Chapter 1

Introduction

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This book is about wetland ecosystems. The operative root word is ‘‘systems.’’ Ecosystem, as a term, was coined in the 1930s by Sir Arthur Tansley (1871–1955) and Roy Clapham (1904–1990), both British botanists. Tansley (1935) defined ecosystems as ‘‘the whole system including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment of the biome—the habitat factors in the widest sense.’’ As described by ecological historian Robert McIntosh (1985), Tansley’s concept of ecosystem was picked up by Lindeman (1942) in his famous and, at the time, controversial study of trophic dynamics in Cedar Bog Lake (a peatland) in Minnesota. (This study is discussed further in Chapter 4, ‘‘Peatlands.’’) Thus, ecosystem ecology was born in wetlands, which may have provided the system for its initial incubation.

A more modern definition of ‘‘ecosystem’’ that we prefer, similar to the Tansley description, is *a complex of ecological communities and their environment, forming a functioning whole in nature* (reworded from Patten and Jørgensen, 1995). Most important to note is that an ecosystem includes the biological communities and the abiotic environment in which they are found. In some cultures, ecosystems are not recognized. For example, in Russia, the term used to define a similar concept is *biogeocoenosis*.

Ecosystems have been considered by many to be the most fundamental unit of study in ecology (McNaughton and Wolf, 1973; Patten and Jørgensen, 1995) and there is still the belief that the entire ecosystem needs to be studied to determine the importance of any one species or community within that ecosystem. We would like to think that is the case today, but, in fact, ecosystems are rarely studied as a whole. Rather, ecologists or teams of ecologists focus on specific parts of the ecosystem—vegetation, animal species, or groups of organisms (communities)—but less commonly include the abiotic environment or describe the interactions between the biotic and abiotic parts of the ecosystem. One exception to this is the investigation of biogeochemical cycles in wetlands, probably because the effects of the abotic environment—hydrology, soils, and so on—are so obvious and important.

Wetland Ecosystems

This book is specifically about wetland ecosystems. Defining wetlands precisely is even more complex than defining ecosystems, although, properly, most wetland definitions include both the biotic (usually vegetation) and abiotic (soils and hydrology) components. Our companion textbook (Mitsch and Gosselink, 2007) gives seven definitions of wetlands, five of which come from the United States. We repeat a diagram from that book as our working definition of wetlands (see Figure 1-1). Wetlands are shown to be a three-component ecosystem. The hydrology of the landscape influences and changes the physiochemical environment, which in turn, along with hydrology, determines the biotic communities that are found in the wetland. Overall, the forcing functions of the wetlands, or any landscape ecosystem for that matter,

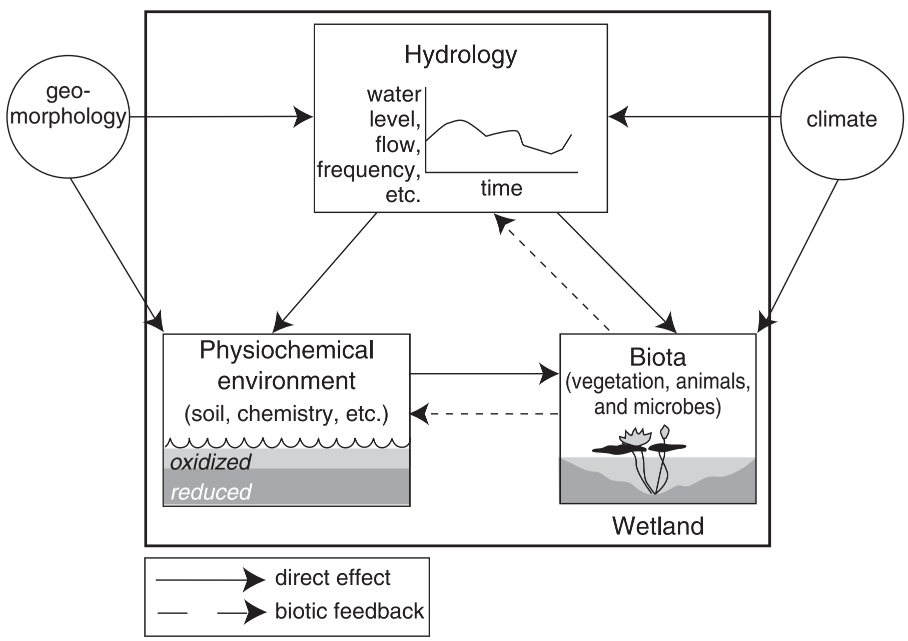

Figure 1-1 Conceptual model of a wetland ecosystem, showing the three-component basis of a wetland often used in wetland definitions, and the principal cause of wetlands—climate and landscape geomorphology. (*From Mitsch and Gosselink, 2007, 2000; NRC, 1995*)

include climate, which includes solar energy, temperature patterns, and precipitation. Climate couples with the geomorphology of the landscape to influence where and when water is present long enough to cause wetlands to exist.

Several wetland classification systems are used by scientists around the world to categorize wetland ecosystems. Some are simple, such as the Circular 39 system first used in the United States in the 1950s (Shaw and Fredine, 1956) with 20 wetland types and the system used internationally by the Ramsar Convention (Mitsch and Gosselink, 2007) with 27 wetland types. The detailed hierarchical system developed in the 1970s in the U.S. (Cowardin et al., 1979) as part of the U.S. National Wetlands Inventory and the more recent (1990s) hydrogeomorphic (HGM) classification system developed by Brinson (1993) in an attempt to include hydrodynamics in the classification of wetlands, are formal and all encompassing but are much too complex to use as way to organize this book. These and other formal wetland classifications are described in more detail in Chapter 8 of *Wetlands*, *4th edition* (Mitsch and Gosselink, 2007).

In this book we describe wetlands divided into three major groups (see Table 1-1):

- Coastal wetlands—salt marshes, tidal freshwater marshes, mangrove swamps
- Freshwater swamps and marshes
- Peatlands

These classes of wetlands are generally recognizable ecosystems for which extensive research literature is available. Regulatory agencies also deal with these wetland system types, and management strategies and regulations have been developed for them. Collectively, these categories encompass most if not all of the 2.5 million km^2 of wetlands of North America and 6 to 8 million km^2 of wetlands in the world as a whole (Mitsch and Gosselink, 2007; Table 1-1).

