Wetlands and Climate Change

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NCSR curriculum modules are designed as comprehensive instructions for students and supporting materials for faculty. The student instructions are designed to facilitate adaptation in a variety of settings. In addition to the instructional materials for students, the modules contain separate supporting information in the "Notes to Instructors" section, and when appropriate, *PowerPoint* slides. The modules also contain other sections which contain additional supporting information such as assessment strategies and suggested resources.

Acknowledgements

We thank Tom Robertson of Portland Community College and David Lonsdale of Chemeketa Community College for their thoughtful reviews. Their comments and suggestions greatly improved the quality of this module. We thank NCSR administrative assistant, Liz Traver, for the review, graphic design and layout of this module. Carla Cudmore located appropriate photographs and figures for this module and obtained permission for their use.

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NCSR *Wetland Ecology and Management Series*
Introduction

Wetlands are among the most productive ecosystems on earth, and as such, provide countless ecological and economic benefits to humans. Management of this valuable resource is complex and represents an opportunity to approach the nature and management of a natural resource from several different perspectives in natural resource or environmental science programs. The NCSR *Wetland Ecology and Management Series* is designed to support the instruction of wetlands topics at the undergraduate level. It is modular in nature and instructors can pick and choose some topics for coverage and de-emphasize or ignore others. Thus, these curriculum materials are designed to meet a variety of instructional needs and strategies. The NCSR *Wetland Ecology and Management Series* is comprised of the following modules:

- ***Wetlands – An Introduction***

This module characterizes the wetlands resource and introduces students to wetlands as ecosystems and to the rationale for wetlands management. Wetland functions and values are also described.

- ***Wetlands – Then and Now***

This module describes the current status of wetlands and compares that to their place in history. Wetland types, classification schemes and causes for wetland loss and degradation are also discussed.

- ***Wetlands Management I – Determination and Delineation***

This module introduces wetlands management and describes wetland determination and delineation as first steps in wetland management projects. A field activity is included that engages students in the essential elements of wetland determination and delineation.

- ***Wetlands Management II – Compensatory Mitigation***

This module introduces the concept of compensatory mitigation and evaluates its effectiveness as a strategy for managing the wetland resource. A wetland mitigation field activity is included that describes how instructors can identify appropriate local wetland mitigation sites and how to organize a mitigation tour.

- ***Wetlands and Climate Change***

This module describes the complex relationship between wetlands and climate change.

- ***Wetlands and Hurricanes***

This module examines the impact of hurricanes on wetlands as well as the role of wetlands in the protection of coastal areas.

- ***Wetland Restoration in the Everglades***

This module uses restoration efforts in south Florida as a case study of wetland restoration.

Each module includes a lecture outline, *PowerPoint* presentation and detailed instructor notes. Modules with field-based activities also include student handouts, detailed procedures, data sheets and notes to instructors. In addition to the presentations and field activities described above, complete citations and brief summaries of relevant web, print and video resources are provided that can be used to:

- Enhance existing lecture topics
- Develop lectures on new topics
- Develop geographically relevant case studies
- Update wetlands statistics
- Select articles for student reading
- Access video and photos for presentation purposes

Intended audience

The NCSR *Wetland Ecology and Management Series* is intended to provide instructional support for undergraduate education at the freshman/sophomore level. Technical programs that include wetlands topics such as Wetlands Management, Civil Engineering and Biological Technician programs will find the modules to be a useful introduction to wetlands science and management. The materials are not designed to provide the training that is required by individuals to become certified wetland delineators or other types of wetlands technicians, as these curriculum materials and mechanisms for their delivery are available elsewhere. Also, NCSR wetlands materials are not designed for K-12 as a number of efforts have addressed wetlands for this level. In addition to providing background for those who will work with wetlands in their profession, NCSR materials also provide the background and context for students in other undergraduate programs. The materials may generate interest in some to pursue wetlands management as a career, but more importantly will result in an informed citizenry on wetlands issues. It is hoped that a more informed public will gather support for wetland conservation efforts as they occur in their local communities and help build a greater understanding of their importance.

