2 Global Distribution, Diversity and Human Alterations of Wetland Resources

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INTRODUCTION

This chapter outlines the distribution and diversity of wetland resources and examines the types of human activities that have resulted in widespread alteration. The term 'wetland' has a variety of meanings, and examples are given of the terminology used to describe different types of wetlands. The processes responsible for the formation and persistence of wetlands are indicated and consideration is given to human perceptions of these ecosystems and threats to them from both natural and anthropogenic activities.

DEFINITIONS AND CLASSIFICATION

Many definitions of wetlands have been developed (Maltby 1991; Dugan 1993; Mitsch and Gosselink 2000; Tiner 1996) and some of them have been changed over time, particularly in the US, in response to an increased understanding of wetland ecology and to political arguments (National Research Council 1995). Two examples of wetland definition demonstrate the range of considerations that have been used to describe their characteristics. The most widely known and internationally adopted wetland definition was developed for purposes of providing international protection for waterfowl across the widest possible range of wetlands. The Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat, published in 1971, gives:

> ... wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.

Another widely used wetland definition was developed by the US Fish and Wildlife Service for purposes of bringing consistency to an ongoing national debate related to inventory, regulation and conservation of wetlands in the United States (Cowardin *et al.* 1979; Mitsch and Gosselink 2000; Tiner 1996). The Cowardin *et al.* definition, developed as part of a classification system, is:

> ... lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For the purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year. ('nonsoil' simply means 'not soil' e.g. rock, undecomposed litter, or the sediments of a water body too deep for the growth of rooted plants (usually >2 m–3 m)).

Both definitions communicate the importance of vegetation and water in the identification, development and persistence of wetlands, and the Cowardin *et al.* definition also recognises the importance of substrate conditions. The two descriptions collectively identify the essential elements of a robust definition of wetlands: hydrology,

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vegetation and substrates. Most wetland definitions are not, however, particularly useful when there is a legal requirement to determine whether or not a given habitat should be classified as a wetland or when wetland delineation is required. The issues of wetland identification and delineation have been particularly contentious in the United States and many efforts have been directed toward providing a definition that can be used to develop methods to identify and delineate wetlands (Tiner 2000). Tiner emphasised that a robust wetland definition that can provide effective guidance toward wetland identification and delineation must include the three elements listed above (hydrology, vegetation, soil). He also suggested that a tiered approach be applied in application of identification procedures. Obvious wetlands can be identified by rapid assessments using vegetation, hydrology or soils alone, while wetlands that are more difficult to identify require additional effort and multiple indicators of these elements. No matter how wetlands are defined, it is common practice to use widely accepted terms to describe different types.

Dugan described globally distributed wetland types based primarily on geomorphic position (Dugan 1993). Estuaries, mangroves and tidal flats are wetlands and wetland habitats associated with coastal features that are tidally influenced. Floodplains and deltas are systems that contain wetlands associated with rivers with various flooding regimes. Marshes, lakes, peatlands and forested swamps are terms used by Dugan to describe wetlands associated with non-tidal inland habitats. Maltby (1991) also described general wetland types based on broad features such as dominant vegetation (marshes, swamps), soil characteristics (peatlands), geomorphic features (floodplain wetlands, lakes, estuaries and lagoons), geographic location (mangroves, Nipa swamps (Nipa palm, *Nipa fructicans*), and tidal freshwater swamp forests) and human activities (artificial wetlands). Mitsch and Gosselink (2000) recognised seven types of wetlands based on whether they were associated with coastal (tidal) or inland (non-tidal) habitats. Coastal wetlands included tidal salt marshes, tidal freshwater marshes and mangroves. Inland wetlands were freshwater marshes, northern peatlands, southern deepwater swamps and riparian wetlands.

While the wetland terms used by Dugan (1993), Maltby (1991) and Mitsch and Gosselink (2000) are widely recognised, the reader should be aware that the use of common terms can lead to confusion because names for a single type of wetland can vary from one language to another (Scott and Jones 1995). At times, common terms used to describe types of wetlands can be confusing. The Ramsar definition given above, lists fens and peatlands, suggesting that they are separate types of wetlands. Gore (1983) defined fens as peat accumulating wetlands that receive rainwater and drainage from surrounding mineral soil and usually support marsh-like vegetation. He defined peatland as a generic term for any wetland that accumulates partially decayed plant matter (Gore 1983), indicating that fens are a type of peatland. It is preferred to describe all active peat-forming wetlands as mires, and separate them into fens and bogs according to whether they are fed predominantly by groundwater or rainfall. Despite the danger of confusion it is nevertheless useful to examine the salient characteristics of the most common categories found in the literature.

Marshes

Marshes (Figure 2.1) are wetlands dominated by herbaceous vascular plants, the stems of which emerge above the water surface. Marshes occur in areas that are frequently or continuously inundated with water and they are most often associated with mineral soils that do not accumulate peat. Typically, dominant plant species in marshes are reeds, rushes, grasses, and sedges that are characterised by thin 'grass-like' leaves. Marshes, however, can also contain a wide variety of plant species with many different life forms. Freshwater tidal marshes, for example, can be dominated by annuals and perennials that range in leaf form from grass-like to broad-leaved (Simpson *et al.* 1983). Marshes have been studied extensively because of their importance as waterfowl habitat (Weller 1994) and many

Fig. 2.1 The author standing in a stream channel at low tide in a freshwater tidal emergent wetland along the Delaware River (USA). Tidal amplitude is approximately 3 m. The dominant emergent species in the foreground is *Nuphar advena* (Yellow waterlily). (Photo by Robert Simpson.)

different types of marsh have been recognised both in the US (e.g. prairie potholes, playas, salinas, salt marshes, brackish marshes, freshwater tidal marshes, vernal pools and Carolina bays) and elsewhere (Semeniuk and Semeniuk 1995).

Peatland (often called mire)

This is a generic term for any wetland that has at some point accumulated partially decayed plant matter because of incomplete decomposition, usually to a depth less than 30 cm (Figure 2.2). The term 'mire' refers to those peatlands in which peat formation is still active. Many terms have been developed to describe peat-forming wetlands, particularly in Europe (Money). Fens can be dominated by herbaceous or woody plant species. Bogs are peatlands dominated by herbaceous or woody species, but they differ from fens because the water chemistry resembles that of precipitation and the peat is usually formed by the slow decomposition of mosses, especially species of *Sphagnum*. A complex and diverse terminology (Heathwaite and Göttlich 1990; Verhoeven 1992; Glooschenko *et al.* 1993) has been developed in different countries to describe different types of bogs.

Fig. 2.2 Richard Hauer in a freshwater swamp dominated by *Acer rubrum* (Red Maple) and *Nyssa aquatica* (Water Tupelo) on the Pearl River in Mississippi (USA). (Photo by the author.)

