WETLANDS

FIFTH EDITION

WILLIAM J. MITSCH · JAMES G. GOSSELINK

WILEY

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William J. Mitsch

James G. Gosselink

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Dedication

This fifth edition of Mitsch and Gosselink is dedicated to my long-time coauthor and friend, Professor James G. Gosselink (1931–2015). He was a gentleman and a scholar whom I will greatly miss.

—WJM

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Preface

This is the fifth edition of *Wetlands*—we updated the book every seven years from 1993 to 2007—since Van Nostrand Reinhold published the first edition in 1986. This fifth edition (referred to here as *Wetlands 5*) is eight years after the *Wetlands 4* but the additional one-year wait is well worth it, especially because so much new has happened the last year in the world of wetlands.

Because of requests by many instructors using this textbook, we reincorporated updated versions of our "ecosystem chapters" that were popular parts of the first three editions of *Wetlands*. Theses ecosystem chapters—now in Part III: Wetland Ecosystems (chapters 8 through 12)—bring back the ecosystem view of tidal marshes, mangroves, freshwater marshes and swamps, and northern peatlands. We had spit the 2000 edition of *Wetlands* into essentially two books—*Wetlands 4* (2007) and *Wetland Ecosystems* (2009), partially because students were asking for a shorter textbook. Most if not all of the pertinent information in those two books, all updated, is now included in one book. Yet *Wetlands 5* is 744 pages long, 20 percent shorter than the 920-page *Wetlands 3*. Instructors now have the choice of including or not including these ecosystem chapters, which were always among our favorites because of their "systems" view, in their syllabi. The chapters, by definition, integrate the otherwise separate fields of hydrology, biogeochemistry, microbiology, vegetation, consumers, and ecosystem function for the main types of wetlands found in the world in single chapters.

There is much new in *Wetlands 5* in addition to the five reinserted and updated ecosystem chapters in Part III. We provide a newly published trend of wetland publications in the world, a summary and list of publications from the every-four-year INTECOL international wetland conferences and the addition of *MegaPython vs. Gatoroid* campy science fiction wetland movie playbill to replace the long-reigning *Swamp Thing* movie playbill in Part I: Introduction. Updates of many of the great wetlands of the world are also provided in this section of the book, including new photos and descriptions of several wetlands in China.

Part II: The Wetland Environment (chapters 4 through 7), is significantly different from previous editions. There are now separate new chapters, "Wetland Soils" (Chapter 5) and "Wetland Vegetation and Succession" (Chapter 7), to complement the updated "Wetland Hydrology" (Chapter 4) and "Wetland Biogeochemistry" (Chapter 6) chapters. This fits better with wetland science as it is now practiced but also fits better the way in which we manage wetlands. The book is now more compatible with hydrology, soils, and vegetation, the three-legged stool of wetland definitions in many countries including the United States.

The management section of the book is now divided into two parts: Part IV: Traditional Wetland Management (chapters 13–15) and Part V: Ecosystem Services (chapters 16–19). Chapter 13, "Wetland Classification," now has an update on the U.S. National Wetland Inventory that was just completed for the lower 48 states after a 35-year effort on May 1, 2014. A web connection is also provided where readers can obtain wetland maps from almost anywhere in the United States. A description of methods that are being used in the United States to rate wetlands is also provided in that chapter, emphasizing systems developed in the states of Washington, Ohio, and Florida. New peat production rates for countries in the world are provided in Chapter 14, "Human Impacts and Management of Wetlands," and compared to rates from 14 years prior. The new regional wetland delineation manuals in the United States are described in Chapter 15, "Wetland Laws and Protection," as is a new U.S. Supreme Court decision on wetland mitigation that occurred in the summer of 2013. That makes three Supreme Court decision of wetlands in the United States since the new century began. The status of the international Ramsar Convention on Wetlands, which is growing in international importance by leaps and bounds, is also brought up to date in Chapter 15.

