and distribution, (3) ecological and evolutionary processes such as disturbance regimes, hydrology, and biotic interactions, and (4) landscapes that respond to environmental changes and maintain evolutionary potential of the biota (Noss & Cooperrider 1994). To this we should add the issue of sustainability. Without recognized benefits to society, programmes to maintain biodiversity in wetlands are likely to be doomed to failure.

Given trends in globalization during the past century, and the acceleration of commerce in the past few decades, human populations have created enormous pressure on all natural

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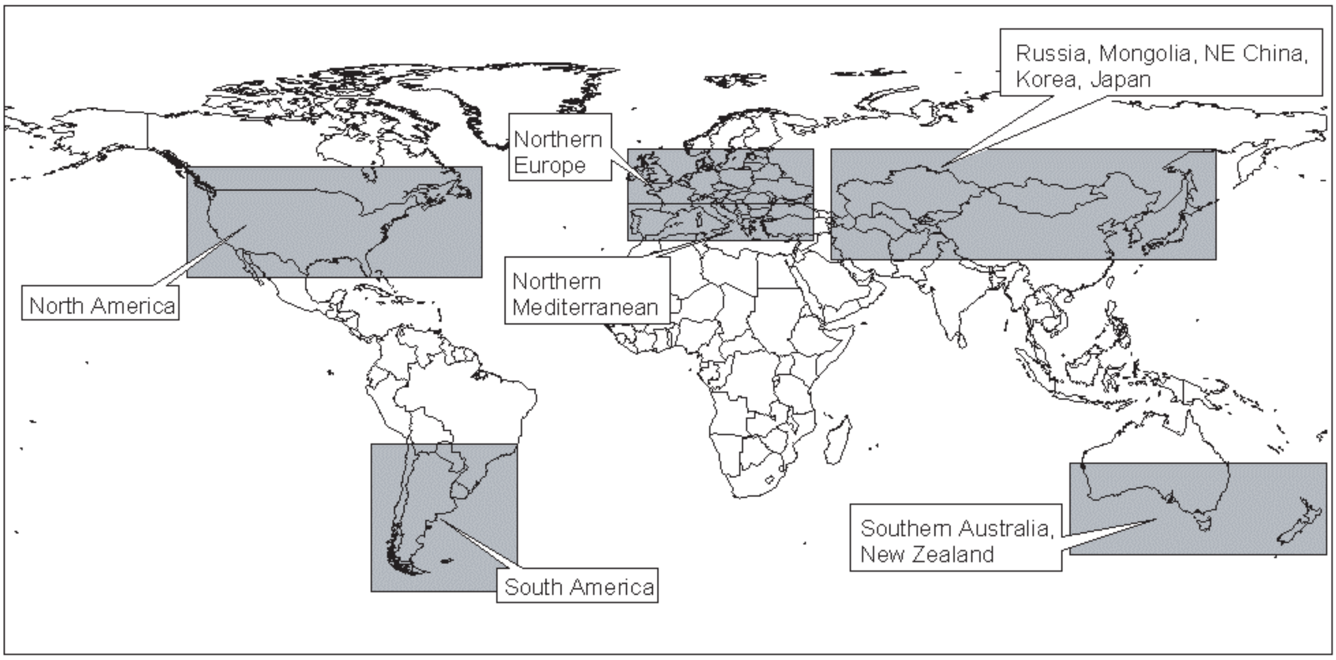

Figure 1 Six geographic regions of temperate wetlands.

environments, including wetlands (Foundation for Environmental Conservation 2001). It is within this context that we evaluate the historic trends in types of alterations to which wetlands have been subjected, and use this information to make projections. Because of the expanding scientific literature on wetlands, and our improved (yet imperfect) understanding of how they function, we are better prepared than ever to make predictions on the effects of human activities on wetland condition and area. Further, there is a growing awareness by the public of the contributions of wetlands to hydrology, biota and water quality. Due to a simultaneous awareness of the negative consequences of losses, some sectors of society have supported efforts to reverse some of these alterations and losses through the practice of restoration (NRC [National Research Council] 2001). Given these developments, we anticipate that society can respond to opportunities that not only reduce the rate of wetland alteration, but also in some cases reverse these trends through restoration. For each of the temperate regions treated, we estimate the expected future trends to around 2025.

We identify wetlands as those areas of the landscape that receive inundation or soil saturation at a duration and frequency that exclude many organisms not tolerant of flooding or soil saturation. Common terms in English include marsh, swamp, fen, bog and mire. Further, we view 'wetness' of wetlands as a relative term depending on the climatic context. For example, the wettest lands of arid and semiarid climates include riverine forests and seasonally wet depressions of internal drainages, such as the Great Salt Lake wetlands in the USA. (Salt lakes themselves are reviewed by Williams 2002.) We also include areas that have been altered from their natural wetland condition to enhance specific functions such as waterfowl habitat and fish production. Some wetland areas, however, have been converted to other uses and are no longer recognized as wetlands. Where information is available, these will be recognized as losses. While some of these land uses are considered irreversible from a societal perspective (e.g. urban regions, industrial areas, large reservoirs), others, such as marginal farmland and pastures, hold potential for a return to wetland status. We consider these sites 'reversible' because of the relative ease with which they can be converted to mitigate some of the consequences of unavoidable wetland losses.

Where possible, specific examples are discussed in their geomorphic settings rather than considering each wetland as being unique (Fig. 2). Wetlands of different geomorphic settings tend to receive different dominant sources of water and have different hydroperiods (Brinson *et al*. 1998), both of which influence the types of organisms that are adapted to live there (Mitsch & Gosselink 2000). Moreover, wetlands that share common geomorphic settings tend to be subjected to the same types of human alterations. For example, depressional wetlands (i.e. they store water due to restricted surface outflow) often have strong groundwater connections with other wetlands and aquatic areas. Some are essential amphibian habitat because seasonal drydown eliminates potential fish predators (Semlitsch & Bodie 1998). Groundwater withdrawal, however, can cause depressions to dry completely, thus eliminating their role in maintaining regional biodiversity of amphibians. Other common geomorphic settings include riverine, or river marginal, wetlands that include portions of alluvial floodplains and river deltas, lacustrine wetlands notable for the narrow fringes that they occupy in sheltered lakeshores and reservoirs, and slope wetlands fed largely by groundwater discharging at topographic breaks. Each of the foregoing geomorphic settings supports wetlands

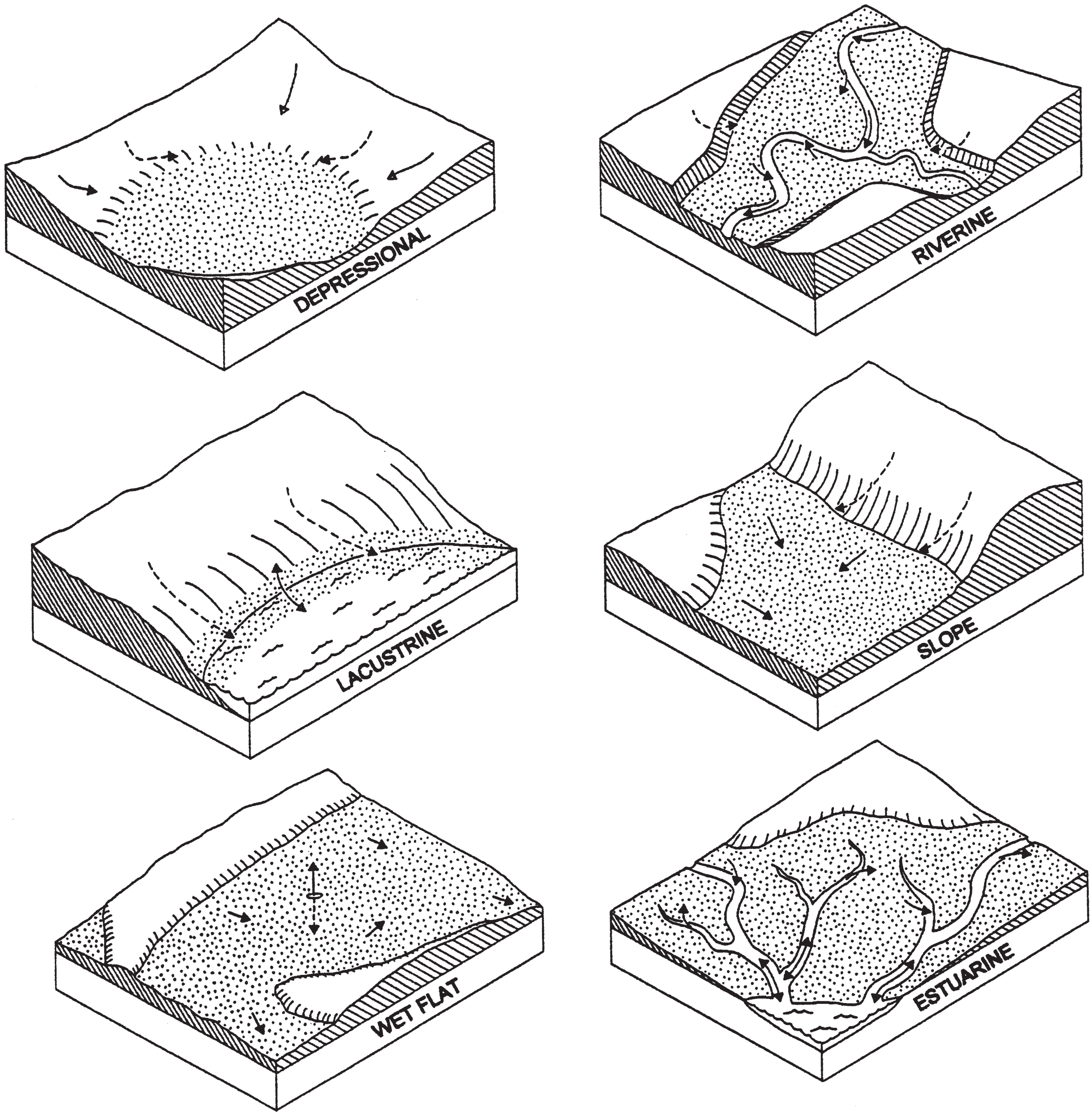

Figure 2 Geomorphic settings for wetlands. Each tends to receive different dominant sources of water and have different hydroperiods.

in climates ranging from arid to humid. Wet flats that occupy topographically flat areas, however, are restricted to climates that are humid enough to support wetland vegetation and soils without groundwater or surface water sources. In some cases, they have accumulated enough organic matter to result in peatlands, known also as organic-soil flats. In contrast, mineral-soil flats lack accumulation of much soil organic matter, but are wet enough to support hydrophytic vegetation. We include freshwater portions of estuarine deltas where levees obstruct the exchange of brackish water.

This review excludes large groups of wetlands in both colder and warmer climates. Moore (2002) reviews the status of cool temperate bogs, most of which occur in boreal regions of the northern hemisphere. We mention in passing some of the high altitude wetlands within temperate latitudes. Freshwater wetlands of subtropical and tropical zones are treated by Junk (2002), while the transitional areas of the Everglades of the USA and the Chaco of Argentina are covered in this review. Tockner & Stanford (2002) review river floodplains, but for consistency, we will discuss wetlands within floodplains of the temperate zone.