The need for an undergraduate wetlands curriculum

Recent interest in wetlands as a valuable and dwindling resource has resulted in a large and growing volume of wetlands-related curriculum. However, the vast majority of these wetlands education resources target audiences other than first- and second-year college students. The K-12 audience, for example, has been well-served by efforts such as Project WET (Slattery and Kesselheim, 2003). The demand for training of wetlands delineators and those with expertise in wetland mitigation has driven the development of a number of continuing education classes that teach this material. The intended audience is those who are in the wetlands profession who seek the proper certification to conduct these activities. Examples include:

The Ohio State University
Olentangy River Wetland Research Park
www.swamp.osu.edu

North Carolina State University
Forestry and Environmental Outreach Program (FEOP)
http://www.ces.ncsu.edu/nreos/forest/feop/

Portland State University
Environmental Professional Program
http://epp.esr.pdx.edu/

The Swamp School
www.swampschool.org

Some degree programs at 4-year colleges and universities include courses in wetland ecology and management. However, the majority are taught at the graduate level and curriculum materials are not widely available for use outside of those institutions.

Thus, there appears to be a lack of classroom-ready materials and resources available for **undergraduate courses** that include some coverage of wetlands topics and form a bridge between the various wetlands curriculum materials described above. The NCSR *Wetland Ecology and Management Series* is designed to fill that void.

Guidelines for use

The manner in which instructors use the modules in this series will depend upon:

- The course in which the module will be used

The wetland mitigation modules are most appropriate for inclusion in undergraduate courses such as *Environmental Science, Introduction to Natural Resources, Wetlands Ecology* and *Introduction to Wetlands Management*. Parts of the modules may also have application in courses with a broader scope such as *General Ecology* and *General Biology*.

- The background of the students

The wetland mitigation modules assume some basic understanding of basic ecology including populations, communities and ecosystem structure and function. The treatment of ecology in either a college- or high school-level general biology course should be sufficient. Instructors may need to provide additional background to students who are not familiar with this material.

- The time that will be dedicated to the study of wetlands

There is sufficient information and resources in the wetlands mitigation modules to present anything from a single one-hour lecture to a significant portion of a full semester-long or quarter-long course. Instructors may select from the various components depending on course objectives and the amount of time allocated for wetlands topics.

A note on wetland field and laboratory experiences

The NCSR *Wetland Ecology and Management Series* emphasizes lecture support for instructors who are looking for wetlands material to insert into their courses. Although classroom lectures and discussions are a necessary element of a course that deals with wetlands issues, field and laboratory experiences enhance the learning experience and allow the instructor to explore topic areas that are not easily covered in the classroom. Additionally, students are more likely to become engaged in the topic when they can experience it firsthand.

Field activities may include a wide variety of experiences ranging from "tours" of various wetland types and restoration or mitigation projects to investigative experiences where students are actively engaged in the "scientific process."

Types of field activities (adapted from Baldwin, 2001):

- Field identification of wetland plants
- Preparation of plant collections using standard herbarium techniques
- Field identification of wetland animals
- Estimates of animal diversity and abundance (e.g., collection of invertebrates in soil litter samples, mammal livetrapping, amphibian surveys)
- Vegetation sampling methods (e.g., qualitative, line-intercept, transect, quadrat sampling)
- Analysis of wetland plant diversity and abundance
- Determination of hydric soils indicators
- Determination of site hydrology

Details of these methods are beyond the scope of this series and have been well-documented elsewhere in field and laboratory manuals designed for college-level courses. See resources below for some examples.

RESOURCES

Baldwin, A.H. 2001. Got mud? Field-based learning in wetland ecology. Journal of College Science Teaching 31:94-100.