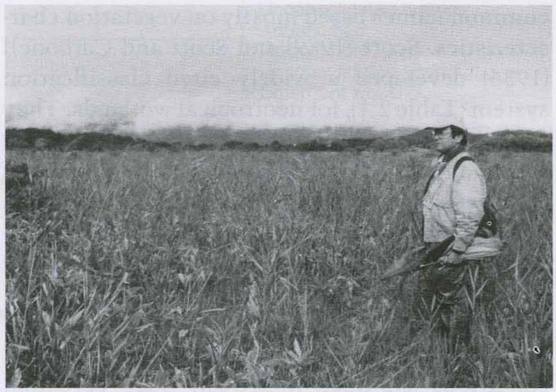

Fig. 2.3 Seiichi Nohara in the Akaiyachi Mire (bog), central Honshu, Japan. *Sphagnum* dominated peat has accumulated to a depth of 150 cm. Below the *Sphagnum* peat are layers of *Moliniopsis* and *Phragmites* dominated peat overlying a layer of volcanic ash and sand with wood and *Phragmites* remains. Four *Sphagnum* species dominate the existing peat mat. Abundant vascular plants are *Phragmites australis, Ilex crenata* var. *paludosa, Vaccinium oxycoccus, Moliniopsis japonica, Rhynchospora alba* and *Sasa palmata.* (Photo by the author.)

Swamps

Wetlands that are covered intermittently or permanently with water, and are dominated by trees or shrubs, are swamps (Figure 2.3). In essence, swamps are marshes that are dominated by woody vegetation. Swamps, like marshes, are diverse and occur in many habitats from the temperate zones to the tropics (Lugo *et al.* 1990). Swamps that are associated with rivers typically have inorganic substrates (Sharitz and Mitsch 1993; Junk 1997). Other swamps develop in areas with little or no connection to flowing streams and rivers, and may develop peat substrates (Richardson 1981; Richardson and Gibbons 1993). Swamps represent a particularly threatened type of wetland in many parts of the world because of exploitation for wood products and conversion to agricultural lands.

There have also been attempts to classify wetlands based mostly on hydrologic and hydrogeomorphic characteristics, thus eliminating some of the confusion associated with the use of common names based mostly on vegetation characteristics. Scott (1989) and Scott and Carbonell (1986) developed a widely cited classification system (Table 2.1), for neotropical wetlands. They used dominant vegetation type to describe three wetland types (08, 18, 19) but location within the landscape, or a combination of landscape position and vegetation, were used to classify most wetlands. Cowardin *et al.* (1979) developed a system to classify wetlands in the US that is hierarchically based on geomorphic features (marine, estuarine, riverine, lacustrine, palustrine) hydrologic conditions (subtidal, intertidal, tidal, perennial streams, intermittent streams, limnetic, littoral) and several modifiers, such as substrate conditions and dominant vegetation type (Figure 2.4).

Table 2.1 Classification of wetlands used in the Directory of Neotropical Wetlands (Scott and Carbonell 1986). Identification of wetland types is based on geomorphic features (e.g. estuaries), habitat type (e.g. freshwater pond), vegetation type (e.g. mangrove), and substrate conditions (e.g. peat bogs). Vegetation type refers to the numbering system used by Scott and Carbonell (1986).

Vegetation type	Description
01	Shallow sea bays and straits
02	Estuaries, deltas
03	Small offshore islands, islets
04	Rocky sea coasts, sea cliffs
05	Sea beaches (sand, pebbles)
06	Intertidal mudflats, sandflats
07	Coastal brackish and saline lagoons and marshes, salt pans
08	Mangrove swamps, brackish forest
09	Slow-flowing rivers, streams (lower perennial)
10	Fast-flowing rivers, streams (upper perennial)
11	Riverine lakes (including oxbows), riverine marshes
12	Freshwater lakes and associated marshes (lacustrine)
13	Freshwater ponds (<8 ha), marshes, swamps (palustrine)
14	Slat lakes, slars (inland systems)
15	Reservoirs, dams
16	Seasonally flooded grassland, savanna, palm savanna
17	Rice paddies, flooded arable land, irrigated land
18	Swamp forest, temporarily flooded forest
19	Peat bogs, wet Andean meadows (bofedales), snow melt bogs

WETLAND DISTRIBUTION

Wetlands occur over wide range of altitudes and latitudes, from the tropics to the arctic, and from below sea level to alpine environments (Figure 2.5). They occur in almost all habitats, from tidally influenced coastal landscapes that flood once or twice daily, to endorheic basins in interior areas of continents that most often have little or no standing water but are transformed into productive wetland systems when rainfall occurs. The total wetland area on earth has been estimated to be 7–8.5 million km^2, approximately 6% of the land surface (Maltby and Turner 1983; Mitsch 1998; Mitsch and Gosselink 2000). The global estimates should, however, be viewed as minimum estimates of wetland coverage, because few countries have completed any detailed national wetland inventories and, even where inventories have been completed, only the largest wetland areas have been identified.

Wetlands are found on all continents, and several publications have included summaries of