Table 1-1 Wetland Ecosystem Types Described in This Book, with Their Estimated Area (x 10^6 ha) in the United States, Canada, and the World

Type of Wetland	Wetland area, $\times 10^6$ ha USA	Canada	World	Book Chapter
Coastal Wetlands				
Tidal Salt Marshes	1.9	1[a]	10[a]	2
Tidal Freshwater Marshes	0.8	—	2[a]	2
Mangrove Wetlands	0.5	—	24	2
Inland Wetlands				
Freshwater Marshes	27	16	95	3
Freshwater Swamps and Riparian Forests	25	—	109	3
Peatlands	55	110	350	4
TOTAL	110	127	580	

[a]Estimated.

How to Read These Ecosystem Diagrams

The energy flow diagrams that follow in this chapter and are found scattered through the remaining chapters in this book are full of information. They are drawn in the energy language, or ''energese,'' developed by the late H. T. Odum (1924–2002). See http://en.wikipedia.org/wiki/Howard_T._Odum. A more appropriate term for the language might be ''ecosystem language.'' The symbols were developed to describe energy flow in ecosystems but are now used to describe the dynamics of any system, from wetland to watershed to the biosphere. The symbolic energy language has been called the ''shorthand for ecology,'' and scientists who are familiar with the language actually ''talk'' energese as they draw and redraw system diagrams until they agree that they have described how the systems work. Key references for the symbols are Odum and Odum (2000). The symbols are defined in Appendix A.

Coastal Wetlands

Several types of wetlands in the coastal areas are influenced by alternate floods and ebbs of oceanic tides. Near coastlines, the salinity of the water approaches that of the ocean, whereas further inland, the tidal effect can remain significant even when the salinity approaches that of freshwater. Coastal wetlands include tidal salt marshes, tidal freshwater wetlands, and mangroves swamps. We estimate that there are 0.36 million km^2 of coastal wetlands in the world (refer to Table 1-1). The area is not well known because of different definitions of "coastal" and because non-vegetated flats are a common type of coastal wetland in many regions and are counted in some inventories but not counted in others. The total area of wetlands considered as coastal or estuarine in the United States, including Alaska, is approximately 3.2 million ha, with about 1.9 million ha as salt marshes and 0.5 million ha as mangrove swamps. Alaskan estuarine wetlands alone are estimated to cover 0.9 million ha with only about 17% of these wetlands vegetated and thus presumably salt marsh (Hall et al., 1994). The vast majority of estuarine wetlands in Alaska were classified by Hall et. al. (1994) as "nonvegetated" or mudflats.

Salt marshes (see Figure 1-2) are found throughout the world along protected coastlines in the middle and high latitudes. As Figure 1-2 suggests, salt marshes are primarily detrital-based, with abundant fauna dependent directly (e.g., crabs) or indirectly (e.g., birds, estuarine fish) on this detrital production. A modest amount of the marsh grass productivity is consumed by grazing. Plants and animals in these systems have adapted to the stresses of salinity, periodic inundation, and extremes in temperature. One of the areas where salt marshes are most prevalent in the world is along the eastern coast of North America from New Brunswick to Florida and on to Louisiana and Texas along the Gulf of Mexico. Salt marshes are also found in narrow belts on the west coast of the United States and along much of the coastline of Alaska