O'Neal, L.H. 1995. Using wetlands to teach ecology and environmental awareness in general biology. American Biology Teacher 57:135-139.

Slattery, B.E. and A.S. Kesselheim. 2003. WOW! The wonders of wetlands: An educator's guide. Environmental Concern, Inc., St. Michaels, MD and The Project WET International Foundation, Bozeman, MT. 348 pp.

Wetlands and Climate Change *Module Description*

This instructional guide is designed to provide instructors with lecture materials and resources that examine the relationship between wetlands and global climate change. Student objectives, a general lecture outline and a more detailed *PowerPoint* presentation with instructor notes are provided. The role of wetlands in global carbon budgets and as sources and sinks of greenhouse gases is discussed. Anticipated impacts of climate change on both coastal and inland wetlands are also presented. Instructors who are looking for videos or additional print and web-based resources on the topics covered here should consult the resources list provided at the end of this module where these resources are summarized and cited.

Objectives

Upon successful completion of this module, students should be able to:

1. Describe the importance of wetlands as sources and sinks of greenhouse gases
2. Describe the impacts of wetlands on global climate change
3. Describe the impacts of global climate change on both coastal and inland wetlands
4. Describe how carbon trading has been applied to wetlands

Wetlands and Climate Change - General Lecture Outline

I. The climate – wetlands connection
   A. Evidence of climate change
   B. Wetlands role in global carbon budget
   C. Wetlands as sinks and sources of greenhouse gases
II. Impact of wetlands on climate change
   A. Wetlands as a source of methane
   B. Wetlands as carbon stores
   C. The role of disturbance
III. Impact of climate change on wetlands
   A. Impacts on coastal wetlands
      1. Effects of sea level rise
      2. Chesapeake Bay as an example
      3. Shrimp production as an example
   B. Impacts on inland wetlands
      1. Effects of increasing temperature
      2. Prairie Pothole Region as an example
      3. Forested wetlands as an example
IV. Carbon trading in wetlands

PowerPoint Presentation with Instructor Notes

Wetlands and Climate Change

By Wynn W. Cudmore, Ph.D.

Northwest **C**enter for **S**ustainable **R**esources

DUE # 0757239

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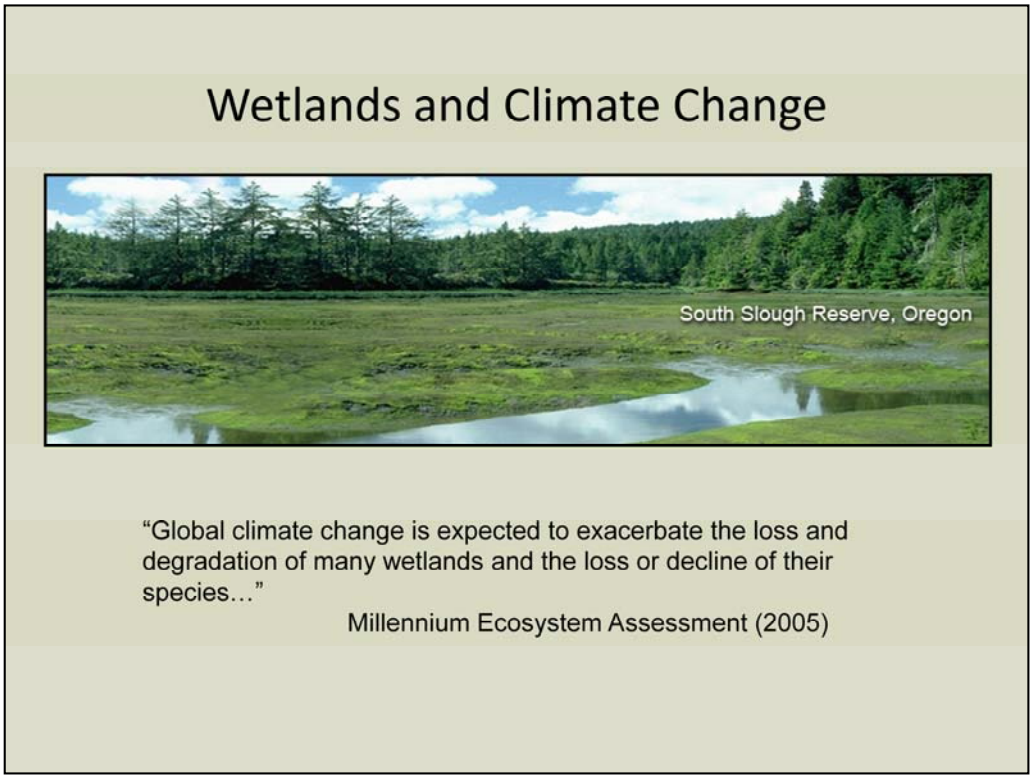