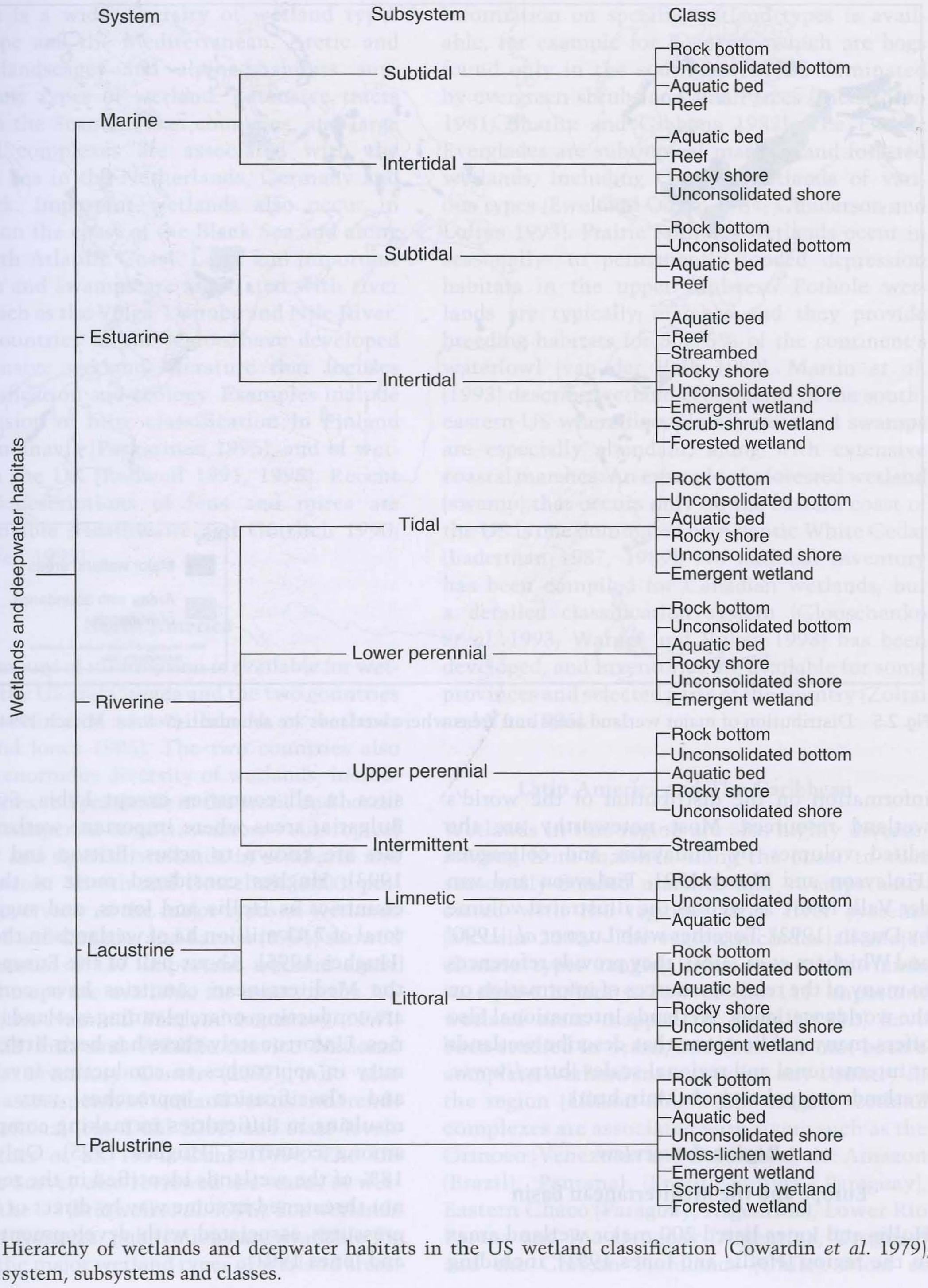

Fig. 2.4 Hierarchy of wetlands and deepwater habitats in the US wetland classification (Cowardin *et al.* 1979), showing system, subsystems and classes.

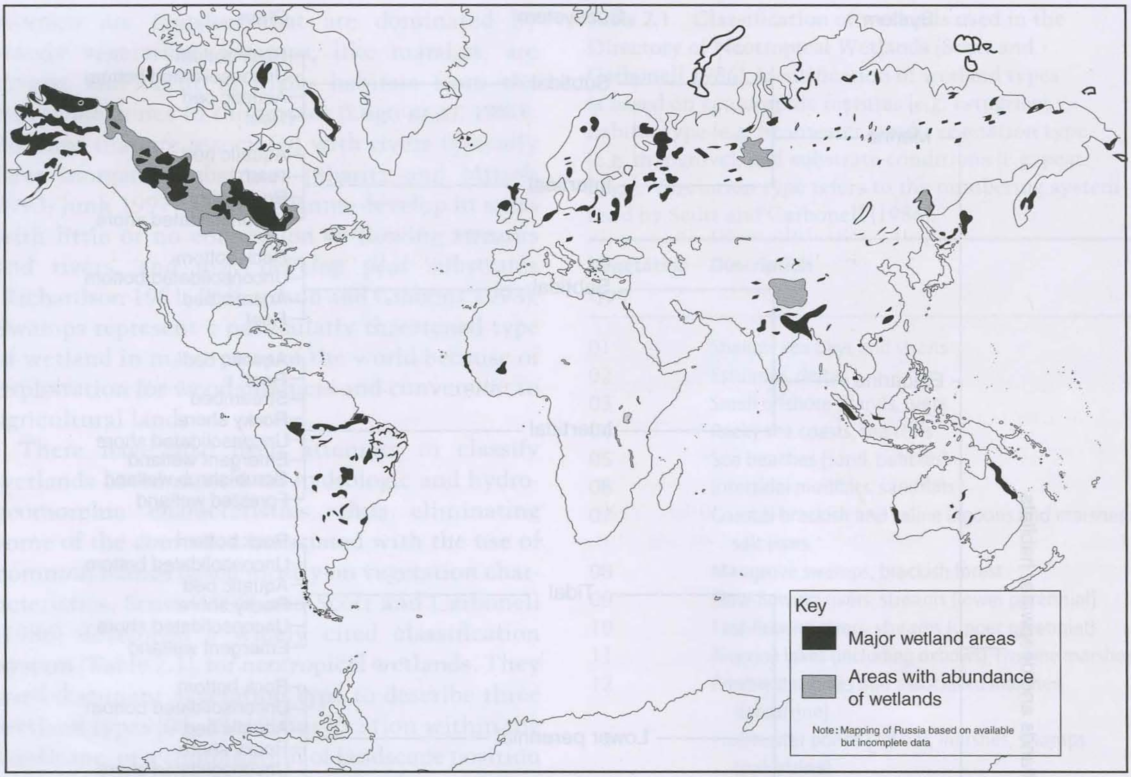

Fig. 2.5 Distribution of major wetland areas and areas where wetlands are abundant. (*Source*: Mitsch 1994.)

information on the distribution of the world's wetland resources. Most noteworthy are the edited volumes by Finlayson and colleagues (Finlayson and Moser 1991; Finlayson and van der Valk 1995), as well as the illustrated volume by Dugan (1993). Together with Lugo *et al.* (1990) and Whigham *et al.* (1993) they provide references to many of the relevant sources of information on the worlds wetlands. Wetlands International also offers many publications that describe wetlands at international and regional scales (http://www.wetlands.org/pubs&/pubsMain.htm).

Regional overview

Europe and the Mediterranean basin

Hollis and Jones listed 200 major wetland areas in the region (Hollis and Jones 1991), including sites in all countries except Lybia, Syria and Bulgaria; areas where important wetland habitats are known to occur (Britton and Crivelli 1993). Hughes considered most of the same countries as Hollis and Jones, and suggested a total of 7.41 million ha of wetlands in the region (Hughes 1995). About half of the European and the Mediterranean countries have completed, are conducting, or are planning wetland inventories. Unfortunately there has been little uniformity in approaches to conducting inventories, and classification approaches vary widely, resulting in difficulties in making comparisons among countries (Hughes 1995). Only about 18% of the wetlands identified in the region are not threatened in some way by direct or indirect pressures associated with development (Hollis and Jones 1991).

There is a wide diversity of wetland types in Europe and the Mediterranean. Arctic and boreal landscapes and alpine habitats support many types of wetland. Extensive tracts occur in the Scandinavian countries, and large wetland complexes are associated with the Wadden Sea in the Netherlands, Germany and Denmark. Important wetlands also occur in Russia, on the coast of the Black Sea and along the North Atlantic Coast. Large and important marshes and swamps are associated with river deltas such as the Volga, Danube and Nile River. Many countries in the region have developed an extensive wetland literature that focuses on classification and ecology. Examples include a discussion of mire classification in Finland and Scandinavia (Parkarinen 1995), and of wetlands in the UK (Rodwell 1991, 1995). Recent regional descriptions of fens and mires are also available (Heathwaite and Göttlich 1990; Verhoeven 1992).