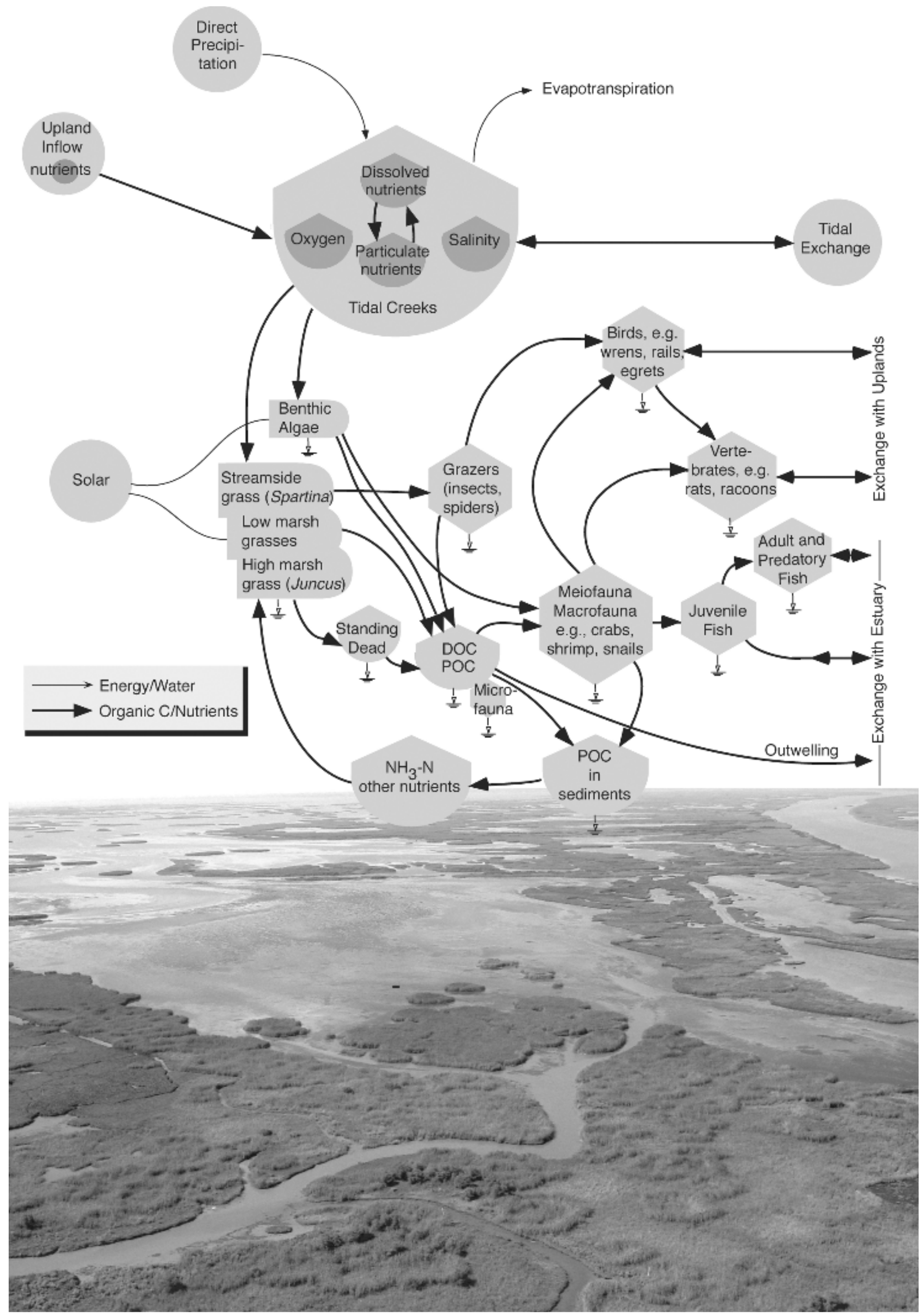

Figure 1-2 Tidal salt marsh: Energy flow diagram (top) and photograph of tidal salt marsh in Louisiana (bottom). Photo by W. J. Mitsch.

and the Hudson Bay in Canada. Overall, there are about 1.9 million ha of salt marshes in the United States and at least as much in Canada. On the eastern coast of the United States, salt marshes are often dominated by the grass *Spartina alterniflora* in the low intertidal zone, *Spartina patens*, and the rush *Juncus* in the upper intertidal zone. *Spartina alterniflora* is also found on many of the extensive salt marshes on China's coastline (estimated to be 2 million ha total) but there it is considered an invasive species. European salt marshes are not nearly as plentiful as those found in North America and generally do not have a plant species such as *S. alterniflora* in the intertidal zone. As the photo in Figure 1-2 shows, salt marshes are crisscrossed with tidal channels that are essential for their survival.

Tidal freshwater marshes and swamps (see Figure 1-3) are found inland from the tidal salt marshes or mangroves but still close enough to the coast to experience tidal effects. In the United States, these wetlands, usually dominated by a variety of grasses and by annual and perennial broad-leaved aquatic plants but sometimes by trees, are found primarily along the Middle and South Atlantic coasts and along the coasts of Louisiana and Texas. Estimates of tidal freshwater wetlands in the United States range from 160,000 ha along the Atlantic coast to 820,000 ha for the conterminous United States. The uncertainty in the estimate depends on where the line is drawn between tidal and non-tidal areas. Tidal freshwater marshes can be described as intermediate in the continuum from coastal salt marshes to freshwater marshes. Because they are tidally influenced but lack the salinity stress of salt marshes, tidal freshwater marshes have often been reported to be very productive ecosystems, although a considerable range in their productivity has been measured. Tidal freshwater swamps are similar to upland riverine swamps, except that the water levels are variable on a daily schedule and are less prone to excessive changes.

Tidal salt marshes are replaced by **mangrove swamps** (see Figure 1-4) in subtropical and tropical regions of the world. The word *mangrove* refers to both the wetland itself and to the salt-tolerant trees that dominate those wetlands. Mangrove swamps are found all over the world in tropical and subtropical regions, generally between 25°N and 25°S, and are estimated to cover 24 million ha worldwide. They are particularly dominant in the Indo-West Pacific region of the world, where more than half of the species of mangrove trees are found. In North America, mangrove wetlands are found on both coastlines in Mexico, where there are an estimated 940,000 ha of mangrove swamps (Martinez et al., 2007); in the United States, they are limited primarily to the southern tip of Florida where 300,000 to 500,000 ha are found. The extent of mangroves in North America (1.3 million ha) is a small fraction of the 24 million ha of mangroves found worldwide. In Florida, mangrove wetlands are generally dominated by the red mangrove tree *(Rhizophora)* and the black mangrove tree *(Avicennia)* and export organic matter to the adjacent estuaries, as do salt marshes. Like salt marshes, the mangrove swamps require protection from the open ocean and occur in a wide range of salinity and tidal influence.