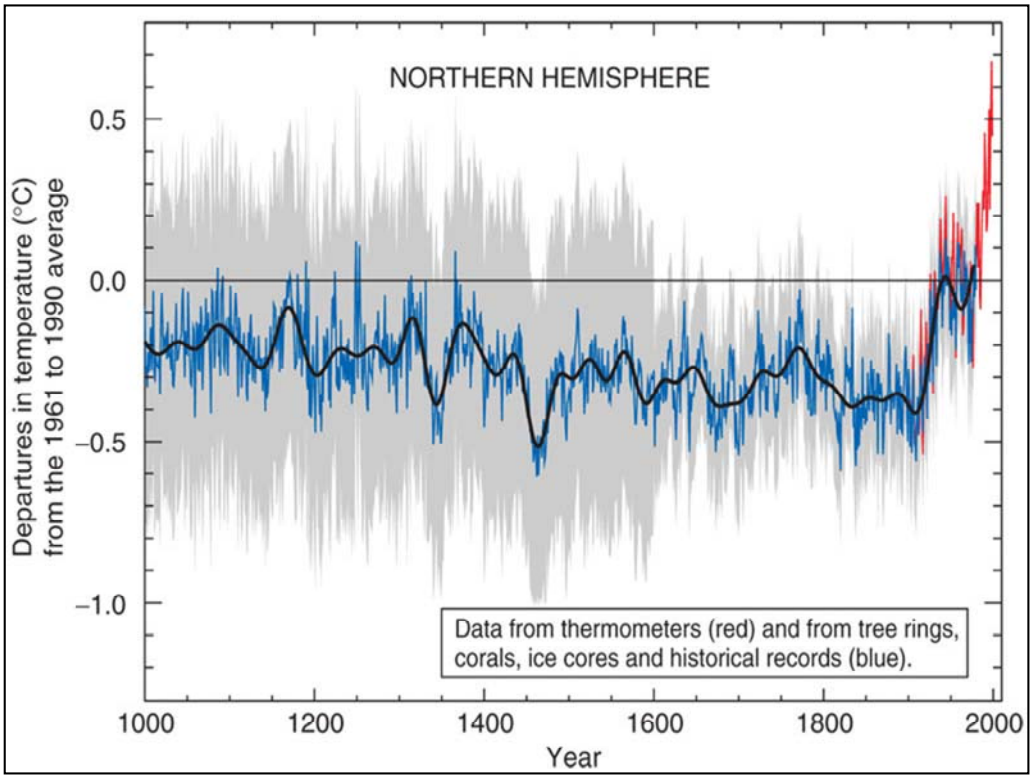
It is now generally accepted among climate scientists that the earth's climate is warming and that human activities, especially fossil fuel use and deforestation, are the primary drivers of that change. Climate change is caused primarily by a disruption to the global carbon cycle in which the accumulation of greenhouse gases such as carbon dioxide and methane are accumulating in the atmosphere at a rate that exceeds the ability for that carbon to be sequestered. As a result, greenhouse gases accumulate. Currently, more than 80% of global energy production is generated by burning fossil fuels, producing more than 24 gigatons of carbon dioxide every year. As a result, atmospheric CO_2 concentrations have risen from 295 parts per million (ppm) to 380 ppm over the last 100 years.