PROPERTIES, STATUS AND THREATS

Within each of six geographic regions (Fig. 1), we describe the properties of major wetland types, the current status based on losses of area and condition, and major threats that appear to be looming in the future. Coverage is very uneven geographically due to the variation in available information, a consequence of greatly differing levels of inventory and research among countries. Sources listed in tables are indicative of geographic concentrations of wetlands (or former wetlands) and are not meant to be comprehensive.

North America

Many kinds of wetlands occur throughout temperate regions of North America. Most of northern Canada and the state of Alaska are excluded, as these areas are dominated by boreal and arctic peatlands (Moore 2002). The border between Mexico and the USA serves more as a convenient boundary than it does a climatic transition.

Major types and their properties
The wetland complexes listed in Table 1 are abundant in the humid climates of North America, but cover a lower proportion of land in arid and semi-arid zones. This rarity factor in dry climates makes them exceptionally important to dependent species. In addition to providing a source of moisture, riverine wetlands in arid landscapes offer the only forest structure available to meet habitat requirements of arboreal species (NRC 2002).

Riverine wetlands elsewhere support anadromous fish, ranging from salmonids along the Pacific coast (Kosa & Mather 2001) to clupeids along the Atlantic coast (Limburg

Table 1 Major wetland areas of North America.

Wetland complex	*Major functions*	*Prominent alterations*	*Sources*
Central California marshes and vernal pools	Support waterfowl, fish, and numerous endemic species	Water diversions and drainage for agriculture	Zedler (1987)
Riparian wetlands of the arid and semi-arid states of the west and south-west USA	Forested structure in grassland and desert landscapes; bird habitat	Water diversion for agriculture and urban uses; grazing of riparian zones and marginal uplands	Patten (1998); Donahue (2000); NRC (2002)
High gradient streams from central California through British Columbia and into south-eastern Alaska	Anadromous salmon runs	Water diversions and dams; forest practices degrade spawning habitat	Gregory *et al.* (1991); Glooschenko *et al.* (1993)
Alpine meadows of the Rocky and Sierra Mountains	Endemic species	Timber harvests; ski resorts	Glooschenko *et al.* (1993)
Prairie potholes, Nebraska sandhills, and south-western playas	Waterfowl wintering and breeding	Groundwater withdrawals; conversion to agriculture and rangeland	Bolen *et al.* (1989); van der Valk (1989); Haukos and Smith (1994); Murkin *et al.* (2000)
Flats and depressions of glaciated regions of the Corn Belt	Major nutrient and soil organic storages prior to drainage	Drainage and conversion to agriculture	Dahl (1990); Mitsch *et al.* (2001)
Depressional wetlands and seeps of New England and south-eastern Canada	Amphibian breeding	Urban and suburban development	Semlitsch and Bodie (1998)
Laurentian Great Lakes marshes of Canada and USA	Waterfowl and fish habitat; shoreline protection	Shoreline stabilization and industrial contamination; invasive species; human regulation and global change effects on lake level fluctuations	Herdendorf *et al.* (1986); Glooschenko *et al.* (1993); Brazner (1997); Detenbeck *et al.* (1999); Keough *et al.* (1999)
Riverine wetlands of the Mississippi drainage	Major fish populations; floodwater storage and sediment deposition	Conversion to agriculture; modification of flows and levels for navigation (locks and dams)	Galat *et al.* (1998)
Bottomland hardwoods of Lower Mississippi alluvial valley and delta	Waterfowl flyway and fisheries; habitat for neotropical migrants; nutrient processing	Conversion to agriculture; isolation with levees	Wigley and Roberts (1997)
Wet pine savannahs of south-eastern Coastal Plain	Habitat for fire-dependent plants; endangered species	Suppression of fire; conversion to agriculture and silviculture	Walker and Peet (1983); Rheinhardt *et al.* (2002)
Hardwood flats and warm temperate peatlands of coastal plain	Habitat for neotropical migrants and wide ranging species	Conversion to agriculture and silviculture; peat mining	Richardson (1981); Rheinhardt and Rheinhardt (2000)
Coastally restricted forests (also in China, Japan and South Korea)	High degree of endemism; often dominated by *Chamaecyparis* spp.	Logging followed by poor regeneration of formerly dominant species	Laderman (1998)
South Florida: Kissimmee River, Lake Okeechobee, Everglades and Big Cypress Swamp	Major wintering habitat for birds; water source for Florida Bay	Altered hydrology and eutrophication; invasion of exotics	Harwell *et al.* (1996); DeAngelis *et al.* (1998); Toth *et al.* (1998)

2001). While these species do not occupy the drier portions of riverine wetlands, the structure provided by river-marginal forests offers bank stability, shade and organic matter for food webs. A combination of depressional, riverine and lacustrine wetlands offers wintering and breeding habitat for waterfowl. The prairie pothole region of Saskatchewan, Manitoba and Alberta in Canada, and the Dakotas and Iowa in the USA, in combination with the lower Mississippi Alluvial Valley, respectively, provide breeding and overwintering habitat for waterfowl along the Mississippi flyway (Sorensen *et al*. 1998). Throughout, wetlands provide habitat for muskrat (*Ondatra zibethicus*), beaver (*Castor canadensis*) and their predators.

Wet hardwood flats and pine-bunchgrass savannas are easily converted to other uses because they are easy to drain. Deciduous wetland forests once covered large areas of the Midwestern USA (e.g. Ohio, Indiana, Illinois), the coastal plain of the Gulf of Mexico and southern coast of the Atlantic. These deciduous forests once provided abundant breeding habitat for Neotropical migrant birds, and still do in remnant stands. Pine-bunchgrass savannas of the south-eastern coastal plain support red-cockaded woodpecker (*Picoides borealis*) and other endangered species (Walker & Peet 1983). High altitude meadows support rich plant associations (Cooper 1996). Coastally restricted forests of the USA and Canada are distinguished by the fact that tree species are endemic (mostly *Chamaecyparis* spp.), poor dispersers and poor competitors (Laderman 1998). These forests are being reduced both in extent and in quality.

The southern part of the Florida Peninsula consists of a huge wetland complex beginning with the Kissimmee River in the north and moving southward to Lake Okeechobee, the Everglades and Big Cypress Swamp (Toth *et al*. 1998). Although technically subtropical, this area is unique both in extent and in the types of plant communities. The Everglades itself receives water from Lake Okeechobee and continues to Florida Bay where mangroves and seagrass beds dominate. Dry season (winter–spring) fires in the largely sawgrass (*Cladium jamaicanse*) community maintain a savannah-like structure interrupted by tree islands and deeper sloughs (DeAngelis *et al*. 1998).

Current status and major threats

At the time of European colonization, wetlands made up roughly 9% of the land surface of what is now the continental USA (Dahl 1990) and 14% (including boreal and arctic zones) in what is now Canada (Glooschenko *et al*. 1993). Since the mid-1700s, however, approximately one-half of the wetlands in the lower 48 USA states have been converted to other uses, and of the remaining wetlands, 75% are privately owned (NRC 1995). Of the other 25% in government ownership, many large tracts are valued public treasures, such as the Everglades, Dismal Swamp, Okefenokee Swamp and many wildlife refuges. Even on private lands, wetlands are sufficiently important to society that conversions to other uses are regulated by the Clean Water Act of 1972 (Whigham 1999). South of Canada's boreal peatlands, major portions of freshwater wetlands have been converted, e.g. 68% in the highly populated region of southern Ontario (Rubec 1994).

Most wetland loss has resulted from conversion to agriculture and other land uses (Fig. 3). This has been particularly prevalent in the USA Midwest, where wet prairies and deciduous swamp forests were made arable simply by clearing and draining. On many large rivers, levee construction prevents over-bank flow by severing the connection with adjacent floodplain wetlands. Losses of these hydrologic connections prevent normal exchanges of water, nutrients, sediments and organisms (Poff *et al*. 1997), which reduce species richness (Ward *et al*. 1999). The lower Mississippi River has levees along most of its length (Sparks 1995) that have reduced water exchange with floodplain wetlands and promoted accretion of the channel bed (Belt 1975). In a 930-km reach of the Missouri River, the surface area was reduced by half between 1879 and 1954, with a concomitant reduction in aquatic habitat diversity, species richness of fish communities and corresponding commercial catches (Funk & Robinson 1974). In arid regions, drainage and diversion of water for agriculture have combined to eliminate wetlands from the Central Valley of California and reduced the condition and extent of riparian areas elsewhere. Dams, locks and other obstructions to water flow have not only converted riverine forest to lakes, but also affected anadromous fish by blocking migration to upstream spawning sites. In the Pacific North-west, forestry practices such as road construction contribute disproportionately to

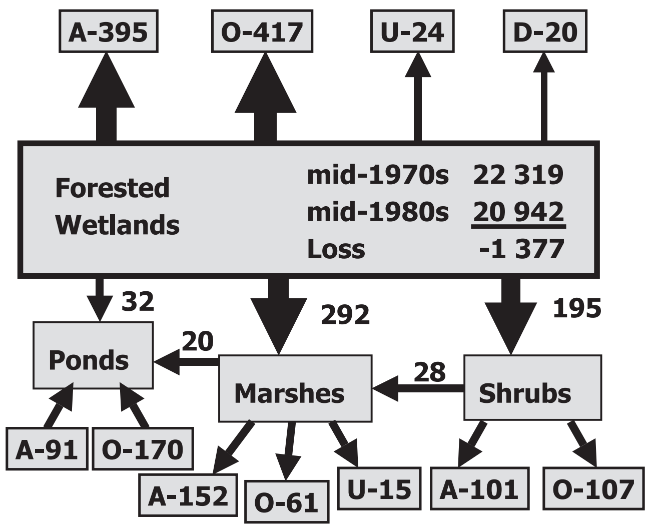

Figure 3 Conversion of wetlands in the USA from the mid-1970s to the mid-1980s. Units are thousands of hectares. While large amounts of swamp forest were converted to agriculture and other land uses, substantial portions were converted to other wetland types. Overall, 2.5% of interior wetlands in the lower 48 states were lost over a nine-year period. A = agriculture, O = other, U = urban, D = deepwater, . 'Other' signifies rural land uses not in agriculture or pasture, usually in the process of conversion. Adapted from Dahl *et al.* (1991).

sediment sources that degrade spawning habitat (Gregory *et al*. 1991). A series of canals and water conservation areas have altered the hydrology of the Florida Everglades so severely, that several billions of dollars have been allocated to restoration (DeAngelis *et al*. 1998).

Eutrophication, toxicity and fire suppression also contribute to wetland degradation. Toxic metals and pesticides contaminate wetlands, particularly in urban and intensively farmed areas. Kesterson Reservoir in California attracted worldwide attention because high selenium concentrations from irrigated lands caused deformities in waterfowl (Ohlendorf 1999). Finally, the role of fire may be overlooked as a necessary factor in the maintenance of wetland quality. Fire is crucial for maintaining high species richness in wet savannahs (Walker & Peet 1983) and sawgrass glades.

The rate of wetland conversion in the USA has slowed considerably due to implementation of regulations over the past 20 years. A number of non-regulatory programmes, particularly those concerned with water quality and indirectly biodiversity, have offered property owners incentives to maintain wetlands and riparian zones through the purchase of development rights and easements (NRC 2001). Recent resurgence of beaver populations has expanded the size of many floodplain wetlands on small streams (Snodgrass 1997). A goal of no net loss of wetlands nationwide has clearly not been achieved. If recommendations are adopted (NRC 2001), prospects for stemming losses, and even reaching net gains, appear to be achievable over the next 20 years.