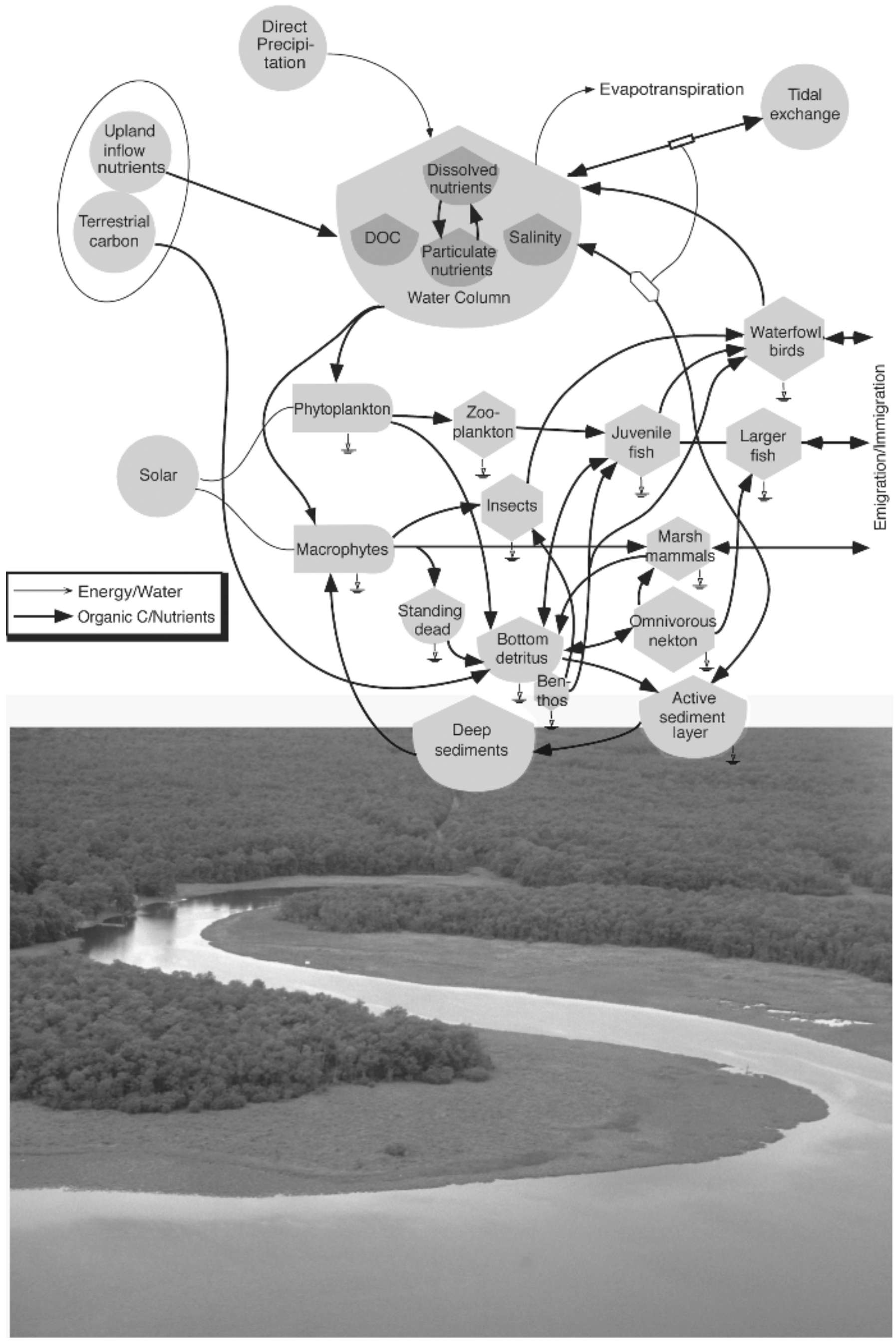

Figure 1-3 Tidal freshwater marsh: Energy flow diagram (top) and photograph of tidal freshwater marsh in Maryland (bottom). Photo by A. H. Baldwin, reprinted with permission.

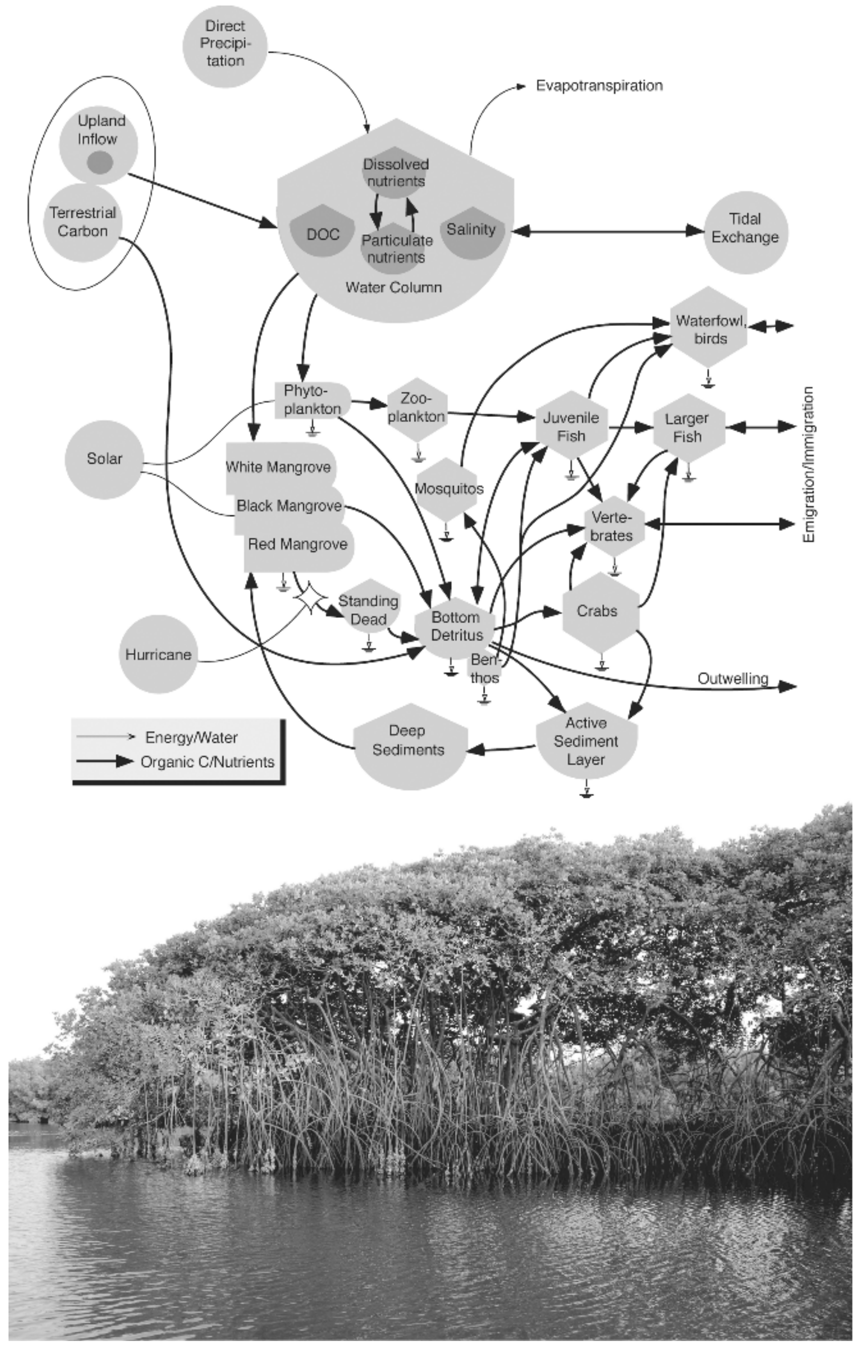

Figure 1-4 Mangrove swamp: Energy flow diagram (top) and photograph of mangrove swamp in Senegal, West Africa (bottom). Photo by W. J. Mitsch.

Freshwater Swamps and Marshes

On a real basis most of the wetlands of the world are not located along coastlines but are found inland (refer to Table 1-1). These wetlands are sometimes referred to as ‘‘non-tidal’’ in coastal regions to distinguish them from the coastal wetlands described previously. Our estimates in Table 1-1 suggest that 5.5 million km^2, or 95 percent of the total wetlands in the world, are inland. Frayer et al. (1983) estimated that in the lower 48 states in the United States, 32 million ha, or about 80 percent of the total wetlands in the lower 48 states, are inland. Including Alaska, there are a total of 107 million hectares of inland wetlands in the United States, representing 97% of the country’s wetlands. It is difficult to divide these inland wetlands into simple categories. We have chosen to describe freshwater marshes and forested swamps in Chapter 3 and peatlands in Chapter 4.