Wetlands play a significant role in global carbon budgets both as sources and sinks for greenhouse gases. Their role in climate change is an active area of research.

sequester – remove and store elsewhere; in this context, CO_2 is being removed from the atmosphere and stored in other reservoirs (e.g., as carbohydrate in plants)

gigaton – one billion (10^9) tons

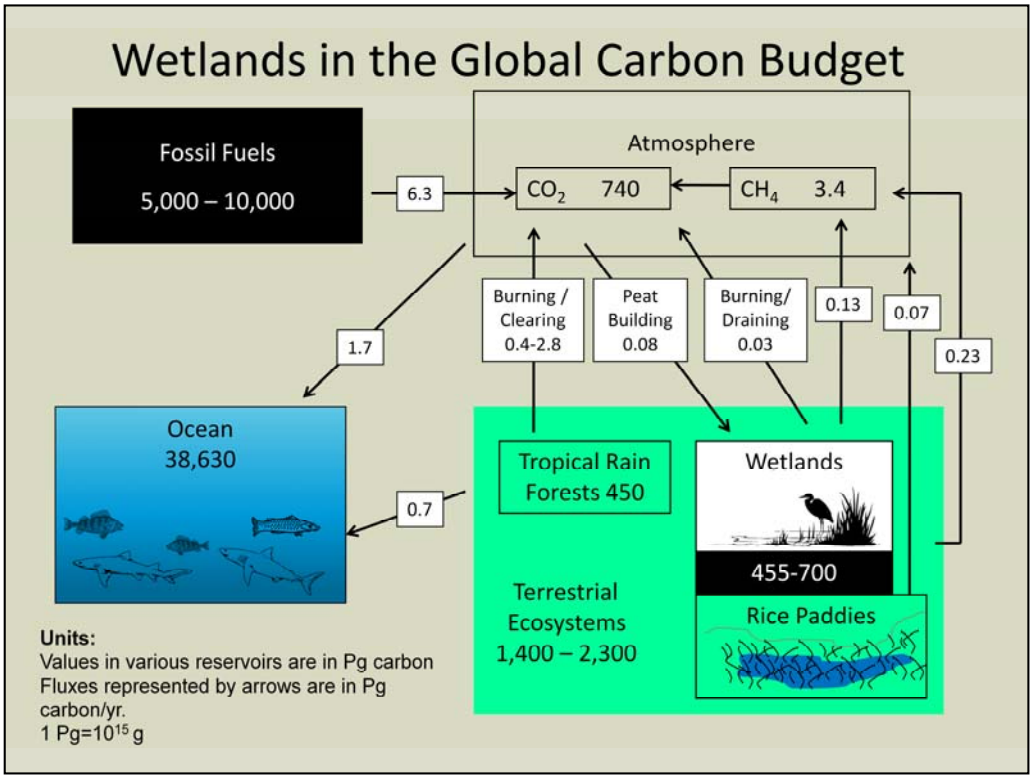
Photo credit: National Estuarine Reserve Research System, National Oceanic and Atmospheric Administration/Department of Commerce



Evidence for increases in global temperature comes from a number of different data sources. Proxy measurements for temperature, such as tree rings, corals, ice cores and various historical records provide historical estimates (in blue). Direct measurement (in red) provides more recent estimates of global temperature.

proxy – a substitute; in this sense, indicators that are known to be influenced by temperature change