North America

A vast amount of information is available for wetlands of the US and Canada and the two countries have an estimated 14.2 million ha of wetlands (Scott and Jones 1995). The two countries also have an enormous diversity of wetlands, including marshes and peatlands in the arctic and boreal zones, temperate-zone swamps, subtropical marshes and riparian wetlands in semi-arid and arid climates. Mitsch and Gosselink (2000) provide an overview of the major types of wetlands in the US and Canada, and Larson (1991) showed the locations of 137 important wetland areas. Wetland maps are available for most of the US through the National Wetland Inventory (NWI) of the US Fish and Wildlife Service National Wetlands Inventory Center (2007), who also conduct assessments of wetland status and trends at the national (e.g. Dahl 2000) and state levels (e.g. Hefner *et al.* 1994; Dahl 1999). The US Geologic Survey also reviewed the status of wetlands in the US (Fretwell *et al.* 1996). For wetlands in North America, publications are available for most of the major wetland types or wetland areas. Information on specific wetland types is available, for example for Pocosins, which are bogs found only in the south-eastern US dominated by evergreen shrubs and small trees (Richardson 1981; Sharitz and Gibbons 1982). The Florida Everglades are subtropical marshes and forested wetlands, including Cypress wetlands of various types (Ewel and Odum 1984; Gunderson and Loftus 1993). Prairie Potholes wetlands occur in seasonally- to permanently-flooded depression habitats in the upper Midwest. Pothole wetlands are typically marshes and they provide breeding habitats for 50–75% of the continent's waterfowl (van der Valk 1989). Martin *et al.* (1993) describe wetland ecosystems of the south-eastern US where floodplain forests and swamps are especially abundant, along with extensive coastal marshes. An example of a forested wetland (swamp) that occurs only on the eastern coast of the US is one dominated by Atlantic White Cedar (Laderman 1987, 1989). No national inventory has been compiled for Canadian wetlands, but a detailed classification system (Glooschenko *et al.* 1993; Warner and Rubec 1998) has been developed, and inventories are available for some provinces and selected parts of the country (Zoltai and Vitt 1995).

Latin America and The Caribbean

Wetlands in this region are also highly diverse, ranging from marshes along the coast to vast seasonally-flooded marshes and swamps associated with the region's large river systems (McLain 2002). The region includes all major climate types ranging from tropical lowlands to alpine habitats. Few of the 111 important wetland areas mapped by Scott (1991b) have been studied in detail, and there has not been a complete wetland inventory for any country in the region (Ellison 2004). The largest wetland complexes are associated with rivers such as the Orinoco (Venezuela and Columbia), the Amazon (Brazil), Pantanal (Brazil, Bolivia, Paraguay), Eastern Chaco (Paraguay, Argentina), Lower Rio Parana and Rio Uruguay (Argentina, Uruguay) and the Chilean Fjordlands (Chile). Most of the information about wetlands in the region, however, is based on a few detailed studies (Olmsted 1993; Naranjo 1995). The most complete inventory of wetlands in the region was prepared by Scott and Carbonell (1986). The Amazon and Orinoco basins contain enormous wetland areas (Junk 1997) and other wetland complexes have received a large amount of international attention because of proposed development activities such as the Hidrovia scheme (Junk).

Africa

Approximately 345 000 km^2 of African wetlands occur in a geologically ancient landscape, and support 'the largest numbers and greatest variety of wildlife in the world' Denny (1991). In addition, they have important functions and values that support the livelihood of hundreds of thousands of people (Denny 2001). The estimate of wetland area offered by Denny (1991) is undoubtedly an underestimate of the total wetland resource, because there have not been any coordinated inventories of wetlands on the continent. The largest mapped wetland complexes are marshes and swamps in the Zaire Basin (Zaire, Congo and Central African Republic), The Sudd (Sudan, Ethiopia), Kafue Flats (Zambia), and the Okavango Inland Delta (Namibia, Botswana and Angola). Other summaries of wetlands in Africa are found in Denny (1985); Burgis and Symoens (1987); Breen *et al.* (1993); Denny (1993); and John *et al.* (1993). Britton and Crivelli (1993) summarised information on wetland resources in the Mediterranean portion of North Africa. There have been a number of ongoing activities related to African wetlands, including a classification and inventory of wetlands (Hughes and Hughes 1992). Wetlands in South Africa have been evaluated (Cowan 1995; Naranjo 1995; Cowan and van Riet 1998) and additional information is available on the South African Wetlands Conservation Programme websites (1999, see also http://www.environment.gov.za/enviro-info/sote/nsoer/resource/wetland/index.htm).

Asia and the Middle East

Wetlands in Asia and the Middle East range from extensive coastal swamps, such as those in the Sunderbans district in India and Bangladesh and the Mesopotamian marshes of Iraq, to expansive arctic and subarctic wetland complexes in northern Russia. Many of the 154 wetlands mapped by Scott (1991a) are marshes associated with dry or seasonal climates. The largest wetland complexes are associated with the Indus Valley and Deltas (Pakistan), the Ganges River and its floodplain, the Brahmaputra Delta and the Sunderbans (India and Bangladesh), together with those in Russia (Tobol and Ismim lakes, Ob and Irtysh Rivers, Taymyr Peninsula, Lena and Vilyuy Rivers, Indigirka and Kolyma basins). There have been few detailed studies and no complete inventories of wetlands in the region (Scott 1989). Relevant publications for Russian wetlands can be found on the Wetlands International website (2007, http://www.ramsar.org/profile/profiles_russia.htm). There has not been an inventory of wetlands in China, but a wetland classification system has been proposed (Lu 1995). Undoubtedly there are many important wetland complexes that were not among those listed by Scott (1991b). For example, the Kushiro wetland complex in south-central Hokkaido (Japan) was not listed but is a Ramsar site but has been internationally recognised for the biodiversity that it supports. Several other wetlands in Japan have been extensively studied (Iwakuma 1996) but most publications are in Japanese and have not been readily available to the international community. Japanese wetlands range from coastal marshes, bogs and fens in temperate areas, to subtropical coastal mangroves in the Okinawa prefecture. Many important national monuments and parks in Japan include large and important wetlands. Gopal and colleagues have provided several summaries of wetland resources in the Indian subcontinent, where the annual monsoon climate dictates the distribution and characteristics of most wewtlands (Gopal 1990; Gopal and Krishnamurthy 1993; Gopal and Sah 1995; Middleton 1999). Finlayson *et al.* (2002)

have developed a protocol for cataloguing Asian wetlands.

The Mesopotamian Marshes (Nicholson and Clark 2003) have been the focus of recent international efforts. Approximately 90% of the original 15 000 km^2 wetland area was drained between 1985 and 2000, resulting in major impacts on indigenous people and millions of migratory waterfowl. Recent studies, however, indicate that 'the restoration potential for a substantial portion of the Mesopotamian marshes is high' even though there are concerns about water availability, levels of soil salinity, and the bioaccumulation of selenium in the food chain (Richardson *et al.* 2005).