Freshwater marshes (see Figure 1-5) includes a diverse group of wetlands characterized by emergent soft-stemmed aquatic plants such as cattail, bulrush, arrowhead, pickerel-weed, reed, and several other species of grasses and sedges, a shallow, seasonally changing water regime, and shallow organic soil deposits. These wetlands are ubiquitous and are estimated to cover 95 million ha around the world and about 27 million ha in the United States. Major regions where marshes dominate include the Okavango Delta in Botswana (see Figure 1-5 photo), the prairie pothole region of the Dakotas, and the Everglades of Florida. They occur in isolated basins, as fringes around lakes, and along sluggish streams and rivers.

Freshwater forested swamps range from wetlands that have standing water for most if not all of the growing season (see Figure 1-6; sometimes referred to as deepwater swamps) to riparian bottomland forests that are less frequently flooded but found all around the world across many climates (see Figure 1-7). The frequently flooded forested swamps occur in a variety of nutrient and hydrologic conditions—as alder (*Alnus*) swamps in Europe, as kahikatea (*Dacrycarpus*) swamps in New Zealand, and as cypress *(Taxodium)* and gum/tupelo *(Nyssa)* swamps in the southeastern United States. In the northern parts of the lower 48 United States, red maple (*Acer rubrum*) swamps are common, although there are no trees quite as adapted to flooding anywhere in North America as are *Taxodium* and *Nyssa*. Extensive tracts of riparian wetlands, which occur along rivers and streams, are occasionally flooded by those bodies of water but are otherwise dry for varying portions of the growing season. Riparian forests and deepwater swamps combined constitute the most extensive class of wetlands in the United States, covering from 22 to 25 million ha (Dahl and Johnson, 1991; Hall et al., 1994). In the eastern United States, riparian ecosystems, often referred to as bottomland hardwood forests, contain diverse vegetation that varies along gradients of flooding frequency. Riparian wetlands also occur in arid and semi-arid regions, where they are often a conspicuous feature of the landscape in contrast with the surrounding arid grasslands and desert. Riparian ecosystems are generally considered to be more productive than the adjacent uplands because of the periodic inflow of nutrients, especially when flooding is seasonal rather than continuous.

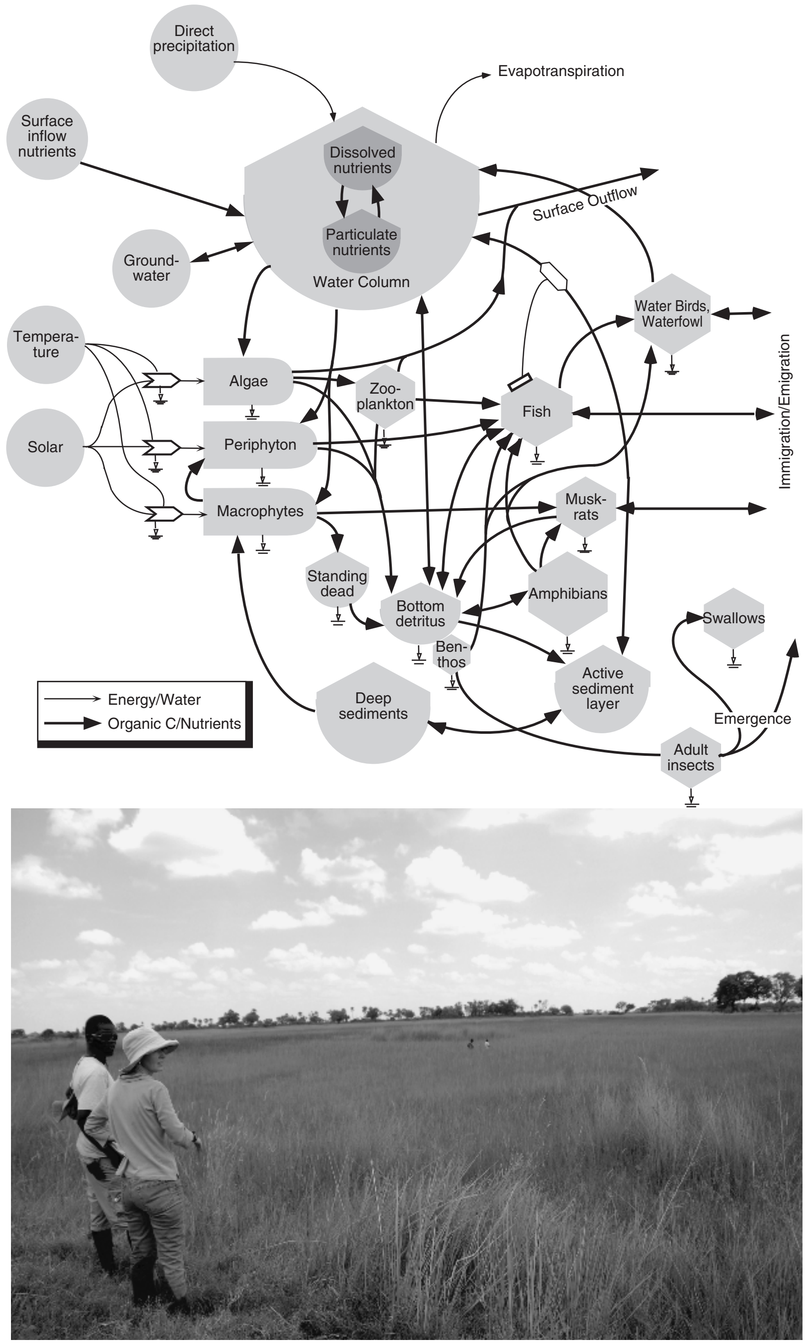

Figure 1-5 Freshwater marsh: Energy flow diagram (top) and photograph of freshwater marsh in Okavango Delta floodplain, Botswana, southern Africa (bottom). Photo by W. J. Mitsch.