South America

The majority of wetlands of the South American continent are tropical and subtropical. Temperate wetlands occupy the southern portion of the continent (Neiff 1999; Fig. 1). The climate in the temperate zone ranges from arid to humid, and the elevations from near sea level to mountains supporting perennial glaciers. This variation supports a large array of wetland types. Biotic diversity arises not only from this complexity, but also because the southward flowing Paraná River contributes species from tropical and subtropical zones that otherwise would be restricted to higher latitudes (Neiff 1990).

Major types and their properties

In the warm temperate wet region, the large Chaco-Pampas plain contains large flats such as the Bajos Submeridionales and the Salado River basin. These areas are quite homogeneous and are covered principally by grassland, with a hydrologic regime of alternating floods and droughts. The East Chaco contains a complex series of swamps and streams. The Esteros del Iberá is a unique combination of shallow lacustrine environments and emergent marshes (Neiff 1997). The wide Paraná River alluvial plain and the Delta lie also in this region, receiving water sources from large watersheds in Brazil, Bolivia, Paraguay and Argentina. The complexity of this floodplain and its wetlands is remarkable, with sharp meanders, deep oxbow lakes and numerous ridge-and-swale environments.

Drier regions have scattered and numerous depressional wetlands with outstanding functions as waterfowl habitat and water sources for other organisms (Neiff 1999). This applies also to the little studied lakes and peatlands in the High Andes. The colder areas in Patagonia have two types of characteristic and locally important wetlands, namely wet meadows (*mallines*), intensively used by cattle, and peatlands (*turberas*), mainly dominated by *Sphagnum*. Peatlands are especially widespread in the Magellanic Tundra Complex including Tierra del Fuego. On the Pacific coast, particularly at its centre, wetlands are associated with numerous rivers flowing from the Andes (Neiff 1999).

Current status and major threats

Compared with similar types of temperate wetlands in the Northern Hemisphere, many of those of temperate South America have not been subjected to extreme and massive hydrologic alterations, and thus have retained the capacity to support much of the original biodiversity. Grazing is a prevalent land use (Table 2). However, the value of wetlands is still not appreciated and numerous projects are planned that would ultimately reduce biodiversity (A.I. Malvárez, personal observations 2001). Wetlands will continue to be affected by urban expansions and highway construction. Portions of the Iberá macrosystem are being converted to agricultural production, and the area's hydrology may be influenced by nearby reservoir manipulations through groundwater flows (Neiff 1997). Streams flowing to the Pacific are becoming more regulated as dams for water supply and hydroelectric power continue to come online. All of these projects have direct effects on wetland biodiversity through drainage, diversions and deep flooding that eliminate entire wetlands or portions of wetlands, and through potentially reversible conversion of wetlands to annual crops and grazing. Local hunting influences populations of waterfowl, capybara (*Hydrochaeris hydrochaeris*), and other highly valued fauna (Bó & Malvárez 1999). Exotics such as the shrub Chinese privet (*Ligustrum sinense*) are prevalent in both temperate South America (Dascanio *et al*. 1994) and North America (Cuda & Zeller 2000).

Most conservation actions rely exclusively on creating and maintaining protected areas such as national parks, Ramsar sites and Man and the Biosphere reserves without a general policy framework for proper management. Inventories of wetland area and change due to human activity are lacking. Economic pressures to convert wetlands outside of protected areas to agriculture will continue, particularly for countries with the burden of high external debt.

Climate change predicted for the next decades (WGI-IPCC [Working Group I of the Intergovernmental Panel on Climate Change] 2001; WGII-IPCC [Working Group II of the Intergovernmental Panel on Climate Change] 2001) is expected to intensify the El Niño-Southern Oscillation rain and drought events. This means a highly dynamic scenario

Table 2 Major wetland areas of South America. [1]Ramsar site.

Wetland complex	*Major functions*	*Prominent alterations*	*Sources*
Puna lakes and peatlands	High altitude waterfowl and flamingos. Water storage	Overgrazing; alterations and contamination due to mining	Caziani (1996); Sarmiento *et al.* (1998)
Arid depressional ponds	Waterfowl. Water storage	Water withdrawal, grazing, and contamination	Iglesias and Pérez (1998)
Iberá macrosystem	Maintenance of water quality. High biodiversity	Partial drainage for agriculture. Potential effects of large dams and other projects	Neiff (1997)
Middle and Low Paraná River and Delta	Flood regulation. Fish production. High biodiversity	Large hydroelectric dams. Modification for navigation. Polder and dyke construction	Neiff (1990); Bonetto and Hurtado (1998); Malvárez (1999)
Swamps, streams and riparian forests of wet Chaco	Water storage. High biodiversity	Cattle grazing. Fire	Morello & Adámoli (1968); Adámoli (1999)
Bajos Submeridionales mineral flat	Waterfowl. Water storage and flood interception	Cattle grazing. Fire. Hydraulic projects	Bucher and Chani (1998)
Salado River basin	Fish and wildlife habitat. Water storage and flood interception	Cattle grazing. Agriculture. Drainage and road construction	Gómez and Toresani (1998)
Humid meadows of Patagonia	Wildlife habitat. Water storage	Cattle overgrazing. Water withdrawal	Collantes and Faggi (1999)
Peatlands of Magellanic Complex and Tierra del Fuego[1]	*Sphagnum* peatlands control drainage, water storage	Drainage, peat and placer mining, overgrazing, forestry	Pisano (1983); Hails (1996); Schlatter (1996); Collantes and Faggi (1999)
Rivers and streams of Pacific coast	Water supply. Waterfowl. Fish habitat	Agriculture. Urban expansion. Hydrological regulation of courses	Schlatter *et al.* (1998)

for all classes of wetlands in this region. Moreover, it is believed that global warming will differ by location (Labraga & López 2000). Temperature increase is projected to affect mainly high altitude Puna wetlands of the Andes and to a lesser extent the Pampas and Patagonia. At the same time, the Chaco-Pampas plains and southern-most Patagonia would receive more precipitation. The Andean region, especially the central portion, would suffer water shortages (Labraga & López 2000).

Northern Europe

Climates range from the cool temperate regions of southern Scandinavia to the alpine environments of the Alps and the warm temperate regions of France and Italy. Many of the wetlands have been altered for hundreds of years. In such highly managed landscapes, wetlands are recognized as some of the last remaining areas for maintaining biodiversity in an otherwise human-dominated region.

Major types and their properties

Most wetlands are associated with rivers, deltas, lake margins and alpine regions (Table 3). Wiegers (1990) classified the forested wetlands of Western Europe into riverine forests consisting of *Alnus* thickets, *Alnus* woodland and *Salix* thickets; other forest types dominated by the genera *Acer*, *Fraxinus*, *Populus* and *Quercus*; and nutrient-rich peatland forests (Moore 2002) that have components of *Alnus*, *Myrica* and *Salix* in competition with sedge-dominated fens. Wet flats and depressions are scarce or lacking, probably because of drainage for agriculture. Connections between river channels and floodplain wetlands that are particularly influential for fish diversity (Fig. 4) have been extensively severed. While the wetlands associated with these rivers have been much diminished, they remain in many cases the only portions of some landscapes that support forests and naturally occurring species. Of the few forest plots remaining in the alluvial valley of the Po River in Italy, hybrid cottonwood is raised for fibre production (Bodini *et al.* 2000).

Current status and major threats

Only wetlands with strong geomorphic signatures, such as those of major river floodplains, lake margins and alpine slopes, have escaped complete extirpation. Even these wetlands, however, have been highly modified through construction of locks, dams and levees, not to mention impacts from atmospheric deposition (Bobbink *et al.* 1998), farming, gravel mining, timber harvesting, species extinctions and invasion of exotics. Few plant or animal communities are adapted to the water regime of reservoir shorelines (Nilsson 1981) that replace species-rich river marginal wetlands.

Nutrient loading of waters entering wetlands is paramount in affecting biodiversity of wetlands worldwide because of dramatic effects on species composition and structure of vegetation (Keddy 2000). Eutrophication is especially prevalent in northern Europe, in part due to agricultural intensification (Lienert *et al.* 2002). Nutrient sources from

Table 3 Major wetland areas of northern Europe. [1]Ramsar site.

Wetland complex	*Major functions*	*Prominent alterations*	*Sources*
Rhine River and delta, Germany and the Netherlands	Flood water storage; historically fish and water fowl	Heavily industrialized; canalization, dams and weirs for navigation; floodplain wetlands isolated; toxicity	Ward *et al.* (1999)
Scandinavian Peninsula wetlands of rivers and lakes	Submerged and emergent vegetation, wildlife and fish	Acid deposition, agriculture and hydropower	Dugan (1993)
Stream corridors of montane wetlands of high Alps, upper Rhône River, France	Maintenance of biodiversity of specialized plant species	Dyking and channelization with sediment infilling of bypass channels	Bornette *et al.* (1998); Girel and Manneville (1998); Amoros *et al.* (2000)
Norfolk Broads, England[1]	Largely artificial marshes and ponds for reeds, waterfowl, and fish	Intense tourist activity; drainage for agriculture; eutrophication and saltwater intrusion	Hails (1996)
Montane wetlands, Switzerland	Maintenance of plant and arthropod diversity	Replace traditional practices with late mowing and low-density cattle grazing; fragmentation	Wettstein and Schmid (1999); Lienert *et al.* (2002)
Northern Adriatic, north-east Italy	Migratory links of wintering Dunlin (*Calidris alpina*) with Azov/Black Sea wetlands	None mentioned	Serra *et al.* (1998)
Po River and Delta	Anadromous fish; forested wetland patches	Agriculture; sand mining; levee construction	Bodini *et al.* (2000)
Saone floodplain, France	Floodplain dynamics maintains habitat for biodiversity	Grassland fragmentation by agriculture	Godreau *et al.* (1999)
Riverine wetlands in France	Butterfly dependence on oligotrophic vegetation	Nutrient enrichment of vegetation leads to butterfly loss	Van Es *et al.* (1999)
Danube River and delta region	Mainstem largely modified; delta a complex array of reedbeds, canals, and ponds supporting bird habitat	Connectivity virtually eliminated by impoundments and levees; pollution from industry and agriculture	Tockner *et al.* (2000)
Baltic Sea region (e.g. Latvia, Estonia)	Representative examples of mixed riverine forests, and peatlands contribute to regional biodiversity	General degradation due to drainage for agriculture, peat mining, and oil shale mining; now 15% of mire area protected in Estonia	Prieditis (1999); Masing *et al.* (2000)
Neusiedlersee, Austria and Fertó, Hungary (shared)[1]	Breeding area for migratory waterfowl; rare plants	Drainage and eutrophication from agriculture; groundwater pumping dries lakes	Hails (1996)

the atmosphere are particularly difficult to control. Restoration of drained wetlands near the Baltic Sea is projected to substantially reduce nitrogen input from the atmosphere, and make contributions to biodiversity (Jansson *et al.* 1998).