Australasia and Oceania

Australasia and Oceania have the smallest total wetland area of any region according to Finlayson and Moser (1991). The diversity of wetlands, however, is impressive and includes seagrass meadows, mangrove swamps, tidal marshes and salt flats, monsoonal freshwater floodplain wetlands, swamps, lakes, river channels and bogs. Even though wetlands in this region may be less extensive than in other parts of the world, they are no less important for their uses by native peoples, for their biodiversity and for societal services that they provide (Finlayson 1991). Overviews of wetlands and ecological processes in wetlands in Australasia are found in McComb and Lake (1988), Jacobs and Brock (1993), Finlayson and von Oertzen (1993), Brock *et al.* (1994), Pressey and Adam (1995) and Giblett and Webb (1996). Numerous studies of individual wetlands and wetland complexes are cited in Pressey and Adam (1995) and a directory of important wetlands in Australia has been published (Environment Australia 2001). Osborne (1993) has described wetlands in Papua New Guinea that range from marshes to swamps and mangroves. Wetland resources, and the effects of anthropogenic activities, have been examined on a few Pacific Islands (e.g. Allen *et al.* 2001; Ewel *et al.* 2003).

WETLAND FORMATION AND PERSISTENCE

Wetland definitions have usually been nonspecific because they were designed to include a wide diversity of wetland types, especially wetlands that are important for waterfowl resting, feeding and reproduction. The Ramsar definition, in particular, is not especially useful if one is interested in processes that are responsible for the formation and persistence of wetlands. A brief review of the history of wetland definition in the US may help to understand the conditions that must be present for wetlands to form and persist.

Mitsch and Gosselink (2000) describe the historical developments that led to the current definition of wetlands in the US, beginning in 1965 and ending with the legal definition of wetlands used by the US Army Corps of Engineers as required by the 1977 Clean Water Act. More recently, a national Committee on Wetlands Characterisation of the National Academy of Sciences reported a very similar definition:

> ecosystems that depend on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturated at or near the surface and the presence of physical, chemical, and biological features reflective of recurrent, sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. These features will not be present where specific physio-chemical, biotic or anthropogenic factors have removed them or prevented their development (National Research Council 1995).

Wetland hydrology is the essential element of the definition, since wetlands will only form and persist, and hydric soils and hydrophytic vegetation (the other two criteria) will only occur when water is present for a suitable period of time.

The formation and persistence of wetlands may be viewed also from broader perspectives. The range of climatic and landscape conditions that are suitable for wetland formation is enormous. Geographically, wetlands can occur in any landscape where there is an excess of annual

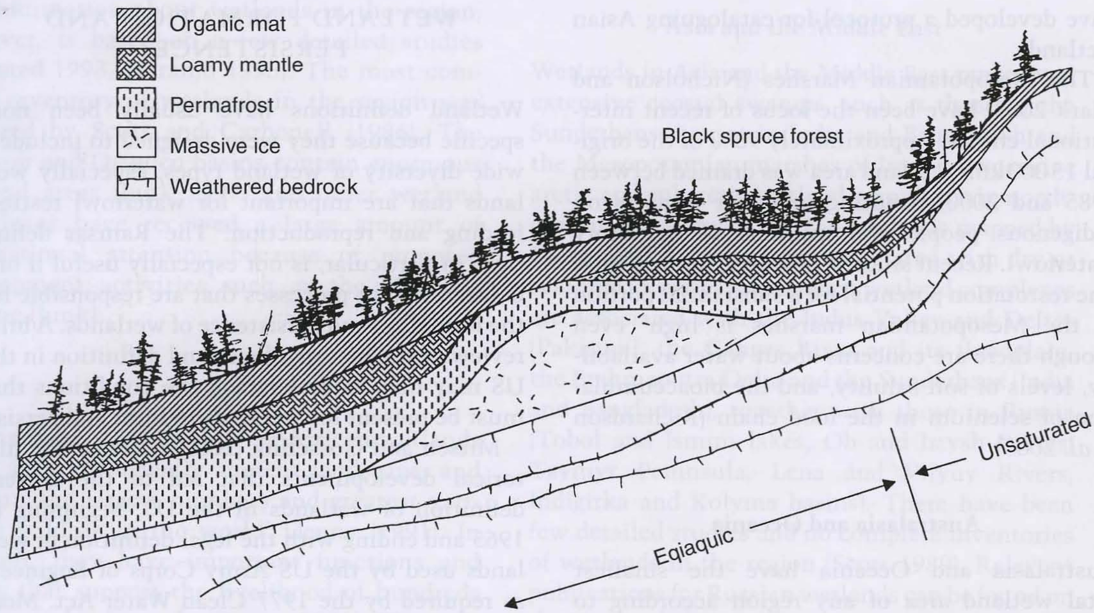

Fig. 2.6 Cross-section showing disposition of *Picea mariana* (Black Spruce) dominated wetlands on steep slopes that are underlain by permafrost in the portion of Alaska (USA) that is characterised by discontinuous permafrost. The forested wetland is underlain by permafrost beneath an organic mat. Following disturbance that results in the disappearance of the permafrost layer (e.g. fire) the wetland can be converted to a non-wetland habitat. Wetlands form on the site again following approximately 250 years of succession (Post 1996). (*Source*: Lee *et al.* 1999.)

precipitation over losses from evaporation and drainage. In areas where annual losses of water exceed total annual precipitation, wetlands can still form where landscapes allow water accumulation for long enough periods for wetland plants to persist. Wetlands are usually extensive and diverse in cool or cold climates where annual precipitation exceeds losses, mostly because of relatively low annual temperatures. More than 62% of the total wetland area in the United States, for example, occurs in Alaska (Hall *et al.* 1994) and many Alaskan wetlands occur in areas where the total annual precipitation is comparatively low (less than 500 mm). Wetlands dominated by Black Spruce (*Picea mariana*) are widespread in both Alaska and Canada and account for approximately 20% of all wetlands in Alaska. Because of the excess of precipitation inputs compared with water losses, Black Spruce wetlands occur in almost any landscape position (Post 1996), including steep slopes (Figure 2.6) and hill tops as well as relatively flat valley bottoms (Figure 2.7). Fire is also an important element in the ecology of Black Spruce wetlands. In parts of its range, Black Spruce wetlands form on substrates that are underlain by permafrost. Following fire, the permafrost can melt, resulting in the conversion of a wetland habitat into a non-wetland habitat. The loss of permafrost results in higher rates of water loss through evaporation and internal drainage. Approximately 250 years of succession, however, result in the conversion of the non-wetland habitat into a wetland, once again underlain by permafrost (Post 1996). Permafrost forms after the site becomes dominated by trees which insulate the soil surface, and result in an accumulation of organic matter, which retains moisture and lowers average soil temperatures.