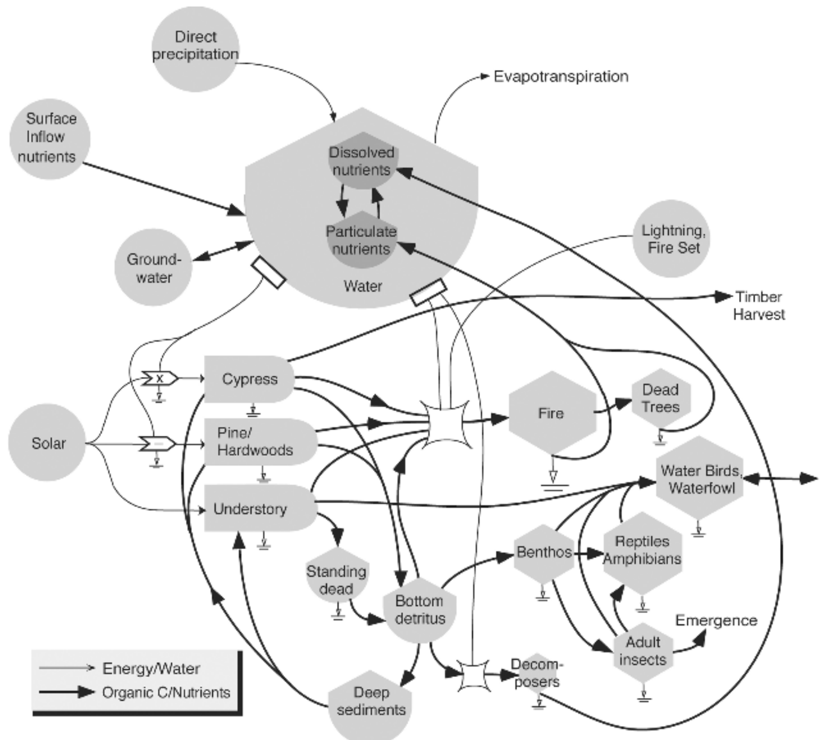

Figure 1-6 Freshwater swamp: Energy flow diagram (top) and photograph of freshwater swamp at Corkscrew Swamp, southwestern Florida (bottom). Photo by W. J. Mitsch.

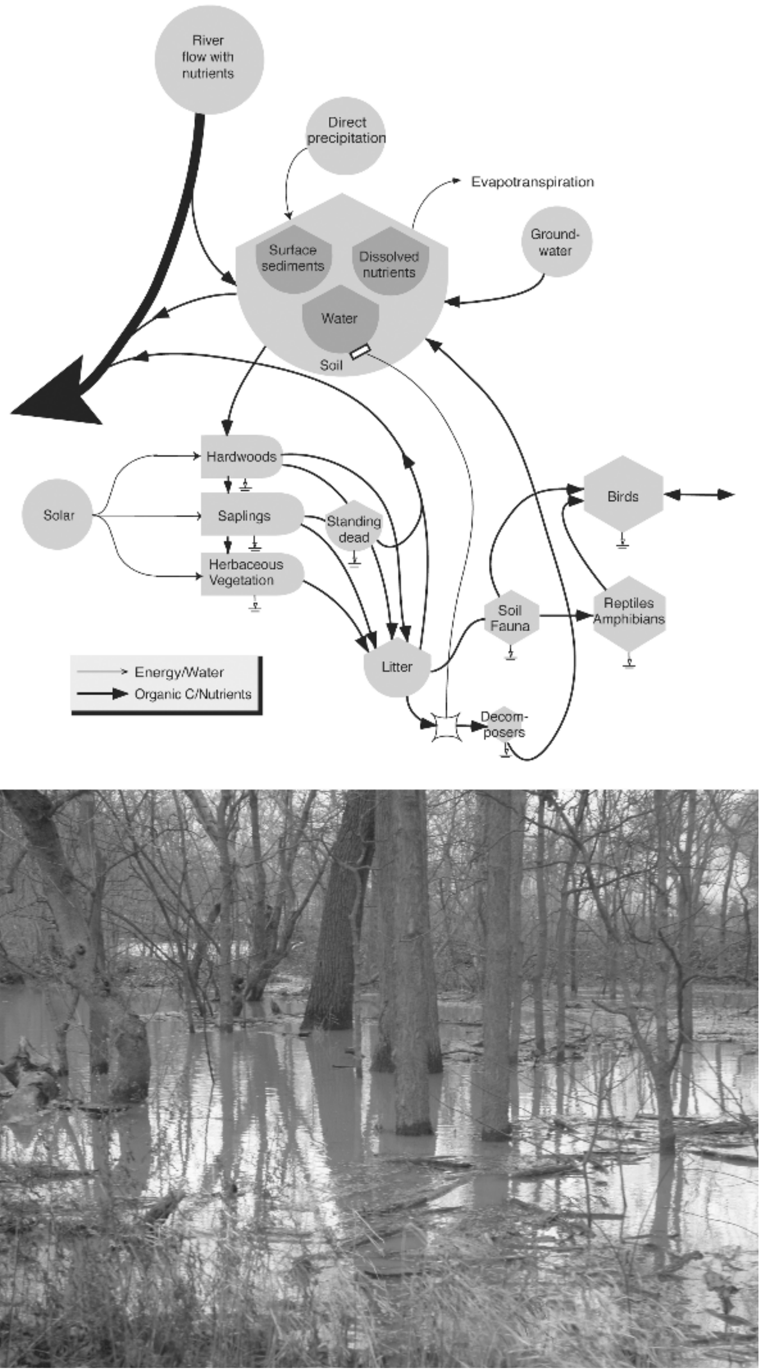

Figure 1-7 Riparian bottomland forest: Energy flow diagram (top) and photograph of riparian forested wetland in central Ohio (bottom). Photo by W. J. Mitsch.