Remaining wetland parcels have received major attention from initiatives oriented toward maintaining and enhancing biodiversity. For example, species such as the dunlin (*Calidris alpina*) in the northern Adriatic portions of Italy have migratory links to wintering in Azov/Black Sea wetlands (Serra *et al.* 1998). Fragmentation continues to result in local extinctions (Lienert *et al.* 2002). Recently, 10 Ramsar Convention areas have been established in Estonia (Masing *et al.* 2000). The high level of attention to such wetlands makes it unlikely that future losses will be acceptable. Opportunities to expand wetlands should be driven by initiatives to enhance biodiversity and the use of wetlands to improve water quality.

Northern Mediterranean, including Spain and Portugal, southern France, Italy, former Yugoslavia, Albania, Greece, Bulgaria and Turkey

Because this region has an arid climate (Fig. 1), wetlands are scarce, except for those on major river floodplains. Wetland protection is of interest because they represent the only sites for very uncommon species and they are important for migratory waterfowl and shorebirds.

Major types and their properties

Wetlands associated with rivers and lakes constitute the major types for this region (Table 4). Wetlands in the

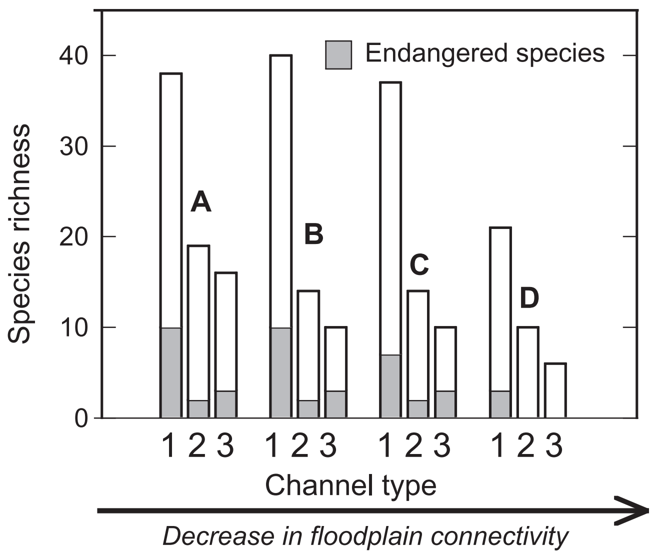

Figure 4 Species richness of fish communities within riverine wetland environments along a gradient of decreasing connectivity from the Austrian Danube River. A and B are free-flowing reaches, C is a floodplain in an impounded reach, and D is disconnected from the floodplain. Clusters represent increasing isolation of habitats within a reach: 1 = dead arms connected to channel; 2 = abandoned braids; 3 = abandoned meander bends. Adapted from Ward *et al.* (1999).

Mediterranean climates of Spain and Portugal, southern France, Italy and Greece have received much attention because of their importance in supporting waterfowl and shorebirds, for which a number of Ramsar sites have been established. Because many wetlands are seasonally dry, most aquatic birds are migratory and do not breed in them (Britton & Crivelli 1993). Riverine wetlands are dependent on flows that arise in mountainous areas with high rainfall, such as the Guadalquivir of Spain, the Rhône in France, the Po in Italy, and the Axios and Evros in Greece. Their perennial flow contributes to the freshwater portions of deltas, while brackish water communities dominate the lagoonal portions. Glacial outwash from the Alps contributes sediments to delta regions as does forest clearing, although reservoirs tend to trap some of these sources (Britton & Crivelli 1993). In river deltas, freshwater marshes are found along old river courses or where water becomes impounded behind levees. Riverine forests dominated by *Populus*, *Salix*, *Fraxinus* and *Ulmus* remain where the flat topography contributes to poor drainage in spite of hydrologic modifications that have removed over-bank flow as a direct water source (Britton & Crivelli 1993).

River floodplain wetlands have been transformed since human occupation to small, isolated remnants of three types: (1) oxbows that support species of *Salix* and *Populus*, as well

Table 4 Major wetland areas of the northern and eastern Mediterranean. [1]Ramsar site.

Wetland complex	*Major functions*	*Prominent alterations*	*Sources*
Guadiana River high basin and Doñana National Park, Spain	Species richness and conservation; water conservation	Pumping of groundwater and lowering of water tables for agricultural use	Benayas *et al.* (1999); Sanz (1999); Fornes *et al.* (2000)
Ebro Delta[1]	Portions contain freshwater marsh; waterfowl, rice, and fishing	Delta subsidence, eutrophication, conversion to aquaculture	Hails (1996)
Camargue (Rhône River delta), southern France	Support waterfowl; flamingos	Rice fields	Tourenq *et al.* (2001)
Greece, Ramsar sites	Nutrient removal, sediment retention, flood flow alteration, and groundwater discharge	Irrigation, cropland expansion, and overgrazing	Gerakis and Kalburtji (1998)
Greece	Wet meadows provided traditional areas for grazing and foraging	Meadows being replaced by cultivated fields	Georgoudis *et al.* (1999)
Major rivers and wadis throughout Middle East, such as the Euphrates	Riparian areas in arid climate	Water diversions for agriculture; Euphrates dam for irrigation in Turkey	Dugan (1993)
Lake district of Turkey	Wintering waterfowl including white-headed duck; inland fisheries	None known	Dugan (1993)
Mogan and Eymir Lakes, Turkey	Wetland controls lake water geochemistry	None known	Camur *et al.* (1997)
Azraq Oasis, Jordan	Migratory birds for wintering and breeding [1]	Overpumping of groundwater from the basin	Hails (1996)

as herbaceous hydrophytes in more permanently wet conditions; (2) freshwater marshes containing *Typha*, *Phragmites* and *Scirpus* in wetter portions, and *Carex* and *Cladium* in drier portions; and (3) forested bottomlands along rivers dominated by *Populus alba* in the Mediterranean region and *Platanus orientalis* in the Balkans (Britton & Crivelli 1993). A narrow band of emergent and submerged species occupies the shorelines of cirque lakes of the high Alps, the caldera lakes of central Italy and the karst lakes of the former Yugoslavia, Albania, and north-western Greece. Reservoirs now exceed the number and area of all freshwater wetlands, and in exceptional cases can offer habitats of considerable wildlife importance. Most, however, are steep-sided with widely fluctuating water levels, a situation that is not conducive to the maintenance of wetland communities. Freshwater marshes exist mainly as a few relatively large areas (Britton & Crivelli 1993), but the total area covered is only partly known and consequently underestimated (Table 5).

Current status and major threats

A number of factors have led to the diminution of wetlands of the northern Mediterranean, such as drainage as early as in the 5th century BC in Italy. Water is stored in reservoirs mostly in upland valleys, diverted to irrigated agriculture, and excluded from floodplains that originally supported river marginal wetlands (Britton & Crivelli 1993), similar to the pattern prevalent worldwide (Dynesius & Nilsson 1994). Other human-induced alterations include fishing and fish culture, hunting, harvesting vegetation, and pressures from tourism and water sports (Britton & Crivelli 1993). The transition from traditional to intensive agriculture has increased pressure on wet meadows (Georgoudis *et al.* 1999).

Water diversions are particularly prevalent in arid regions where the combination of fertile soils and abundant sunlight means that water is the major factor limiting agricultural productivity (Brendonck & Williams 2000). Socioeconomic pressures for water in arid regions have spawned an expansion of water supply reservoirs as recently as the 1990s on rivers such as the Euphrates (Dugan 1993). There is little evidence that these pressures will diminish, and trends in water management are unlikely to leave resources available for wetlands. Reservoirs both displace riverine wetlands and reduce sediment supplies for maintaining coastal deltas. Riverine forests are represented by small fragments and have been eliminated from most river courses. Because only small amounts of wetlands currently remain, the situation is similar to, but perhaps worse than, that in northern Europe. In order to expect an improvement in wetland area and condition, aggressive measures would be needed.

Temperate Russia, Mongolia, north-eastern China, Korea and Japan

This vast region is bordered by extensive boreal peatlands to the north and subtropical lands to the south (Fig. 1). As such, important migratory routes for waterbirds dominate much of the wetland functions of this region. In contrast to the arid and human-dominated regions just covered, large areas of temperate Russia and north-eastern China have sparsely populated areas of poorly drained flats in addition to rivers and lake districts. The wetlands of Japan, Korea, and eastern China have been exposed to long periods of intensive land use.

Major types and their properties

In addition to the wetlands treated here, there are extensive peatlands in the region, such as those in the Jilin and Heilongjiang Provinces of China. The largest freshwater marshes in China are found in the Nenjiang-Songhuajiang-Heilongjiang Basin in the north-western part of the country. At the high altitudes of the Qinghai-Tibetan Plateau (4000–5500 m), internal drainage creates numerous saline lakes and ponds important for breeding waterfowl (Lu 1995). The great plains of the Yangtze-Yellow-Huaihe Basin in eastern China are replete with freshwater lakes, many of which have fringing marshes. Marshes along the lower portions of the Yangtze River itself support one of the country's most productive fisheries (Lu 1995). In addition to extensive rice fields, Japan has a number of bog and fen peatlands. Except on the island of Hokkaido where peatlands cover large areas, small areas of mires have been protected for their unique habitats for plants and animals (Iwakuma 1996). Very little is known about the freshwater wetlands of Korea.

Current status and major threats

Areas in Russia are increasingly being exposed to activities associated with forestry, mining, and oil and gas exploration (Table 6). Wildlife poaching has become a problem (Dugan 1993). The extensive wetlands of the Jilin province in China, some of which are peatlands, are undergoing conversion to agriculture. Further south, the massive flood control and

Table 5 Estimated areas (km^2) of wetlands in the Mediterranean region: ? = present but area unknown; empty cells = not estimated or reported. From Britton and Crivelli (1993). Asterisks indicate countries with national wetland inventories (Hughes 1995).

Wetland type	*Portugal**	*Spain**	*France**	*Italy**	*Albania*	*Yugoslavia*	*Greece**	*Bulgaria**
Freshwater coastal lagoons	?		37	?	?	?	?	
Freshwater lakes	?		5	30	>350		1641	
Reservoirs	?		36	?	?	?	125	?
Freshwater marshes	?	>65	203	15	?	?	53	?
Forested wetlands	?	?	<10	>3	?	?	3	?

Table 6 Major wetland areas of temperate Russia, Mongolia, north-eastern China, Korea and Japan. [1] Location of Dongdongtinghu (East Dongting Lake), a Ramsar site. [2] Location of Kushiro Marsh, a Ramsar site.