In warmer climates, a greater amount of precipitation would be required for wetlands to form and

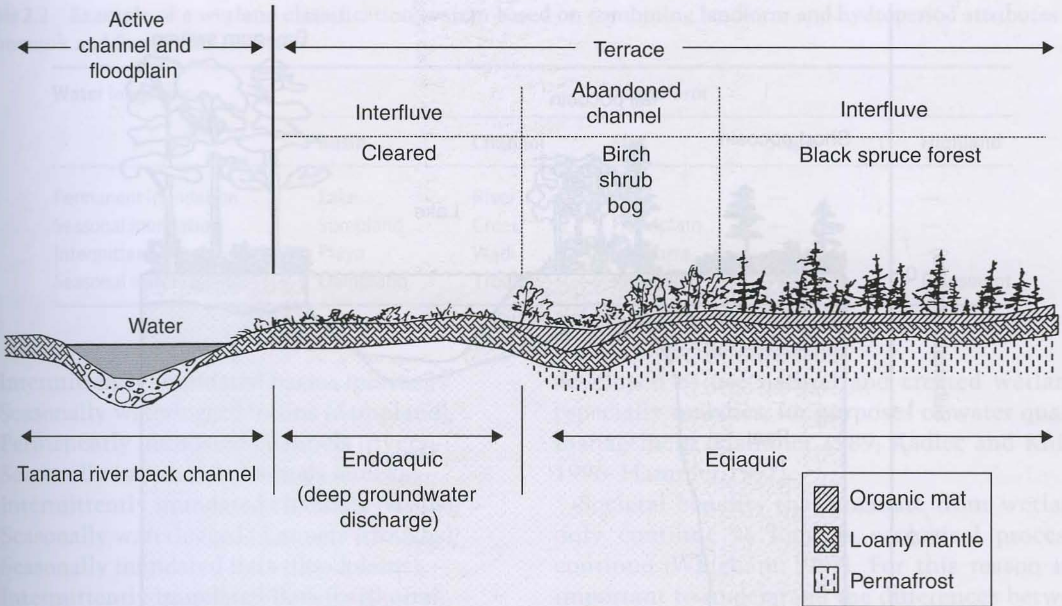

Fig. 2.7 Cross-section showing disposition of Black Spruce dominated wetlands on alluvial floodplains in Interior Alaska. Black Spruce dominated sites are found on alluvial sites that are underlain by permafrost. (*Source*: Lee *et al.* 1999.)

persist because of warmer annual temperatures and greater losses of water through evaporation and evapotranspiration. Pocosin is an example of a type of non-tidal coastal wetland dominated by evergreen shrub and tree species that is found only in the south-eastern US (Richardson 1981; Sharitz and Gibbons 1982). Pocosins form through the process of paludification, a process that typically only occurs in colder climates over several thousand years (Figure 2.8). Pocosins have formed primarily because the Coastal Plain landscape is flat, the water table is shallow because of proximity to estuarine habitats, and there are large distances between streams, resulting in slow runoff and accumulation of water (Daniels *et al.* 1977).

Wetlands also form in arid climates. Vernal pools are seasonally flooded depressions found in many arid and semi-arid landscapes around the world. In the US, they are widespread in the western states, especially California where they occur on a variety of landscape formations, including alluvial formations deposited by water and ancient volcanic mudflows (Zedler 1987). Vernal pools in California are found mostly in depressions on ancient soils that have an impermeable subsurface layer, such as a hardpan, claypan or basalt. The impermeable layer allows the pool to retain water for much longer than the surrounding uplands, even though vernal pools typically dry completely during the annual rainfall cycle. While they are widespread, vernal pools are typically small (<1 ha) and occupy less than 10% of most landscapes where they are found. They are important for a variety of reasons, and have historical and cultural significance as sites that were used by Native Americans for securing food and for use in ceremonial activities. Vernal pools also provide wetland habitat for migrating waterfowl, act to regulate seasonal flooding, maintain water quality and contain a high proportion of endemic plant and animal species.

Mountainous regions provide an example of landscapes that contain habitats that include

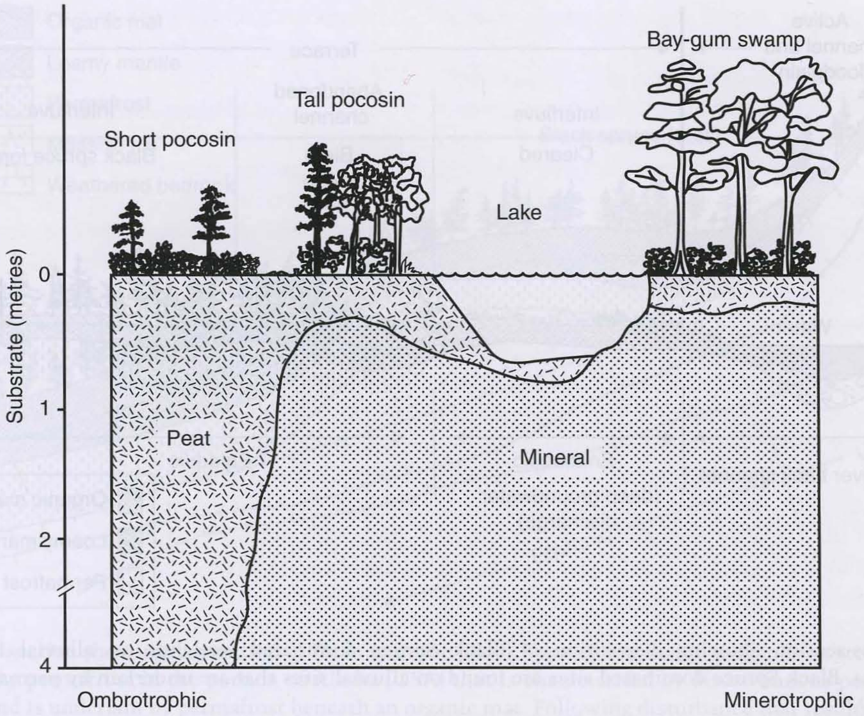

Fig. 2.8 Cross-section showing peat forming Pocosin – bay-gum wetland forests that develop over mineral soils on the lower Coastal Plain, south-eastern USA. The structure and species composition of the vegetation is determined, in part, by the nutrient status of the substrate. Short Pocosin, for example, develops on nutrient deficient deep peat accumulations. (*Source*: Martin *et al.* 1993.)

a wide diversity of wetland types due to large differences in altitude, slope, aspect and geologic substrata. Investigation of Mt. St Helens following its eruption in 1980 has revealed 24 wetland types 14 years after the eruption (Titus *et al.* 1999). Some wetlands occurred in locations where they were present prior to the eruption, while others formed as a result of primary succession in habitats created by the eruption. This research has found that stochastic events played a more important role than environmental factors in wetland formation. This may yet provide a valuable lesson which managers need to consider further when dealing more generally with the effects of major events.

The relationship between landscape position and wetland formation and persistence can also be explained using more straightforward geomorphic criteria. An example of geomorphic criteria that was used to describe landscape positions where wetlands will form is given by Semeniuk and Semeniuk (1995). The geomorphic approach to wetland classification for inland wetlands includes two essential elements: host landform and degree of wetness (Table 2.2). Five inland landforms (basins, channels, flats, slopes and hills or highlands) and three degrees of wetness (permanently inundated, seasonally inundated, seasonally waterlogged) were used to develop a matrix of wetland types. Thirteen wetland types are recognised, with examples given in parentheses:

- Permanently inundated basins (lakes);
- Seasonally inundated basins (sumplands);

Table 2.2 Example of a wetland classification system based on combining landform and hydroperiod attributes (Semeniuk and Semeniuk 1995).