Peatlands

As defined here, peatlands include the deep peat deposits of the boreal regions of the world (see Figure 1-8). They are the most ubiquitous wetland in the world, covering from 2.4 to 4.1 million km^2. A recent estimate of 3.3 million km^2 of peatlands was given by Wieder et al. (2006) for most of the world (where peatland coverage has been measured). In North America, the extensive peatlands of Alaska and Canada cover an estimated 0.52 and 1.11 million km^2, respectively (Zoltai, 1988; Hall et al., 1994), or 1.6 million km^2, a significant portion of the world's peatlands. Europe has about 0.96 million km^2 of peatlands, covering about 20% of the continent (Mitsch and Gosselink, 2007). The Western Siberian Lowland in Asia has about 0.79 million km^2 of peatlands. In total that is 3.37 million km^2. In the conterminous United States, peatlands are limited primarily to Wisconsin, Michigan, Minnesota, and the glaciated Northeast. Minnesota, with an estimated 2.7 million ha, has the largest peatland area in the United States (Glaser, 1987). There are also mountaintop bogs in the Appalachian Mountains of West Virginia such as those found in the Canaan Valley and peat-dominated wetlands, called pocosins, in the Coastal Plain of southeastern United States. Bogs and fens, the two major types of peatlands, occur as thick peat deposits in old lake basins or as blankets across the landscape. Many of these lake basins were formed by the last glaciation, and the peatlands are considered to be a late stage of a ''filling-in'' process. There is a wealth of European scientific literature on this wetland type, much of which has influenced the more recent North American literature on the subject. Bogs are noted for their nutrient deficiency and waterlogged conditions and for the biological adaptations to these conditions such as carnivorous plants and nutrient conservation.

Wetland Ecosystems Services

Wetlands are far more important in the biosphere than their 5 to 7% of the landscape suggests. They provide an immense storage of carbon that, if released with climate shifts, could accelerate those changes. They are known for their role in protecting clean water, so much so that thousands of wetlands have been constructed to clean all types of wastewater around the world. They protect coastlines from hurricanes and tsunamis, mitigate flooding of streams and rivers, and, most importantly to some, provide a bountiful habitat for a great diversity of plant and animal species. These ''ecosystem services'' of wetlands are discussed in great detail in Mitsch and Gosselink (2007) and are only summarized here.

Climate Stability

Wetlands as ecosystems represent one of the important linchpins of climate change. The amount of carbon stored in wetlands, particularly in boreal peatlands, is enormous (on the order of 30% of all the organic carbon storage in the planet) and any climate change that could affect that storage, say by drying the boreal regions, could result in a massive positive feedback of even more emissions of carbon dioxide to the atmosphere (see Chapter 10, Mitsch and Gosselink, 2007). Just as important, wetlands, especially

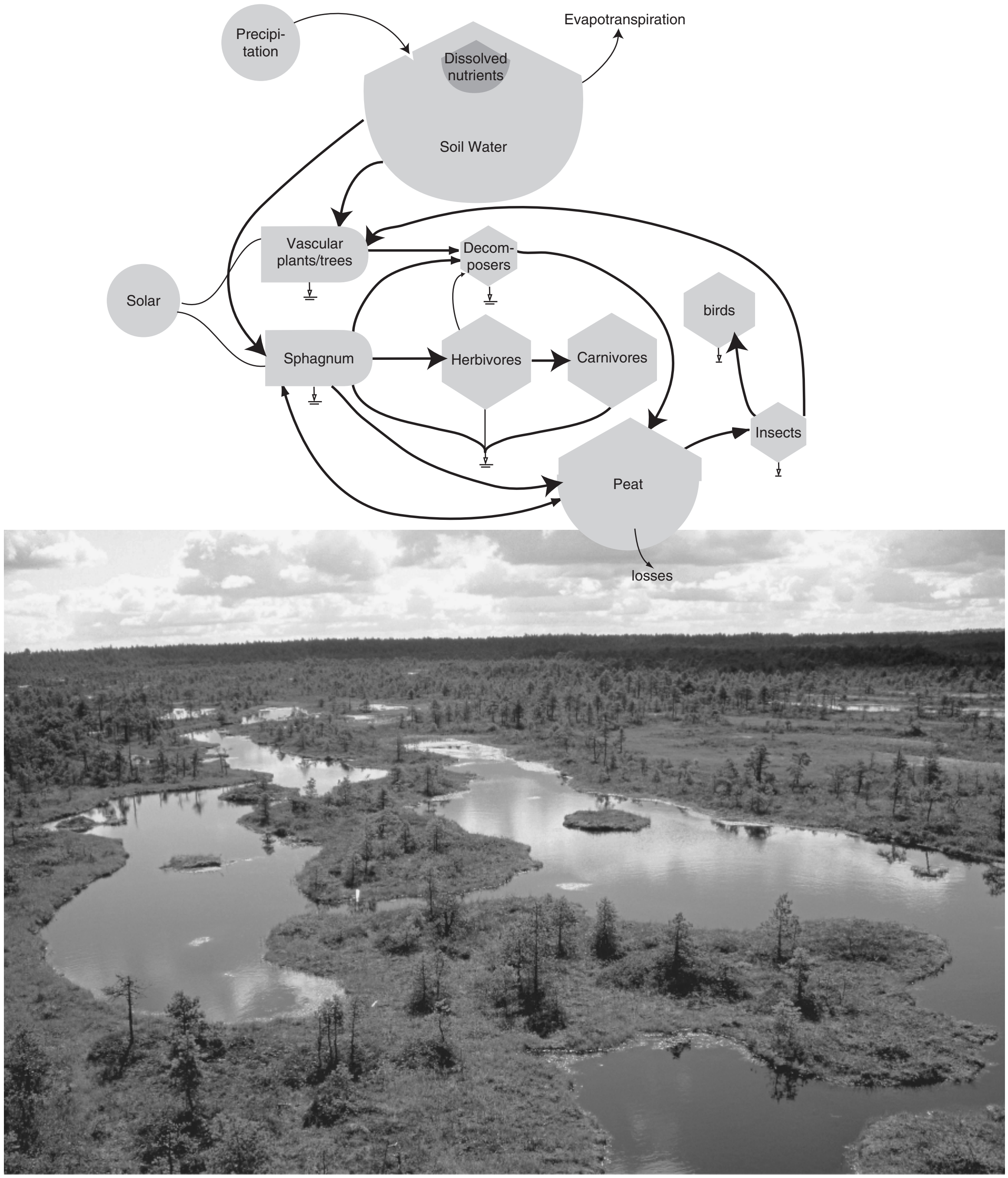

Figure 1-8 Peatland: Energy flow diagram (top) and photograph of peatland in Estonia (bottom). Photo by Valdo Kuusemets, reprinted with permission.

when they are in the early stages of succession or recovering from alterations such as beaver damming or herbivory, can be one of the best ecosystems on the planet for sequestering carbon from the atmosphere and permanently storing that carbon, first in plants, then in detrital matter, and finally as part of the soil structure itself.