Wetland complex	*Major functions*	*Prominent alterations*	*Sources*
South of Siberian lowlands and into north and central Kazakhstan	Waterfowl breeding area	Activities associated with forestry, mining, and oil and gas exploration on the rise	Dugan (1993)
Mongolian rivers and lakes	Breeding and staging for migratory waterfowl	Minor	Dugan (1993)
Three Rivers Plain (Sanjiang) including Ussuri River, Far East Russia and north-eastern China	Migratory and breeding cranes and endemic plants and animals; reed production	Poaching and wildlife trafficking; water diversion and conversion to agriculture and silviculture	Marcot *et al.* (1997)
Middle and lower Yangtze River, China	Migratory waterfowl, grazing, reed cutting source, fishing[1]	Three Gorges dam on Yangtze; unsustainable reed cutting; waste water	Qing (1998)
Lower Changjiang Valley, China	Endangered Chinese alligator (*Alligator sinensis*)	Multiple, from human activities	Thorbjarnarson *et al.* (2002)
Eastern Hokkaido marshes, Japan (fen, reed and sedge marsh)	Waterfowl and waders; salmon fishery; water quality[2]	Channelization and sedimentation causing replacement of sedges and *Alnus japonica* by *Salix* spp.	Hails (1996); Nakamura *et al.* (1997)
Isolated peatlands, Japan	Reservoirs of rare species	Drainage, peat extractions, and land reclamation	Iwakuma (1996)
Rice fields, Japan	Maintenance of frog (*Rana*) species in earthen irrigation ditches	Species threatened by concrete and piped irrigation	Fujioka and Lane (1997); Lane and Fujioka (1998)

hydroelectric generation being developed by the Three Gorges Dam on the Yangtze River constitute one of the largest modifications to a major river ever attempted. This dam will flood 632 km of free-flowing river channels of the mainstem of the Yangtze River and tributaries (Qing 1998). Because of low population densities in Mongolia, wetlands have been little altered where they occur.

Little is known about the alteration of freshwater wetlands in Korea. Environmental groups in South Korea are instead preoccupied with one-third of the country's tidal flats lost since 1945, and a current project slated to drain 40 100 ha of tidal flat in Namyang Bay (http://eco.kfem.or.kr/wetland/index.html). Extensive natural wetlands in Japan are limited to the eastern portion of Hokkaido, the mountainous central region of the main island, and isolated pockets elsewhere. Many have been converted to agriculture through drainage and harvested for peat (Iwakuma 1996). Lowland wetlands are dominated by rice culture, which affords some habitat for aquatic and wetland species. Marginal rice fields are receiving increasing attention as refugia for endangered species.

Except for Japan, where some wetland restoration is occurring (M. Miyamoto, personal communication 2001), there is little attention given to protecting or restoring wetlands. Instead, wetlands are drained for conversion to agriculture. Published research on wetlands is practically non-existent in forms available for review outside of the countries, except for Japan. In general, attention to managing wetlands for their natural attributes is lacking, except for information provided by non-governmental organizations on their importance as bird and fish habitat.

Southern Australia and New Zealand

Jacobs and Brock (1993) consider temperate Australia as south of the Tropic of Capricorn (Fig. 1). The country has state-by-state surveys, but there are significant gaps in coverage within states and differing classification systems among states (Pressey & Adam 1995). Wetlands of Tasmania and New Zealand have received lesser attention.

Major types and their properties

Jacobs and Brock (1993) recognize the following freshwater wetland types: (1) upland swamps at the heads of coastal rivers with peat-like deposits and heath-like vegetation; (2) rivers and tributaries that harbour submerged vegetation, emergent species and trees; (3) riverine swamps and billabongs (i.e. oxbows) with trees of *Melaleuca quinquenervia* and an understorey dominated by Cyperaceae and Restionaceae; (4) coastal lagoons and lakes with submerged and emergent vegetation similar to that of rivers and tributaries; (5) mountain lakes and swamps, mostly with emergent species (e.g. *Phragmites*); (6) inland rivers that originate in areas of relatively high rainfall, but flow to more arid climates where they may disappear; and (7) mound springs of very limited distribution that are fed by artesian aquifers, and are vegetated mostly by Cyperaceae, *Typha* and *Phragmites*.

The Murray River drainage basin in the south-eastern-most part of the continent has the largest extent of forested wetlands. However, few stands are of sufficient area to be considered commercially viable for timber extraction (Specht 1990). Common tree dominants are in the genera *Casuarina* (two species), *Eucalyptus* (eight species), and *Melaleuca* (seven species) (Specht 1990). These species are well adapted to survive fire. The Lake Eyre Basin has the greatest area of persistent wetland unregulated by humans (Roshier *et al.* 2001).

At high altitudes, bogs and fens are found above 1650 m in south-eastern Australia (Wahren *et al.* 1999) and alpine valleys of New Zealand and Tasmania. Oceanic currents, mild temperatures and high rainfall make New Zealand more suited for wetland development than Australia (Campbell 1983).

Current status and major threats

Because Australia is such an internally arid continent, human activities are in direct competition with wetlands for sources of water (Specht 1990). Historically, riverine wetlands of high rainfall coastal areas were modified through flow regulation (Table 7) to supply livestock production and other water uses (Kingsford 2000). Modifications elsewhere included pollution, burning, grazing, sedimentation, extraction of water and recreation (Pressey & Adam 1995). The Murray-Darling system is being affected by salinity from irrigation for agriculture and urban withdrawal (Jacobs & Brock 1993). Flow alterations are believed to affect the breeding cycles of waterbirds, fish and other animals. Exotics include the herbaceous *Eichhornia crassipes, Salvinia molesta* and *Alternanthera philoxeroides*. Feral animals and urban sprawl are cited as minor (Jacobs & Brock 1993).

Lowland wetlands have been severely altered in former large wetland complexes of New Zealand and Tasmania. Only 8% of the original wetlands remain in New Zealand (Jones *et al.* 1995). The floating islands of the Lagoon of Islands complex in Tasmania became threatened due to artificially raised water levels and boating (Campbell 1983).

The highly altered state of many of the wetlands in temperate Australia can be traced largely to a multitude of human activities that compete for water in a relatively arid climate with high interannual variability in precipitation. Without reduction in water use, there appear to be few opportunities to improve the state of wetlands over the next several decades. Some efforts are directed toward restoration (Reid & Brooks 2000). Inventories of wetland area and condition are needed to track changes and provide information on what wetlands are being converted and at what rate. Such information would be useful in developing strategies for conservation and restoration in both Australia and New Zealand.

GENERAL FORECAST AND STRATEGIES FOR MANAGEMENT

This review was undertaken to summarize the types of wetlands found in temperate zones, assess their condition based on the types of alterations to which they have been subjected, and project threats to them between now and the time frame of 2025. Available information points to an unequivocal pattern of enormous losses in surface area, condition and associated biodiversity. In northern Europe and the northern Mediterranean, losses have been ongoing for hundreds of years. Tremendous losses occurred in North America during the 1950s–1970s, in part because USA-sponsored programmes subsidized drainage. In contrast, areas such as China appear to be on the cusp of expanding drainage projects and building impoundments that will eliminate and degrade freshwater wetlands. The most industrialized countries are likely to conserve their already impacted, remaining wetlands and move toward selective restoration as oppor-

Table 7 Major wetland areas of southern Australia and New Zealand.

Wetland complex	*Major functions*	*Prominent alterations*	*Sources*
Murray-Darling River systems, Australia	Closed and open forested wetlands support fish, birds, and marsupials	Grazing; erratic flows due to overcommitment to agriculture and urban usages; pollution from urban and agricultural sources; alteration of flow; increased salinity; introduction of non-native species	Specht 1990; Jacobs and Brock (1993)
Floodplains of Murray-Darling River, Australia	Waterbirds and fish populations	Dams, with upstream and downstream effects	Kingsford (2000)
Lake Eyre Basin, Australia	Waterbirds, fish production, and unique species	Reduced rainfall from global climate change	Roshier *et al.* (2001)
Alpine and subalpine, Bogong High Plains, Australia	Support endemism and diversity	Cattle grazing and trampling	Wahren *et al.* (1999)
Varied wetlands of New Zealand	Supports indigenous vegetation and waterfowl	Land drainage, mining, and agricultural development	Campbell (1983)
Waikaia Ecological Region, New Zealand	Supports indigenous vegetation and invertebrates	Cattle grazing	Dickinson *et al.* (1998)

tunities arise and the value of wetland services gain more recognition. Nations undergoing rapid industrialization are accelerating wetland losses now, and may continue to do so for the next several decades, with little attention paid to protection and virtually none to restoration. Data on how much and where losses are occurring are difficult to obtain and very hard to forecast. Generalizations that can be gleaned from this paper should be considered only as a starting point for developing worldwide data sets for temperate-zone wetlands.

Common alterations

Alterations to wetlands may be generalized as falling into one or more of the following categories: geomorphic, hydrologic, nutrients and contaminants, harvesting, extinctions/invasive species, and climate change (Table 8). Estimated intensity of effects by alterations on various wetland classes are expressed as severe, moderate or minor. Table 8 indicates that the intensity of effects from geomorphic through to climate change generally decreases. Even so, there are examples of estimated severe effects due to extinctions, invasions and climate change. Human-induced alterations reduce species richness of wetland-dependent taxa. Moreover, the effects of alterations are not mutually exclusive, and may have cumulative and multiplicative interactions.

Geomorphic and hydrologic alterations

Dams severely affect riverine wetlands, in both upstream and downstream directions. In some geographic regions (North America, Europe and Japan), additional dam construction is unlikely because the most productive sites for hydroelectric generation have been captured and environmental regulations make further projects difficult to implement (World Commission on Dams 2001). In fact, government programmes are facilitating the removal of dams that no longer have a useful function (Bednarek 2001). In other areas, dam building is ongoing and expected to continue, especially in arid zones of the Mediterranean for irrigation of agriculture and in Asia and South America for hydroelectric generation and flood control. Water diversions of any kind can be viewed as potentially competing with freshwater wetlands. Dyking that has created and stabilized coastal non-tidal wetlands (mostly deltas) has been in place for many years in Europe and the Mediterranean. While plans to convert large areas of tidal flats in Korea to agriculture may produce incidental gains in freshwater wetlands, as in European deltas, such projects do so at the expense of critical habitat for migratory waterbirds. Drainage and filling of wetlands continues to occur in the USA in spite of national and local regulations (NRC 2001). Expansion of agriculture in any geographic region may be considered an indicator of declining biodiversity, since many agricultural practices result either in drainage in humid climates or in irrigation in arid climates, both stressful to native wetland taxa.

Nutrients and contaminants

Nutrient loading is especially prevalent in Europe and North America where industrialized nations practice intensive agriculture and support livestock industries. Sources of nutrients, especially nitrogen, enter wetlands via surface water, groundwater and the atmosphere. While wholesale changes in wetland type do not result from nutrient additions as for geomorphic and hydrologic alterations, plant community and faunal composition can change by displacing species incapable of competition under nutrient-rich regimes (Bedford *et al.* 1999). Eutrophication often encourages invasive species in oligotrophic wetlands, which further compromises biodiversity. Assuming that agricultural intensification parallels industrialization, we expect nutrient and contaminant pollution to continue in those nations undergoing the most rapid development.

Harvests, extinctions and invasions

Harvests of wetland species range from timber removal to trapping and fishing. In theory, harvest practices can be sustainable if properly regulated and managed. Where other types of alterations have driven some species populations to rare and endangered status, poaching may drive them to extinction. Wetland-dependent species are particularly vulnerable because habitats are often geographically isolated and small, as in the case of vernal pools (Semlitsch & Bodie 1998), making dispersal and repopulation more difficult after local population extinctions. Invasions of exotics can lead to diminished native populations. Grazing is a chronic problem, particularly in arid climates where wetlands attract domestic cattle.