Chapter 16, "Wetland Ecosystem Services," now provides a new description of the ecosystem services that wetlands provide to society, newly categorized into the system developed by the Millennium Ecosystem Assessment of 2005 and also updates new economic value of different types of wetlands as published in mid-2014. Chapter 17, "Wetlands and Climate Change," updates the trends in greenhouse gases in the atmosphere and sea level rise, both of which affect and are affected by wetlands. A newly published model that provides a way of balancing the fluxes of methane with carbon sequestration in the same wetlands is also presented in that chapter as are more references on these two wetland processes. We updated the "permitted" versus "mitigated" data from the U.S. Army Corps of Engineers on trends in the USA on mitigating wetlands loss in Chapter 18, "Wetland Creation and Restoration." We now have seven wetland restoration case studies thoroughly updated in this chapter: the Florida Everglades, the Mesopotamia Marshlands in Iraq, the Bois-des-Bel experimental peatlands in Quebec, Canada, the Delaware Bay and Hackensack Meadowlands salt marsh restorations in the eastern United States, mangrove around the Indian Ocean, and the Skjern River channel and floodplain system in western Denmark.

Chapter 19, "Wetlands and Water Quality," provides updates on long-term studies that have investigated improving water quality by wetlands at the Houghton Lake treatment peatlands in Michigan and the freshwater marshes at the Olentangy River

Wetlands in Ohio, and the wetlands filtering agricultural runoff in south Florida called stormwater treatment areas (STAs). A new promising design of a stormwater treatment wetland, located at Freedom Park in Naples Florida is presented with preliminary data. New estimates of the costs of creating wetlands to improve water quality are also provided in this last chapter.

We continued the tradition of "boxes" or sidebars in *Wetlands 5*. There are now 41 such sidebars or case studies, especially in Chapter 16, "Wetland Ecosystem Services," and Chapter 18, "Wetland Creation and Restoration." New citations were added in this edition, with over 120 from 2010 or later, to augment some classics from the past. Many older citations, particularly those that would be hard to find, were eliminated.

On a personal note, I am pleased to write this edition of *Wetlands* from my new venue as director and professor at the Everglades Wetland Research Park of Florida Gulf Coast University, located at the Naples Botanical Garden in Naples Florida.

We could not have completed this edition without help from many friends and colleagues. Anne Mischo provided dozens more of new illustrations for *Wetlands 5* to supplement her beautiful work carried over from previous editions. We are honored to have the cover photo of a mangrove swamp from southwest Florida, on the fringe of the Florida Everglades, taken by a long-time friend and world-class birder Bernie Master. Ruthmarie Mitsch provided assistance in editing some parts of this edition. Li Zhang and Chris Anderson need to be especially thanked for the updates that they provided in *Wetland Ecosystems* that were used in this book. Li Zhang also helped on many technical details related to publishing the book. We also appreciate the input, illustrations, or insight provided by the following, listed in alphabetical order: Jim Aber, Andy Baldwin, Jim Bays, Jenny Davis, Frank Day, Max Finlayson, Brij Gopal, Glenn Guntenspergen, Wenshan He, Wolfgang Junk, David Latt, Pierrick Marion, Mike Rochford, Line Rochefort, Clayton Rubec, Kenneth Strait, and Ralph Tiner. We also appreciate the professional effort on the part of editors and assistants at Wiley & Sons, Inc. It has always been a pleasure to work with the Wiley brand.

Finally, you will note that there is only one author of this preface. My coauthor Jim Gosselink, Professor Emeritus of Louisiana State University, had been ill for several years and was unable to participate in this new edition. Jim died on January 18, 2015, at the age of 83. But his spirit and incredible knowledge of wetlands are embedded in this book from his contributions to the previous editions, so there was no question that his name should remain on the front of this book. I have also taken the liberty to dedicate this book to my long-time friend and coauthor Jim Gosselink.