On the other side of the ledger, wetlands are known sources of at least two so-called greenhouse gases—methane and nitrous oxides—and have been so for all the time that ecosystems have been on planet Earth. Methane production occurs when other anaerobic metabolisms have spent themselves and the soils are in extremely reduced conditions. Rates of carbon emission as methane are generally less than 10% of the rate at which carbon is being sequestered by the same wetland, but methane as a gas is 22 times more effective than carbon dioxide at adsorbing radiation in the atmosphere. While there have been many studies investigating methane emissions from wetlands, particularly in boreal regions, it has been extraordinarily difficult to extrapolate these studies to the biosphere level because of enormous landscape and hydrologic variability of wetland ecosystems.

Nitrous oxide (N_2O) is a powerful greenhouse gas, and it is often released in trace amounts by wetlands. That release is a byproduct of a desirable process in many wetlands—denitrification. Denitrification is the microbial reduction of nitrate-nitrogen under anaerobic conditions and its subsequent gaseous emissions. While most of the gaseous emissions from denitrification result in harmless nitrogen gas (N_2), a low percentage of the emissions occur as N_2O. Much more needs to be known about the balance between carbon sequestration in wetlands on the one hand and emission of trace greenhouse gases on the other.

Water Quality Improvement

Wetlands are sometimes referred to as *nature's kidneys* for the role that they actually and potentially play in improving water quality. It is indeed impressive to see how well wetlands with flow-through characteristics change water chemistry. They generally increase water clarity and remove chemicals such as nitrate-nitrogen. But they can be sources of organic matter, particularly if water entering the wetlands is low in organic matter, and often they can serve as sources of phosphorus if overloaded for a number of years. There are thousands of published papers in the past 35 years that have illustrated how natural and constructed wetlands improve water quality.

Coastal Protection

Coastal wetlands have been shown time and time again to be important coastline protection ecosystems. Major disasters just in the first decade of the 21st century have supported the cause for protecting coastal wetlands to protect humans and their resources, and conversely showing extraordinary damage when wetlands are removed. In December 2004, the great Indian Ocean tsunami caused by an earthquake off the coast of Indonesia led to 230,000 deaths around the entire Indian Ocean and billions of dollars of damage. Subsequent studies (e.g., Danielsen et al., 2005) showed that where coastal mangrove swamps were left in place to "bear the brunt" of the sometimes 10-m high tsunami waves, areas behind the mangroves were most protected. Conversely areas where mangrove swamps were drained or destroyed for commercial operations such as shrimp farms were devastated.

Eight months later, in late August 2005, the city of New Orleans was struck by the powerful Hurricane Katrina, causing billions of dollars of damage. Tens of thousands of people moved to higher grounds as a 6-m high storm surge overwhelmed New Orleans's levee system. New Orleans' real protection shield—the salt marshes of the Mississippi River delta—had been slowly eroding away for decades and the disaster was, unfortunately, predictable (Day et al., 2007) and may even happen again unless the salt marshes can be restored (Costanza et al., 2006).

Flood Mitigation

In addition to protecting coastal regions from storms, hurricanes, typhoons, and tsunamis, wetlands adjacent to rivers or in upstream reaches of watersheds are key to mitigating downstream river flooding. For example, with predictable and even more frequent occurrence, economically disastrous floods have occurred at least twice in a 15-year period (1993 and 2008) on the Upper Mississippi River Basin in the United States, partially as a result of river restrictions and development of floodplains into uses that are incompatible with flooding. Each time, there was an initial cry for restoring hundreds of thousands if not more wetlands in the region to be there to sponge the excess river water; but each time, before the water level even reached its base, the opportunity for flood mitigation with wetlands was forgotten and the basins were back to usual business.

Wildlife Protection

Wildlife often represents the entry point for the general public and wetlands. The wildlife in wetlands is fascinating and diverse. Wetlands are also known as *nature's supermarket* for the role that they play in supporting food chains, both aquatic and terrestrial. Wetlands are where critters go to eat or be eaten. Most people are familiar with birdbaths that are used in backyards to attract birds. Wetlands are *nature's birdbaths* in the sense that they attract sometimes hundreds of species, not for the water itself, but as a location of food, protection, and/or procreation. The vast Pantanal seasonal wetland in central South America is estimated to be the habitat for almost 500 species of birds. The Okavango Delta in south central Africa provides a pulsing wetland landscape that supports more than 400 bird species. If the wetland is connected to a stream, river, lake or ocean, wetlands can serve as fish nursery and feeding grounds. Isolated wetlands are important habitats for reptiles and amphibians, some of which depend on the wetland not being wet during the dry season. The value of wetlands for waterfowl, fish, and nature in general has always been known to naturalists, fishers, and hunters but not always by others; it is now known to school children everywhere through education programs that find wetlands to be good teaching opportunities.

Role of This Book

This book is meant as a stand-alone text that provides an ecosystem description (biotic and abiotic) of the major types of wetlands that are found in the world, simply categorized in Chapters 2, 3, and 4—coastal wetlands, freshwater marshes and forested swamps, and peatlands. The book provides descriptions of the ecosystem structure and function of these wetlands. Chapter 5 provides a review of the three fundamental ways that we can study wetland ecosystems in a "systems" way—mesocosms, full-scale experimental ecosystems, and mathematical modeling. As such, the text is a good "undergraduate" introduction to wetland ecosystems, especially when the course includes field trips to local wetlands. It is also meant to complement the textbook Wetlands, 4th edition (Mitsch and Gosselink, 2007) in upper-level undergraduate or graduate wetland courses. That book describes the human history and definitions of wetlands, and presents basic wetland science and applied wetland management, topics that are lightly touched upon in this book.

Recommended Readings

Mitsch, W. J., and J. G. Gosselink. 2007. *Wetlands, 4th ed.*, John Wiley & Sons, Hoboken, NJ.