Climate change

There is widespread agreement that average global temperatures will continue to rise over the next century (WGI-IPCC 2001). Changes in temperature, precipitation, oceanic and atmospheric circulation, and the frequency and severity of storms are predicted to vary regionally and are likely to affect temperate freshwater wetlands. Except for the flats, which are dominated by precipitation, wetland classes (Table 8) occur in all temperate climatic regions. A simplistic view is that, given an increase in temperature, a region could become drier or wetter, and thus support smaller or larger areas of wetland, respectively. Further, species composition would simply change from its present condition to one that occurred in a similar climate but at a different location prior to climate change. Not addressed by this scenario is the differing capacity of species to disperse and the formidable natural and human-created barriers to migration (Davis & Shaw 2001). Indigenous wetland plants are likely to find their potential colonization sites already occupied by recently introduced, non-native species (Galatowitsch *et al.* 1999). Some geographic barriers are so formidable that they are unlikely to be overcome in the time frame projected for climate change, especially alpine wetland flora, now isolated by temperate climates at lower altitudes.

Table 8 Estimated effects on biotic communities from types of alterations and their interactions with wetland classes. Effects on biotic communities are estimated with ratings of severe, moderate, or minor. For example, a lacustrine fringe receiving hydrologic alterations (e.g. stabilized lake levels) may lead to moderate effects on species composition by reducing the natural disturbance regime (Keddy 2000). Types of impacts are (1) geomorphic changes that alter a wetland's shape or convert it from one type to another (from riverine to lacustrine fringe, for example, or even wetland to upland); (2) hydrologic changes that alter the sources and sinks of water, or significantly change hydroperiod; (3) nutrient and contaminant loading that may cause excessive nutrient loading or result in the contamination of soils and biota; (4) harvesting activities that remove biotic components through hunting, fishing, and logging; (5) extinctions and invasive species that may out-compete native species; and (6) climate change that may shift the distribution of species. Empty cells indicate that interactions are uncommon. The table lacks rigorous review and cannot express the complexity of situations throughout the temperate zone.

Type of alteration	*Wetland class*									
	Riverine		*Lacustrine fringe*		*Depression/flats*		*Slope*		*Coastal non-tidal*	
	Type of impact	*Intensity rating*	*Type of impact*	*Intensity rating*	*Type of impact*	*Intensity rating*	*Type of impact*	*Intensity rating*	*Type of impact*	*Intensity rating*
Geomorphic	Dams	Severe	Navigation dredging	Moderate	Road fill	Moderate	Road fill	Severe	Transgression stalled	Moderate
Hydrologic	Diversions of water	Severe	Stabilized levels	Moderate	Drainage	Severe	Drainage	Severe	Dykes for pest control	Moderate
Nutrients and contaminants	Eutrophication	Severe	Eutrophication	Severe	Selenium accumulation	Severe	Loss of nutrient-sensitive species	Severe		
Harvests	Timber and fuel	Minor	Waterfowl	Moderate	Timber and fuel	Minor			Furbearers	Minor
Extinctions and invasions	Tamarisk	Moderate	*Lythrum salicaria*	Severe	Non-native grasses	Severe			Common reed	Minor
Climate change	Eutrophication	Minor	Level change	Moderate	Shallow basins dry	Severe	Loss if drier	Moderate	Transgression faster	Moderate

It is unlikely that projected effects due to climatic changes could be as far-reaching as those induced more directly by other forms of human activity. The USA converted half of the wetlands to other uses in only 200 years, and most of that during the last century (Dahl 1990). It is difficult to imagine that losses of this magnitude due to climate change could approach those from more direct alterations in the next 25 years.

Strategies for management

Most countries, including some of the most populated ones (Table 5), do not have accurate or current inventories that use congruent classification schemes to allow comparisons among countries. As a practical matter, information is a first and necessary component of effective resource management. Both rates of change in area and of condition should be evaluated. Change in area can be approached at several scales of resolution (Poiani *et al.* 2000), but large-scale overviews based on a relatively small number of aggregated classes are obvious starting points. Finer-scaled inventories can follow as needed. Estimates of rates of change can assist in establishing priorities for management programmes by targeting the most rapidly altered type, or types that harbour particularly valuable components of biodiversity.

Assessment of condition also has important implications for biodiversity. Information on condition puts a qualitative face on otherwise featureless inventories. It is not enough simply to know whether an area qualifies as a wetland. Assessments of condition are needed to evaluate whether restoration projects are successful.

We know of no clear examples in the temperate zone where wetland area and condition has increased substantially over decadal periods. Protection of wetlands from human alterations, or even modest restoration and enhancement programmes, are insufficient to result in a net increase of both wetland area and condition (NRC 2001). Consequently, information on both reductions in rates of wetland loss and degradation, and increases in rates of restoration and enhancement are needed for accountability.

Suggestions for maintaining biodiversity in general include (1) creating nature reserves that contain large pools of species and rare species (Keddy & Fraser 1999), and (2) buying time to identifying the linkages that must be established between institutions in order for coordination and integration to overcome conflicting management objectives (Myers 1999). These options alone are unlikely to stem the loss of wetlands area and condition. As long as temperate-zone wetlands continue to attract urbanization, agriculture, and other forms of human activity, it is not likely that substantial gains in wetland-related biodiversity will occur. In some cases, wetland losses may be neutralized by protection and restoration campaigns resulting from public recognition of wetland functions and values. However, in some other cases, such as countries with the burden of a high external debt, strong economic pressures make difficult, if not impossible, the implementation of wetland conservation programmes and policies.

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References

Adámoli, J. (1999) Los humedales del Chaco y del Pantanal. In: *Topicos Sobre Humedales Subtropicales y Templados de Sudamérica*, ed. A.I. Malvárez, pp. 85–93. Montevideo, Uruguay: MAB-ORCYT.

Amoros, C., Bornette, G. & Henry, C.P. (2000) A vegetation-based method for ecological diagnosis of riverine wetlands. *Environmental Management* **25**: 211–27.

Bedford, B.L., Leopold, D.J. & Gibbs, J.P. (2001) Wetland ecosystems. In: *Encyclopedia of Biodiversity*, Volume 5, ed. S.A. Levin, pp. 781–804. Orlando, Florida, USA: Academic Press.

Bedford, B.L., Walbridge, M.R. & Aldous, A. (1999) Patterns in nutrient availability and plant diversity of temperate North American wetlands. *Ecology* **80**: 2151–69.

Bednarek, A.T. (2001) Undamming rivers: A review of the ecological impacts of dam removal. *Environmental Management* **27**: 803–814.

Belt, C.B., Jr (1975) The 1973 flood and man's constriction of the Mississippi River. *Science* **189**: 681–4.

Benayas, J.M.R., Colomer, M.G.S. & Levassor, C. (1999) Effects of area, environmental status and environmental variation on species richness per unit area in Mediterranean wetlands. *Journal of Vegetation Science* **10**: 275–80.

Bó, R.F. & Malvárez, A.I. (1999) Las inundaciones y la biodiversidad en humedales: un análisis del efecto de eventos extremos sobre la fauna Silvestre. In: *Topicos Sobre Humedales Subtropicales y Templados de Sudamérica*, ed. A.I. Malvárez, pp. 147–68. Montevideo, Uruguay: MAB-ORCYT.

Bobbink, R., Hornung M. & Roelofs, J.G.M. (1998) The effects of air-borne nitrogen pollutants on species diversity in natural and semi-natural European vegetation. *Journal of Ecology* **86**: 717–738.

Bodini, A., Ricci A. & Viaroli P. (2000) A methodological approach for the sustainable management of perifluvial wetlands of the Po River (Italy). *Environmental Management* **26**: 59–72.

Bolen, E.G., Smith L.M. & Schramm, H.L. (1989) Playa lakes - prairie wetlands of the southern high plains. *BioScience* **39**: 615–623.

Bonetto, A. A. & Hurtado, S. (1998) Región 1. Cuenca del Plata. In: *Los Humedales de la Argentina: Clasificación, Situación Actual, Conservación y Legislación*, ed. P. Canevari, D.E. Blanco, E. H. Bucher, G. Castro & I. Davidson, pp. 31–72. Buenos Aires, Argentina: Wetlands International Publication 46.

Bornette, G., Amoros, C. & Lamouroux N. L. (1998) Aquatic plant diversity in riverine wetlands: the role of connectivity. *Freshwater Biology* **39**: 267–283.

Brazner, J.C. (1997) Regional, habitat, and human development influences on coastal wetland and beach fish assemblages in Green Bay, Lake Michigan. *Journal of Great Lakes Research* **23**: 36–51.

Brendonck, L. & Williams, W.D. (2000) Biodiversity in wetlands of dry regions (drylands). In: *Biodiversity in Wetlands: Assessment, Function, and Conservation*, *Volume 1*, ed. B. Gopal, W.J. Junk & J.A. Davis, pp. 181–194. Leiden, the Netherlands: Backhuys Publishers.

Brinson, M.M., Smith, R.D., Whigham, D.F., Lee, L.C., Rheinhardt, R.D. & Nutter, W.L. (1998) Progress in development of the hydrogeomorphic approach for assessing the functioning of wetlands. In: *Wetlands for the Future*, ed. A.J. McComb & J.A. Davis, pp. 393–406. Adelaide, Australia: Gleneagles Publishing.

Britton, R.H. & Crivelli, A.J. (1993) Wetlands of southern Europe and North Africa: Mediterranean wetlands. In: *Wetlands of the World: Inventory, Ecology, and Management, Volume 1*, ed. D.F. Whigham, D. Dykyjová, & S. Hejný, pp. 129–194. Dordrecht, the Netherlands: Kluwer Academic Publishers.

Bucher, E.H. & Chani, M. (1998) Región 2. Chaco. In: *Los Humedales de la Argentina: Clasificación, Situación Actual, Conservación y Legislación*, ed. P. Canevari, D.E. Blanco, E.H. Bucher, G. Castro & I. Davidson, pp. 73–96. Buenos Aires, Argentina: Wetlands International Publication 46.

Campbell, E.O. (1983) Mires of Australasia. In: *Mires: Swamp, Bog, Fen and Moor, Regional Studies, 4b*, ed. A.J.P. Gore, pp. 153–180. Amsterdam, the Netherlands: Elsevier.

Camur, M.Z., Yazicigil, H. & Altinbilek, D.H. (1997) Hydrogeochemical modeling of waters in Mogan and Eymir lakes special environmental protection area, Ankara, Turkey. *Water Environment Research* **69**: 1144–53.

Caziani, S. (1996) Case Study 1: Argentina/ Bolivia/ Chile/ Peru. Wetlands of La Puna.. In: *Wetlands, Biodiversity and the Ramsar Convention: The Role of the Convention on Wetlands in the Conservation and Wise Use of Biodiversity*, ed. A.J. Hails, pp. 118–121. Gland, Switzerland: Ramsar Convention Bureau.

Collantes, M.B. & Faggi, A.M. (1999) Los humedales del sur de Sudamérica. In: *Topicos Sobre Humedales Subtropicales y Templados de Sudamérica*, ed. A.I. Malvárez, pp. 15–25. Montevideo, Uruguay: MAB-ORCYT.

Cooper, D.J. (1996) Water and soil chemistry, floristics, and phytosociology of the extreme rich High Creek fen, in South Park, Colorado, USA. *Canadian Journal of Botany* **74**: 1801–11.

Cuda, J.P. & Zeller, M.C. (2000) Chinese privet, *Ligustrum sinense*: Prospects for classical biological control in the southeastern United States. *Wildland Weeds* Spring: 17–19.