William J. Mitsch, Ph.D.
Naples, Florida

February 2015

Part I

Introduction

Chapter 1

Wetlands: Human Use and Science

Wetlands are found in almost all parts of the world. They are sometimes referred to as "kidneys of the landscape" and "nature's supermarkets" to bring attention to the important ecosystem services and habitat values that they provide. Although many cultures have lived among and even depended on wetlands for centuries, the modern history of wetlands until the 1970s is fraught with misunderstanding and fear, as described in much of our Western literature. Wetlands have been destroyed at alarming rates throughout the developed and developing worlds. Now, as their many benefits are being recognized, wetland conservation has become the norm. In many parts of the world, wetlands are now revered, protected, and restored; in other parts, they are still being drained for human development.

Because wetlands have properties that are not adequately covered by current terrestrial and aquatic ecology paradigms, a case can be made for wetland science as a unique discipline encompassing many fields, including terrestrial and aquatic ecology, chemistry, hydrology, and engineering. Wetland management, as the applied side of wetland science, requires an understanding of the scientific aspects of wetlands balanced with legal, institutional, and economic realities. As awareness of the ecosystem services of wetlands has grown, so too have public interest for wetland protection, wetland science programs in universities, and publications about wetlands in scientific journals.

Wetlands are among the most important ecosystems on Earth. In the great scheme of things, the swampy environment of the Carboniferous period produced and preserved many of the fossil fuels on which our society now depends. In more recent biological and human time periods, wetlands have been valuable as sources, sinks, and transformers of a multitude of chemical, biological, and genetic materials. Although

the value of wetlands for fish and wildlife protection has been known for a century, some of the other benefits have been identified more recently.

Wetlands are sometimes described as kidneys of the landscape because they function as the downstream receivers of water and waste from both natural and human sources. They stabilize water supplies, thus mitigating both floods and drought. They have been found to cleanse polluted waters, protect shorelines, and recharge groundwater aquifers.

Wetlands also have been called nature's supermarkets because of the extensive food chain and rich biodiversity that they support. They play major roles in the landscape by providing unique habitats for a wide variety of flora and fauna. Now that we have become concerned about the health of our entire planet, wetlands are being described by some as important carbon sinks and climate stabilizers on a global scale.

These values of wetlands are now recognized worldwide and have led to wetland conservation, protection laws, regulations, and management plans. But our history before current times with wetlands had been to drain, ditch, and fill them, never as quickly or as effectively as was undertaken in countries such as the United States beginning in the mid-1800s. In some regions of the world that destruction of wetlands continues.

Wetlands have become the cause célèbre for conservation-minded people and organizations throughout the world, in part because they have become symptoms of our systematic dismantling of our water resources and in part because their disappearance represents an easily recognizable loss of natural areas to economic "progress." Scientists, engineers, lawyers, and regulators are now finding it both useful and necessary to become specialists in wetland ecology and wetland management in order to understand, preserve, and even reconstruct these fragile ecosystems. This book is for these aspiring wetland specialists as well as for those who would like to know more about the structure and function of these unique ecosystems. It is a book about wetlands—how they work and how we manage them.

Human History and Wetlands

There is no way to estimate the impact humans have had on the global extent of wetlands except to observe that, in developed and heavily populated regions of the world, the impact has ranged from significant to total. The importance of wetland environments to the development and sustenance of cultures throughout human history, however, is unmistakable. Since early civilization, many cultures have learned to live in harmony with wetlands and have benefited economically from surrounding wetlands, whereas other cultures quickly drained the landscape. The ancient Babylonians, Egyptians, and the Aztec in what is now Mexico developed specialized systems of water delivery involving wetlands. Major cities of the world, such as Chicago and Washington, DC, in the United States, Christchurch, New Zealand, and Paris, France, stand on sites that were once part wetlands. Many of the large airports (in Boston, New Orleans, and J. F. Kennedy in New York, to name a few) are situated on former wetlands.

While global generalizations are sometimes misleading, there was and is a propensity in Eastern cultures not to drain valuable wetlands entirely, as has been done in the West, but to work within the aquatic landscape, albeit in a heavily managed way. Dugan (1993) makes the interesting comparison between *hydraulic civilizations* (European in origin) that controlled water flow through the use of dikes, dams, pumps, and drainage tile, in part because water was only seasonally plentiful, and *aquatic civilizations* (Asian in origin) that better adapted to their surroundings of water-abundant floodplains and deltas and took advantage of nature's pulses, such as flooding. It is because the former approach of controlling nature rather than working with it is so dominant today that we find such high losses of wetlands worldwide.