Water longevity	Landform				
	Basin	Channel	Flat	Slope	Highland
Permanent inundation	Lake	River	—	—	—
Seasonal inundation	Sumpland	Creek	Floodplain	—	—
Intermittent inundation	Playa	Wadi	Barlkarra	—	—
Seasonal waterlogging	Dampland	Trough	Palusplain	Paluslope	Palusmont

- Intermittently inundated basins (playas);
- Seasonally waterlogged basins (dampland);
- Permanently inundated channels (rivers);
- Seasonally inundated channels (creeks);
- Intermittently inundated channels (wadis);
- Seasonally waterlogged channels (troughs);
- Seasonally inundated flats (floodplains);
- Intermittently inundated flats (barlkarra);
- Seasonally waterlogged flats (palusplains);
- Seasonally waterlogged slopes (paluslopes); and
- Seasonally waterlogged highlands (palusmont).

GOODS AND SERVICES PROVIDED BY WETLAND ECOSYSTEMS

No matter where wetlands occur in the landscape, and no matter the processes that were responsible for their formation and persistence, wetland resources are used for a wide variety of purposes and all of the wetland-related goods and services that benefit human societies emanate ultimately from natural ecological processes. Three such examples of wetland resources are peat (wetland soils), reed (wetland vegetation) and fish (wetland-dependent animals). Benefits from ecological processes that occur in wetlands are not so obvious and are often ignored when decisions are made to alter wetlands. Some types of wetland, for example, store large amounts of water and release it slowly, thus lowering flood peaks and minimising damaging floods (Hey and Philippi 1995). Processes related to the cycling and storage of nutrients in wetlands are responsible for water quality benefits, and techniques have been developed to use natural and created wetlands, especially marshes, for purposes of water quality management (Hammer 1989; Kadlec and Knight 1996; Hammer 1997).

Societal benefits that emanate from wetlands only continue as long as ecological processes continue (Whigham 1997). For this reason it is important to understand the differences between ecological processes that occur in wetlands, and values that are placed on wetland resources and services by societies around the world.

Wetland functions are the result of ecological processes that are necessary for the self-maintenance of ecosystems (Richardson 1994; Whigham 1997). They occur in all types of ecosystem and occur without human intervention. Examples of ecological functions in wetlands are: storage of surface water; storage of subsurface water; reduction of the energy level of surface water; recharge and discharge of groundwater; transformation of nutrients and maintenance of primary production.

Wetland values result from the goods and services that emanate from natural ecological functions (Taylor *et al.* 1990). Each of the three broad types of wetland provide, to varying degrees, these ecological functions.

Marshes and peatlands almost always provide long-term storage of surface water. The degree to which swamps store surface water depends primarily on landscape position. Some swamps occur in areas that have standing water for extended periods of time and thus provide significant surface water storage (Ewel and Odum 1984). Other swamps occur along rivers, and provide only short-term storage of surface water during flooding events; a time when they provide the important function of reducing the energy level of the flow (Lugo *et al.* 1990). Peatlands typically do not reduce the energy level of surface water because precipitation is generally the primary source. Whether a wetland provides groundwater recharge or discharge depends on many factors, including landscape position and substrate characteristics (Winter 2001; Rosenberry and Winter 1997). Swamps usually occur in topographically low areas and are sites for groundwater discharge. Since precipitation is often the dominant source of water to peatlands, particularly bogs, they are usually not considered to be important sites for groundwater discharge or recharge. All wetlands transform nutrients and most are habitats where nutrients accumulate (Mitsch and Gosselink 2000). The level of primary production that occurs in wetlands varies considerably, primarily depending on the nutrient status of water that enters the wetland. Bogs typically have low levels of primary production because of low nutrient levels in precipitation, but nutrient-rich fens and tropical papyrus communities are among the most productive ecosystems, although they are also peat-forming. Swamps and marshes typically have high levels of productivity because of high nutrient inputs from surrounding landscapes.

The relationship between functions and values is demonstrated in Figure 2.9 (see also Section 4). Examples of linkages between wetland functions and values can be demonstrated for the functions listed above. The storage of surface water results directly in the reduction of flood-related damage in downstream areas. Reduction in the energy of surface water directly reduces erosive power, and therefore the amount of erosion associated with storms and floods. Recharge of groundwater directly influences the amount available for extractive uses (i.e. drinking water, irrigation water). Discharge of groundwater from wetlands is responsible for maintaining base flow in streams and water levels in lakes. Nutrient transformation (e.g. nitrogen and phosphorus) directly influences the quality of surface and groundwater. Primary production directly influences the amounts of plant and animal biomass available for human uses.

THREATS TO WETLANDS

Wetlands are threatened in most areas of the world and in some countries the majority of wetland resources have already been converted to other land uses (Fretwell *et al.* 1996). In some landscapes (e.g. the Gulf Coast of Louisiana, USA), wetlands are threatened by direct and indirect activities (Mitsch *et al.* 2001) and recent hurricane damage in the region has exacerbated the problem (Dean *et al.* 2005; Boesch *et al.* 2006). The estimated costs of restoration and the prevention of further losses are in the order of billions of dollars for wetlands in coastal Louisiana as well as the Florida Everglades (Bahr *et al.* 2005). Many losses occurred before there was any general understanding of the importance of wetlands to wider human needs. The primary challenges in the present and future will be to provide appropriate information to decision makers regarding the impacts of ongoing or proposed activities that will negatively affect wetland functions. The challenge is daunting, and little success can be expected in the near future unless it can be demonstrated that the maintenance of human societies requires the sustainable management of wetland resources. Similarly, little progress can be expected in areas where economic progress encourages activities that result in the conversion of wetlands to other uses, or wetland uses that are not sustainable. Examples are provided to demonstrate the difficult nature of the situation.

Some large wetland areas have become the focus of major international conservation efforts. One of the most widely cited examples is the Pantanal of Brazil, Paraguay and Bolivia (see Junk). The Pantanal is a seasonally flooded wetland and upland complex of approximately 140 000 km^2. It has been recognised as an important 'hot spot' of global biodiversity, particularly because it supports an enormous range of mammals (Ricklefs 1995) and birds (Por 1995). Until recently, a balance seemed to