Dahl, T.E. (1990) Wetland losses in the United States, 1789s to 1980s. Washington, DC, USA: US Department of the Interior, Fish and Wildlife Service.

Dahl, T.E., Johnson, C.E. & Frayer, W.E. (1991) Status and trends of wetlands in the conterminous United States mid-1970s to mid-1980s. Washington, DC, USA: US Department of the Interior, Fish and Wildlife Service.

Dascanio, L.M., Barrera, M.B. & Frangi, J.L. (1994) Biomass structure and dry-matter dynamics of subtropical alluvial and exotic *Ligustrum* forests at the Rio-de-La-Plata, Argentina. *Vegetatio* **115**: 61–76.

Davis, M.B. & Shaw, R.G. (2001) Range shifts and adaptive responses to Quaternary climate change. *Science* **292**: 673–679.

DeAngelis, D.L., Gross, L.J., Huston, M.A., Wolff, W.F., Fleming, D.M., Comiskey, E.J. & Sylvester, S.M. (1998) Landscape modeling for Everglades ecosystem restoration. *Ecosystems* **1**: 64–75.

Detenbeck, N.E., Galatowitsch, S.M., Atkinson, J. & Ball, H. (1999) Evaluating perturbations and developing restoration strategies for inland wetlands in the Great Lakes Basin. *Wetlands* **19**: 789–820.

Dickinson, K.J.M., Mark, A.F., Barratt, B.I.P. & Patrick, B.H. (1998) Rapid ecological survey, inventory and implementation: A case study from Waikaia ecological region, New Zealand. *Journal of the Royal Society of New Zealand* **28**: 83–156.

Donahue, D.L. (2000) *The Western Range Revisited: Removing Livestock from Public Lands to Conserve Native Biodiversity*. Norman, Oklahoma, USA: University of Oklahoma Press.

Dugan, P. (1993) *Wetlands in Danger*. New York, USA: Oxford University Press.

Dynesius, M. & Nilsson, C. (1994) Fragmentation and flow regulation of river systems in the northern 3rd of the world. *Science* **266**: 753–62.

Fornes, J., Rodriguez, J.A., Hernandez, N. & Llamas, M.R. (2000) Possible solutions to avoid conflicts between water resources development and wetland conservation in the 'La Mancha Humeda' Biosphere Reserve (Spain). *Physics and Chemistry of the Earth Part B-Hydrology Oceans and Atmosphere* **25**: 623–627.

Foundation for Environmental Conservation (2001) An introduction to long-term environmental trends [www document]. URL http://www.ncl.ac.uk/icef

Fujioka, M. & Lane, S.J. (1997) The impact of changing irrigation practices in rice fields on frog populations of the Kanto Plain, central Japan. *Ecological Research* **12**: 101–108.

Funk, J.L. & Robinson, J.W. (1974) *Changes in the Channel of the Lower Missouri River and Effects on Fish and Wildlife*. Aquatic Series No. 11. Jefferson City, Missouri, USA: Missouri Department of Conservation.

Galat, D.L., Fredrickson, L.H., Humburg, D.D., Bataille, K.J., Bodie, J.R., Dohrenwend, J., Gelwicks, G.T., Havel, J.E., Helmers, D.L., Hooker, J.B., Jones, J.R., Knowlton, M.F., Kubisiak, J., Mazourek, J., McColpin, A.C., Renken, R.B. & Semlitsch, R.D. (1998) Flooding to restore connectivity of regulated, large-river wetlands. *BioScience* 48: 721–733.

Galatowitsch, S.M., Anderson, N.O. & Ascher, P.D. (1999) Invasiveness in wetland plants in temperate North America. *Wetlands* **19**: 733–755.

Georgoudis, A.G., Papanastasis, V.P. & Boyazoglu, J.G. (1999) Use of water buffalo for environmental conservation of waterland - Review. *Asian-Australasian Journal of Animal Sciences* **12**: 1324–1331.

Gerakis, A. & Kalburtji, K. (1998) Agricultural activities affecting the functions and values of Ramsar wetland sites of Greece. *Agriculture Ecosystems & Environment* **70**: 119–128.

Girel, J. & Manneville, O. (1998) Present species richness of plant communities in alpine stream corridors in relation to historical river management. *Biological Conservation* 85: 21–33.

Glooschenko, W.A., Tarnocai, C., Zoltai, S. & Glooschenko, V. (1993) Wetlands of Canada and Greenland. In: *Wetlands of the World: Inventory, Ecology and Management,* ed. D. Whigham, D. Dykyjová & S. Hejný, pp. 415–514. Dordrecht, the Netherlands: Kluwer Academic Publishers.

Godreau, V., Bornette, G., Frochot, B., Amoros, C., Castella, E., Oertli, B., Chambaud, F., Oberti, D. & Craney, E. (1999) Biodiversity in the floodplain of Saone: a global approach. *Biodiversity and Conservation* **8**: 839–64.

Gómez, S. & Toresani, N.I. (1998) Región 3. Pampas. In: *Los Humedales de la Argentina: Clasificación, Situación Actual, Conservación y Legislación*, ed. P. Canevari, D.E. Blanco; E.H. Bucher; G. Castro & I. Davidson, pp. 99–114. Buenos Aires, Argentina: Wetlands International Publication 46.

Gregory, S.V., Swanson, F.J., McKee, W.A. & Cummins, K.W. (1991) An ecosystem perspective of riparian zones. *BioScience* **41**: 540–551.

Hails, A.J., ed. (1996) *Wetlands, Biodiversity, and the Ramsar Convention: The Role of the Convention on Wetlands in the Conservation and Wise Use of Biodiversity*. Gland, Switzerland: Ramsar Convention Bureau.

Harwell, M.A., Long, J.F., Bartuska, A.M., Gentile, J.H., Harwell, C.C., Myers, V. & Ogden, J.C. (1996) Ecosystem management to achieve ecological sustainability: the case of South Florida. *Environmental Management* **20**: 497–521.

Haukos, D.A. & Smith, L.M. (1994) The importance of playa wetlands to biodiversity of the Southern High Plains. *Landscape and Urban Planning* **28**: 83–98.

Herdendorf, C.E., Raphael, C.N. & Jaworski, E. (1986) The ecology of Lake St Clair wetlands: a community profile. Report 85(7.7). Washington, DC, USA: US Fish and Wildlife Service.

Hughes, J.M.R. (1995) The current status of European wetland inventories and classifications. In: *Classification and Inventory of the World's Wetlands*, ed. C.M. Finlayson & A.G. van der Valk, pp. 17–28. Dordrecht, the Netherlands: Kluwer Academic Publishers.

Iglesias, G.J. & Pérez, A.A. (1998) Región 4. Patagonia. In: *Los Humedales de la Argentina: Clasificación, Situación Actual, Conservación y Legislación*, ed. P. Canevari, D.E.Blanco, E.H. Bucher, G. Castro, & I. Davidson, pp. 115–135. Buenos Aires, Argentina: Wetlands International Publication 46.

Iwakuma, T., ed. (1996) *Mires of Japan*. Tsukuba, Japan: National Institute for Environmental Studies: 127 pp.

Jacobs, S.W.L. & Brock, M.A. (1993) Wetlands of Australia: southern (temperate) Australia. In: *Wetlands of the World: Inventory, Ecology, and Management, Volume 1*, ed. D.F. Whigham, D. Dykyjová & S. Hejný, pp. 244–304. Dordrecht, the Netherlands: Kluwer Academic Publishers.

Jansson, A., Folke, C. & Langaas, S. (1998) Quantifying the nitrogen retention capacity of natural wetlands in the large-scale drainage basin of the Baltic Sea. *Landscape Ecology* **13**: 249–262.

Jones, D., Cocklin, C. & Cutting, M. (1995) Institutional and landowner perspectives on wetland management in New Zealand. *Journal of Environmental Management* **45**: 143–61.

Junk, W.J. (2002) Long term environmental trends in tropical wetlands. *Environmental Conservation* **29**: (in press).

Keddy, P.A. (2000) *Wetland Ecology: Principles and Conservation.* Cambridge, UK: Cambridge University Press.

Keddy, P. & Fraser, L.H. (1999) On the diversity of land plants. *Ecoscience* **6**: 366–380.

Keough, J.R., Thompson, T.A., Guntenspergen, G.R. & Wilcox, D.A. (1999) Hydrogeomorphic factors and ecosystem responses in coastal wetlands of the Great Lakes. *Wetlands* **19**: 821–834.

Kingsford, R.T. (2000) Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Australian Ecology* **25**: 109–127.

Kosa, J.T. & Mather, M.E. (2001) Processes contributing to variability in regional patterns of juvenile river herring abundance across small coastal systems. *Transactions of the American Fisheries Society* **130**: 600–19.

Labraga, J.C. & López, M.A. (2000) Climate change scenario for the Argentine Republic: 1999 update. Inter American Institute for Global Change Research, IAI Newsletter, Issue 23.

Laderman, A.D., ed. (1998) *Coastally Restricted Forests*. New York, USA: Oxford University Press.

Lane, S.J. & Fujioka, M. (1998) The impact of changes in irrigation practices on the distribution of foraging egrets and herons (Ardeidae) in the rice fields of central Japan. *Biological Conservation* **83**: 221–230.

Lienert, J., Fischer, M. & Diemer, M. (2002) Local extinctions of the wetland specialist *Swertia perennis* L. (Gentianaceae) in Switzerland: A revisitation study based on herbarium records. *Biological Conservation* **103**: 65–76.

Limburg, K.E. (2001) Through the gauntlet again: demographic restructuring of American shad by migration. *Ecology* **82**: 1584–96.

Lu, J. (1995) Ecological significance and classification of Chinese wetlands. In: *Classification and Inventory of the World's Wetlands,* ed. C.M. Finlayson & A.G. van der Valk, pp. 49–56. Dordrecht, the Netherlands: Kluwer Academic Publishers.

Malvárez, A.I. (1999) El Delta del Río Paraná como mosaico de humedales. In: *Topicos Sobre Humedales Subtropicales y Templados de Sudamérica*, ed. A.I. Malvárez, pp. 35–53. Montevideo, Uruguay:MAB-ORCYT.

Marcot, B.G., Ganzei, S.S., Zhang, T.F. & Voronov, B.A. (1997) A sustainable plan for conserving forest biodiversity in Far East Russia and northeast China. *Forestry Chronicle* **73**: 565–571.

Masing, V., Paal, J. & Kuresoo, A. (2000) Biodiversity in Estonia wetlands. In: *Biodiversity in Wetlands: Assessment, Function, and Conservation, Volume 1*, ed. B.Gopal, W.J. Junk & J.A. Davis, pp. 259–279. Leiden, the Netherlands: Backhuys Publishers.

Mitsch, W.J., Day, J.W., Jr, Gilliam, J.W., Groffman, P.M., Hey, D.L., Randall, G.W. & Wang, N. (2001) Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River basin: strategies to counter a persistent ecological problem. *BioScience* **51**: 373–388.

Mitsch, W.J & Gosselink, J.G. (2000) *Wetlands,* Third edition. New York, USA: John Wiley and Sons.

Moore, P.D. (2002) The future of temperate bogs. *Environmental Conservation* **29**(1): 3–20.