Wetlands have been and continue to be part of many human cultures in the world. Coles and Coles (1989) referred to the people who live in proximity to wetlands and whose culture is linked to them as *wetlanders*.

Sustainable Cultures in Wetlands

Some of the original wetlander cultures are described here. The Marsh Arabs of southern Iraq (Fig. 1.1) and the Camarguais of southern France's Rhone River Delta (Fig. 1.2) are two examples of ancient cultures that have lived in harmony and sustainably with their wetland environments for centuries. In North America, the Cajuns of Louisiana and several Native Americans tribes have lived in harmony with wetlands for hundreds of years. The Louisiana Cajuns, descendants of the French colonists of Acadia (present-day Nova Scotia, Canada), were forced out of Nova Scotia by the English and moved to the Louisiana delta in the last half of the

Figure 1.1 The Marsh Arabs of present-day southern Iraq lived for centuries on artificial islands in marshes at the confluence of the Tigris and Euphrates rivers in Mesopotamia. The marshes were mostly drained by Saddam Hussein in the 1990s and are now being restored.

Figure 1.2 The Camargue region of southern France in the Rhone River Delta is a historically important wetland region in Europe where Camarguais have lived since the Middle Ages. (Photo by Tom Nebbia, reprinted with permission)

Figure 1.3 A Cajun lumberjack camp in the Atchafalaya Swamp of coastal Louisiana. (Photo courtesy of the Louisiana Collection, Tulane University Library, reprinted with permission)

eighteenth century. Their society and culture flourished within the bayou wetlands (Fig. 1.3). The Chippewa in Wisconsin and Minnesota have harvested and reseeded wild rice (*Zizania aquatica*) along the littoral zone of lakes and streams for centuries (Fig. 1.4). They have a saying: "Wild rice is like money in the bank."

Likewise, several Native American tribes lived and even thrived in large-scale wetlands, such as the Florida Everglades. These include the ancient Calusa, a culture that based its economy on estuarine fisheries rather than agriculture. The Calusa disappeared primarily as a result of imported European disease. In the nineteenth century, the Seminoles and especially one of its tribes, the Miccosukee, moved south to the Everglades while being pursued by the U.S. Army during the Seminole Indian wars. They never surrendered. The Miccosukee adapted to living in hammock-style camps

Figure 1.4 "Ricer" poling and "knocking" wild rice (*Zizania aquatica*) into canoes as Anishinaabe (Chippewa, Ojibwe) tribes and others have done for hundreds of years on Rice Lake in Crow Wing County, Minnesota. (Photo by John Overland, reprinted with permission)

spread throughout the Everglades and relied on fishing, hunting, and harvesting of native fruits from the hammocks (Fig. 1.5). A recent quote in a Florida newspaper by Miccosukee tribal member Michael Frank is poignant yet hopeful about living sustainably in the Florida Everglades:

> We were taught to never, ever leave the Everglades. If you leave the Everglades you will lose your culture, you lose your language, you lose your way of life.
>
> **—Michael Frank, as quoted by William E. Gibson, "Pollution Is Killing Everglades, Miccosukee Warn," *South Florida Sun Sentinel*, August 10, 2013**

Literary References to Wetlands

With all of these important cultures vitally depending on wetlands, not to mention the aesthetics of a landscape in which water and land often provide a striking panorama, one might expect wetlands to be more respected by humanity; this has certainly not always been the case. Wetlands have been depicted as sinister and forbidding and as having little economic value throughout most of Western literature and history. For example, in the *Divine Comedy*, Dante describes a marsh of the Styx in Upper Hell as the final resting place for the wrathful:

> Thus we pursued our path round a wide arc of that ghast pool,
> Between the soggy marsh and arid shore,
> Still eyeing those who gulp the marish [marsh] foul.