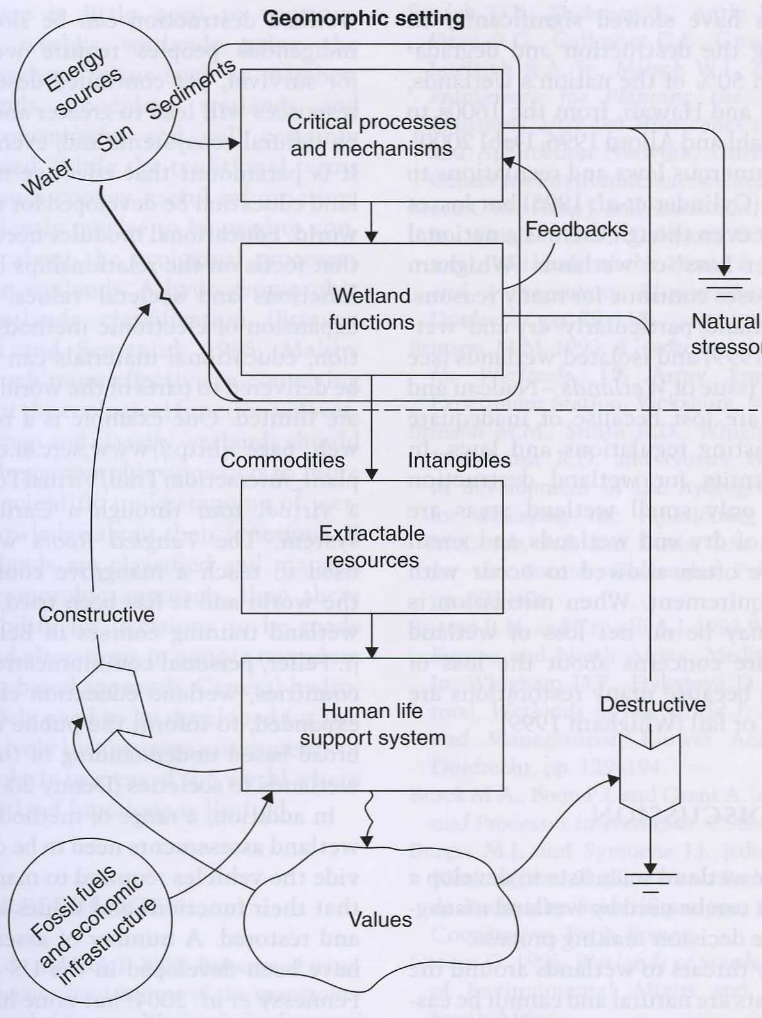

Fig. 2.9 The diagram broadly depicts the relationship between ecological functions of wetlands and the societal values of wetlands. The dashed line separates ecological processes (above line) from societal interactions (below the line) with wetlands. Ecological processes and the structure of ecosystems above the line continue in the absence of society. Items below the line do not continue, or are greatly diminished, if ecological processes above the line stop, or are degraded, owing to natural or anthropogenic activities. (*Source*: Brinson 1993.)

exist between wetland functions in the Pantanal and human uses of the wetland complex. The integrity of the Pantanal wetland complex is now being threatened, however, by many factors that are typically encountered around the world. Threats to the Pantanal include conversion of upland habitats in the watershed, resulting in increased rates of sedimentation, the development of a major international waterway project that will significantly alter the hydrology of the system, and river channelisation (Junk *et al.*, Chapter 40).

Wetland losses have slowed significantly in the US following the destruction and degradation of more than 50% of the nation's wetlands, excluding Alaska and Hawaii, from the 1600s to the mid-1980s (Dahl and Allord 1996; Dahl 2000). There are now numerous laws and regulations to protect wetlands (Cylinder *et al.* 1995) but losses continue to occur even though there is a national policy of 'No Net Loss' of wetlands (Whigham 1999). Wetland losses continue for many reasons. Some types of wetland, particularly 'dry end' wetlands (Whigham 1999) and isolated wetlands (see articles in special issue of *Wetlands* – Nadeau and Leibowitz 2003) are lost because of inadequate protection by existing regulations and laws. In many states, permits for wetland destruction are given when only small wetland areas are involved. Losses of dry end wetlands and small wetland areas are often allowed to occur with no mitigation requirement. When mitigation is required, there may be no net loss of wetland area, but there are concerns about the loss of wetland function because many restorations are never completed, or fail (Whigham 1999).

DISCUSSION

It is important for wetland scientists to develop a range of tools that can be used by wetland managers to assist in the decision making process.

There are many threats to wetlands around the world. Some threats are natural and cannot be easily avoided. Examples include wetland destruction resulting from volcanic eruptions (Titus *et al.*, 1999), hurricanes (Michener *et al.* 1997; Alleng 1998; Boesch *et al.* 2006) and floods (Day *et al.* 1995; Stromberg *et al.* 1997; Patten 1998). Climate change related to human activities has a high potential for impacting wetlands (Poiani and Johnson 1991), particularly coastal wetlands (Day *et al.* 1995; Michener *et al.* 1997). Direct impacts of human activities on wetlands due to drainage, conversion to other uses and alterations of hydrologic conditions also have a significant impact on wetlands (e.g. Richardson *et al.* 2005). In many areas of the world there is little hope that the ongoing wetland destruction can be slowed or stopped. Indigenous peoples require wetland resources for survival, yet continued destruction of those resources will lead to greater and greater stresses on natural ecosystems and, eventually, societies. It is paramount that effective methods for wetland education be developed for those parts of the world. Educational modules need to be developed that focus on the relationships between wetland functions and societal values. With the rapid expansion of electronic methods of communication, educational materials can more effectively be delivered to parts of the world where resources are limited. One example is a recent interactive web page (http://www.serc.si.edu/labs/animal_plant_interaction/Trail/VirtualTour.html) that is a virtual tour through a Caribbean mangrove system. The *Tangled Roots* website could be used to teach a mangrove course anywhere in the world and it has been used, for example, in wetland training courses in Belize and Panama (I. Feller, personal communication). In developed countries, wetland education efforts need to be expanded, to inform the public and to develop a broad-based understanding of the importance of wetlands to societies (Denny 2001).

In addition, a range of methods for conducting wetland assessments need to be developed to provide the vehicles required to manage wetlands so that their functions and values are both retained and restored. A number of assessment methods have been developed in the US (Bartoldus 1999; Fennessy *et al.* 2004) but none have proven to be completely satisfactory. The hydrogeomorphic approach to wetlands assessment, for example, may prove useful in conducting assessments at several levels of complexity (Whigham *et al.* 2007) but the method needs further development and testing (Brinson *et al.* 1998; Whigham 1999; Hill *et al.* 2006; see Brinson). The hydrogeomorphic approach being developed for Europe (Functional Analysis of European Wetland Ecosystems, FAEWE) is also promising (Maltby *et al.* 1996; McInnes *et al.* 1998; see Maltby *et al.*, Chapter 23).

How can we accomplish the dual and related tasks of wetland education and wetland assessment? There is little need to continue to classify the world's wetlands using the traditional approaches. Terms such as marshes, swamps, peatlands, floodplain wetlands and mangroves are meaningful and will certainly continue to be used. While the traditional terms to describe wetlands convey useful information, they are insufficiently precise to be used to convey information about the ecological processes that occur within wetlands. A hydrogeomorphic approach to wetlands classification (Brinson 1993; Semeniuk and Semeniuk 1995; Maltby *et al.* 1996) is much more effective in conveying information about the ecological functions of wetlands. Efforts to map and classify wetlands should focus on the hydrogeomorphic approach to more closely link the scientific understanding of wetland types to knowledge about their functions. If the world's wetlands are classified and mapped using a hydrogeomorphic approach, then there exists the possibility for decisions to be made regarding wetland alterations in a more complete and scientifically-based approach. General hydrogeomorphic models need to be developed for use in rapid and relatively inexpensive assessments of wetlands, particularly in areas of the world where knowledge of wetland functions is limited.

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