Morello, J. & Adámoli, J. (1968) Las grandes unidades de vegetación y ambiente del Chaco Argentino II. *INTA, Serie Fitogeográfica* 10: 1–126.

Murkin, H.R., van der Valk, A.G. & Clark, W.C.R., eds. (2000) *Prairie Wetland Ecology*. Ames, Iowa, USA: Iowa State University Press.

Myers, N. (1999) Saving biodiversity and saving the biosphere. In: *The Living Planet in Crisis,* ed. J. Cracraft & F.T. Grifo, pp. 237–254. New York, USA: Columbia University Press.

Nakamura, F., Sudo, T., Kameyama, S. & Jitsu, M. (1997) Influences of channelization on discharge of suspended sediment and wetland vegetation in Kushiro Marsh, northern Japan. *Geomorphology* **18**: 279–289.

Neiff, J.J. (1990) Ideas para la interpretación ecológica del Paraná. *Interciencia* **15**: 424 – 441.

Neiff, J.J. (1997) Ecología evolutiva del macrosistema Iberá. Master's Thesis, Universidad Nacional del Litoral, Santa Fé, Argentina.

Neiff, J.J. (1999) El regimen de pulsos en rios y grandes humedales de Sudamerica. In: *Topicos sobre Humedales Subtropicales y Templados de Sudamerica,* ed. A.I. Malvárez, pp. 97–146. Montevideo, Uruguay: UNESCO.

Nilsson, C. (1981) Dynamics of the shore vegetation of a north Swedish hydroelectric reservoir during a 5-year period. *Acta Phytogeographica Suecica* **69**: 1–96.

Noss, R. & Cooperrider, A.Y. (1994) *Saving Nature's Legacy:*

Protecting and Restoring Biodiversity. Covelo, California, USA: Island Press.

NRC (1995) *Wetlands: Characteristics and Boundaries*. Washington, DC, USA: National Academy Press.

NRC (2001) *Compensating for Wetland Losses Under the Clean Water Act*. Washington, DC, USA: National Academy Press.

NRC (2002) *Riparian Areas: Functions and Strategies for Management*. Washington, DC, USA: National Academy Press.

Ohlendorf, H.M. (1999) Selenium was a time bomb. *Human and Ecological Risk Assessment* **5**: 1181–1185.

Patten, D.T. (1998) Riparian ecosystems of semi-arid North America: Diversity and human impacts. *Wetlands* **18**: 498–512.

Pisano, E. (1983) The Magellanic Tundra Complex. In: *Mires: Swamp, Bog, Fen and Moor, Regional Studies, 4b,* ed. A.J.P. Gore, pp. 295–1329. Amsterdam, the Netherlands: Elsevier.

Poff, N.L., Allen, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E. & Stromberg, J.C. (1997) The natural flow regime: a paradigm for conservation and restoration of riverine ecosystems. *BioScience* **47**: 769–784.

Poiani, K.A., Richter, B.D., Anderson, M.G. & Richter, H.E. (2000) Biodiversity conservation at multiple scales: functional sites, landscapes, and networks. *BioScience* **50**: 133–146.

Pressey, R.L. & Adam, P. (1995) A review of wetland inventory and classification in Australia. In: *Classification and Inventory of the World's Wetlands*, ed. C.M. Finlayson & A.G. van der Valk, pp. 81–101. Dordrecht, the Netherlands: Kluwer Academic Publishers.

Prieditis, N. (1999) Status of wetland forests and their structural richness in Latvia. *Environmental Conservation* **26**: 332–346.

Qing, D. (1998) *The River Dragon Has Come: The Three Gorges Dam and the Fate of China's Yangtze River and Its People*. Armonk, New York, USA: M.W. Sharpe.

Rheinhardt, M.C. & Rheinhardt, R.D. (2000) Canopy and woody subcanopy composition of wet hardwood flats in eastern North Carolina and southeastern Virginia. *Journal of the Torrey Botanical Society* **127**: 33–43.

Rheinhardt, R.D., Rheinhardt, M.C. & Brinson, M.M. (2002) A regional guidebook for applying the hydrogeomorphic approach to wet pine flats on mineral soils in the Atlantic and Gulf coastal plains. Technical Report TR-WRP-DE, Waterways Experiment Station, Army Corps of Engineers, Vicksburg, Mississippi, USA.

Reid, M.A. & Brooks, J.J. (2000) Detecting effects of environmental water allocations in wetlands of the Murray-Darling Basin, Australia. *Regulated Rivers-Research & Management* **16**: 479–96.

Richardson, C.J. (1981) *Pocosin Wetlands*. Stroudsburg, Pennsylvania, USA: Hutchinson Ross Publishing Company.

Roshier, D.A., Whetton, P.H., Allan, R.J. & Robertson, A.I. (2001) Distribution and persistence of temporary wetland habitats in arid Australia in relation to climate. *Australian Ecology* **26**: 371–84.

Rubec, C.D.A. (1994) Canada's federal policy on wetland conservation: a global model. In: *Global Wetlands: Old World and New*, ed. W.J. Mitsch, pp. 909–17. Amsterdam, the Netherlands: Elsevier.

Sanz, G.L. (1999) Irrigated agriculture in the Guadiana River high basin (Castilla La Mancha, Spain): environmental and socioeconomic impacts. *Agricultural Water Management* **40**: 171–181.

Sarmiento, J., Barrera, S., Caziani, S. & Derlindati, E.J. (1998) Región 6. Andes del Sur. In: *Los Humedales de la Argentina: Clasificación, Situación Actual, Conservación y Legislación,* ed. P. Canevari, D.E. Blanco, E.H. Bucher, G. Castro & I. Davidson, pp. 169–181. Buenos Aires, Argentina: Wetlands International Publication 46.

Schlatter, R.P. (1996) Case Study 2: Argentina/ Chile. Tierra del Fuego. In: *Wetlands, Biodiversity and the Ramsar Convention: The Role of the Convention on Wetlands in the Conservation and Wise Use of Biodiversity*, ed. A.J. Hails, pp. 122–125. Gland, Switzerland: Ramsar Convention Bureau.

Schlatter, R.P., Espinosa, L.A. & Vilina, Y.A. (1998) Costas del Centro y Sur de Chile. In: *Los Humedales de América del Sur. Una Agenda para la Conservación de Biodiversidad y Políticas de Desarrollo*, ed. P. Canevari, I. Davidson, D.E. Blanco, G. Castro & E.H. Bucher. Wetlands International Report [www document]. URL http://www.wetlands.org/SAA/Body/15chile@.htm

Semlitsch, R.D. & Bodie, J.R. (1998) Are small, isolated wetlands expendable? *Conservation Biology* **12**: 1129–1133.

Serra, L., Baccetti, N., Cherubini, G. & Zenatello, M. (1998) Migration and moult of Dunlin *Calidris alpina* wintering in the central Mediterranean. *Bird Study* **45**: 205–218.

Snodgrass, J.W. (1997) Temporal and spatial dynamics of beaver-created patches as influenced by management practices in a south-eastern North American landscape. *Journal of Applied Ecology* **34**: 1043–56.

Sparks, R.E. (1995) Need for ecosystem management of large rivers and their floodplains. *BioScience* **45**: 168–182.

Specht, R.L. (1990) Forested wetlands of Australia. In: *Forested Wetlands*, ed. A.E. Lugo, M.M. Brinson & S. Brown, pp. 387–406. Amsterdam, the Netherlands: Elsevier.

Sorenson, L.G., Goldberg, R., Root, T.L. & Anderson, M.G. (1998) Potential effects of global warming on waterfowl populations breeding in the Northern Great Plains. *Climatic Change* **40**: 343–369.

Thorbjarnarson, J., Wang, X.M., Ming, S., He, L.J., Ding, Y.Z., Wu, Y.L. & McMurry, S.T. (2002) Wild populations of the Chinese alligator approach extinction. *Biological Conservation* 102: 93–102.

Tockner, K. & Stanford, J.A. (2002) Riverine flood plains: present state and future trends. *Environmental Conservation* **29**: (in press).

Tockner, K., Baumgartner, C., Schiemer, F. & Ward, J.V. (2000) Diversity of Danubian floodplain: structural, functional, and compositional aspects. In: *Biodiversity in Wetlands: Assessment, Function, and Conversation, Volume 1,* ed. B. Gopal, W.J. Junk, & J.A. Davis, pp. 141–159. Leiden, the Netherlands: Backhuys Publishers.

Toth, L.A., Melvin, S.L., Arrington, D.A. & Chamberlain, J. (1998) Hydrologic manipulations of the channelized Kissimmee River. *BioScience* **48**: 757–764.

Tourenq, C., Bennetts, R.E., Kowalski, H., Vialet, E., Lucchesi, J.L., Kayser, Y. & Isenmann, P. (2001) Are ricefields a good alternative to natural marshes for waterbird communities in the Camargue, southern France? *Biological Conservation* **100**: 335–43.

van der Valk, A.G., ed. (1989) *Northern Prairie Wetlands*. Ames, Iowa, USA: Iowa State University Press.

Van Es, J., Paillisson, J.M. & Burel, F. (1999) Eutrophication impacts of wetland vegetation in floodplain on butterfly (Lepidoptera) biodiversity. *Vie Et Milieu - Life and Environment* 49: 107–116.

Wahren, C.H., Williams, R.J., & Papst, W.A. (1999) Alpine and subalpine wetland vegetation on the Bogong High Plains, south-eastern Australia. *Australian Journal of Botany* **47**: 165–88.

Walker, J. & Peet, R.K. (1983) Composition and species diversity of pine-wiregrass savannas of the Green Swamp, North Carolina. *Vegetatio* **55**: 163–179.

Ward, J.V., Tockner, K. & Schiemer, F. (1999) Biodiversity of floodplain river ecosystems: ecotones and connectivity. *Regulated Rivers: Research and Management* **15**: 125–139.

Wettstein, W. & Schmid, B. (1999) Conservation of arthropod diversity in montane wetlands: effect of altitude, habitat quality and habitat fragmentation on butterflies and grasshoppers. *Journal of Applied Ecology* **36**: 363–373.

WGI-IPCC (2001) *Climate Change 2001: The Scientific Basis*. Cambridge, UK: Cambridge University Press.

WGII-IPCC (2001) *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge, UK: Cambridge University Press.

Whigham, D.F. (1999) Ecological issues related to wetland preservation, restoration, creation and assessment. *Science of the Total Environment* **240**: 31–40.

Wiegers, J. (1990) Forested wetlands of Western Europe. In: *Forested Wetlands*, ed. A.E. Lugo, M.M. Brinson & S. Brown, pp. 407–436. Amsterdam, The Netherlands: Elsevier.

Wigley, T.B. & Roberts, T.H. (1997) Landscape-level effects of forest management on faunal diversity in bottomland hardwoods. *Forest Ecology and Management* **90**: 141–154.

Williams, W.D. (2002) Environmental threats to salt lakes and the likely status of inland saline ecosystems on 2025. *Environmental Conservation* **29**(2): (in press).

World Commission on Dams (2001) *Dams and Development: A New Framework for Decision-Making*. London. UK: Earthscan Publications. (Compact disk format.)

Zedler, P.H. (1987) The ecology of Southern California vernal pools: a community profile. US Fish and Wildlife Service, Biological Report 85(7.11), Washington, DC, USA.