Figure 1.5 The Miccosukee Native Americans adapted to life in the Florida Everglades in hammock-style camps. They relied on fishing, hunting, and harvesting of native fruits from the hammocks. (Photo by W. J. Mitsch of panorama at Miccosukee Indian Village, Florida Everglades)

Centuries later, Carl Linnaeus, crossing the Lapland peatlands in 1732, compared that region to that same Styx of Hell:

> Shortly afterwards began the muskegs, which mostly stood under water; these we had to cross for miles; think with what misery, every step up to our knees. The whole of this land of the Lapps was mostly muskeg, hinc vocavi Styx. Never can the priest so describe hell, because it is no worse. Never have poets been able to picture Styx so foul, since that is no fouler.

In the eighteenth century, an Englishman who surveyed the Great Dismal Swamp on the Virginia–North Carolina border and is credited with naming it described the wetland as

> [a] horrible desert, the foul damps ascend without ceasing, corrupt the air and render it unfit for respiration . . . . Never was Rum, that cordial of Life, found more necessary than in this Dirty Place.
>
> **—Colonel William Byrd III, "Historie of the Dividing Line Betwixt Virginia and North Carolina," in *The Westover Manuscripts*, written 1728–1736 (Petersburg, VA: E. and J. C. Ruffin, printers, 1841)**

Even those who study and have been associated with wetlands have been belittled in literature:

> Hardy went down to botanise in the swamp, while Meredith climbed towards the sun. Meredith became, at his best, a sort of daintily dressed Walt Whitman: Hardy

> became a sort of village atheist brooding and blaspheming over the village idiot.
>
> **—G. K. Chesterton, Chapter 12 in *The Victorian Age in Literature* (New York, NY: Henry Holt and Company, 1913)**

The English language is filled with words that suggest negative images of wetlands. We get *bogged down* in detail; we are *swamped* with work. Even the mythical *bogeyman*, the character featured in stories that frighten children in many countries, may be associated with European bogs. Grendel, the mythical monster in *Beowulf*, one of the oldest surviving pieces of Old English literature and Germanic epic, comes from the peatlands of present-day northern Europe:

> Grendel, the famous stalker through waste places, who held the rolling marshes in his sway, his fen and his stronghold. A man cut off from joy, he had ruled the domain of his huge misshapen kind a long time, since God had condemned him in condemning the race of Cain.
>
> **—*Beowulf*, translated by William Alfred, *Medieval Epics* (New York, NY: The Modern Library, 1993)**

Hollywood has continued the depiction of the sinister and foreboding nature of wetlands and their inhabitants, in the tradition of Grendel, with movies such as the classic *Creature from the Black Lagoon* (1954), a comic-book-turned-cult-movie *Swamp Thing* (1982), and its sequel *Return of the Swamp Thing* (1989). Even Swamp Thing, the man/monster depicted in Figure 1.6, evolved in the 1980s from a feared creature to a protector of wetlands, biodiversity, and the environment. A more modern approach to scaring and entertaining the public with megafauna from the swamps is a science fiction movie *Mega Python vs. Gatoroid* (2011) that is set in the Florida Everglades (Fig. 1.7). The movie exaggerates much of the current dynamics about the Florida Everglades including conservation, invasive species, genetically altered organisms, fund-raising by conservationists, and conflicts among hunters, conservation agencies, and environmentalists. In some respects, current life in the Everglades imitates art. Big snakes and alligators from wetlands continue to strike fear.

As long as wetlands remain more difficult to stroll through than a forest and more difficult to cross by boat than a lake, they will remain misunderstood by the general public unless a continued effort of education takes place.

Food from Wetlands

Domestic wetlands such as rice paddies feed an estimated half of the world's population (Fig. 1.8). Countless other plant and animal products are harvested from wetlands throughout the world. Many aquatic plants besides rice, such as Manchurian wild rice (*Zizania latifolia*), are harvested as vegetables in China. Cranberries are harvested from bogs, and the industry continues to thrive today in North America (Fig. 1.9). Coastal marshes in northern Europe, the British Isles, and New England were used for centuries and are still used today for grazing of animals and production of salt hay. Salt marsh coastlines of Europe are still used for the production of salt.