Image credit: Wikipedia



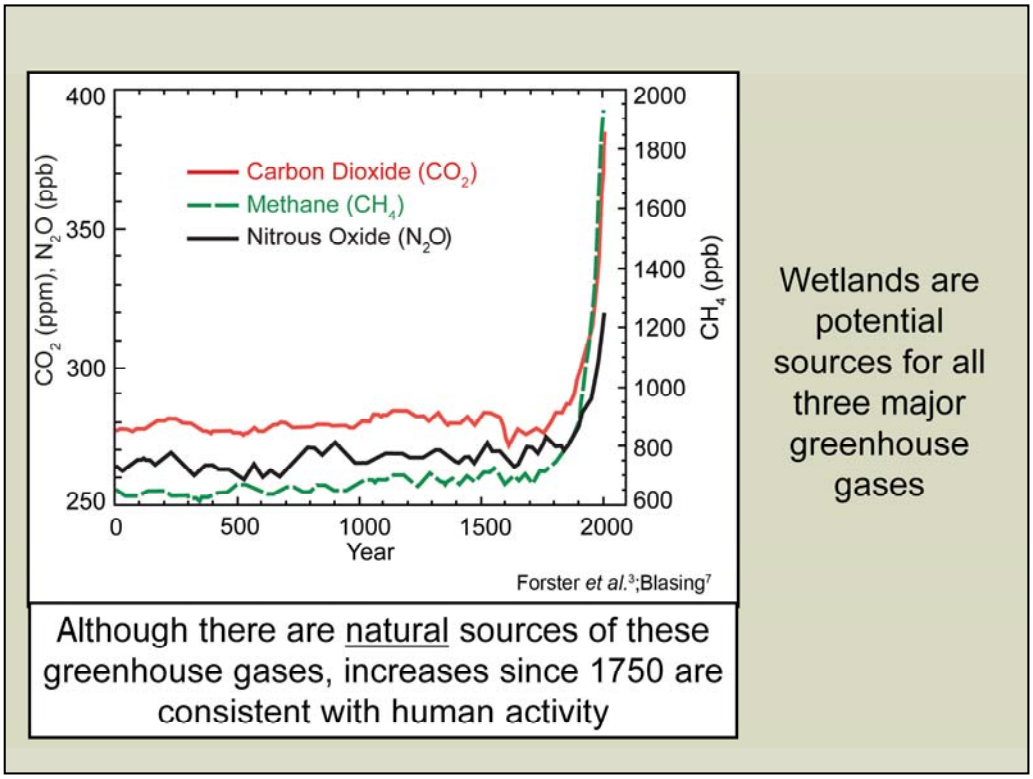
Where do wetlands fit into global carbon budgets?

The figure above illustrates the global carbon budget. The various **reservoirs** of carbon storage (including wetlands) are represented by the squares and rectangles. Transfers (**fluxes**) from one reservoir to another are represented by arrows. The units of carbon storage are petagrams (1 Pg = 10^{15} g) and fluxes are in Pg carbon per year. The important points are as follows:

1. At 455-700 Pg, wetlands (mostly as peat soils) are a significant portion (20-30%) of the total amount of carbon stored in the world's soils
2. The peat building rate (see arrow) is 0.08 Pg carbon/year, which is only 1.3% of the 6.3 Pg carbon/year released due to human fossil fuel burning.
3. The estimated rate of CO_2 release from wetland soils is 0.03 Pg carbon/year (see arrow). Due to the large peat deposits present in wetland soils, if disturbed (harvested, burned, drained or decomposed) this rate could increase substantially. This would contribute significantly to global atmospheric carbon dioxide levels.
4. Wetlands emit about 20-25% of current global methane (CH_4) emissions – 0.13 Pg per year from natural wetlands and an additional 0.07 Pg per year from rice paddies (see arrows).

Since wetlands both store carbon and release greenhouse gases (methane and carbon dioxide), the question is often raised - "Are intact wetlands 'good' or 'bad' for climate change?" Attempts to answer the question have been made by climate scientists and wetland ecologists, but their calculations are necessarily fraught with many approximations and assumptions. Those who have been brave enough to offer an answer suggest that, all things considered, wetlands are either climate neutral or climate positive.

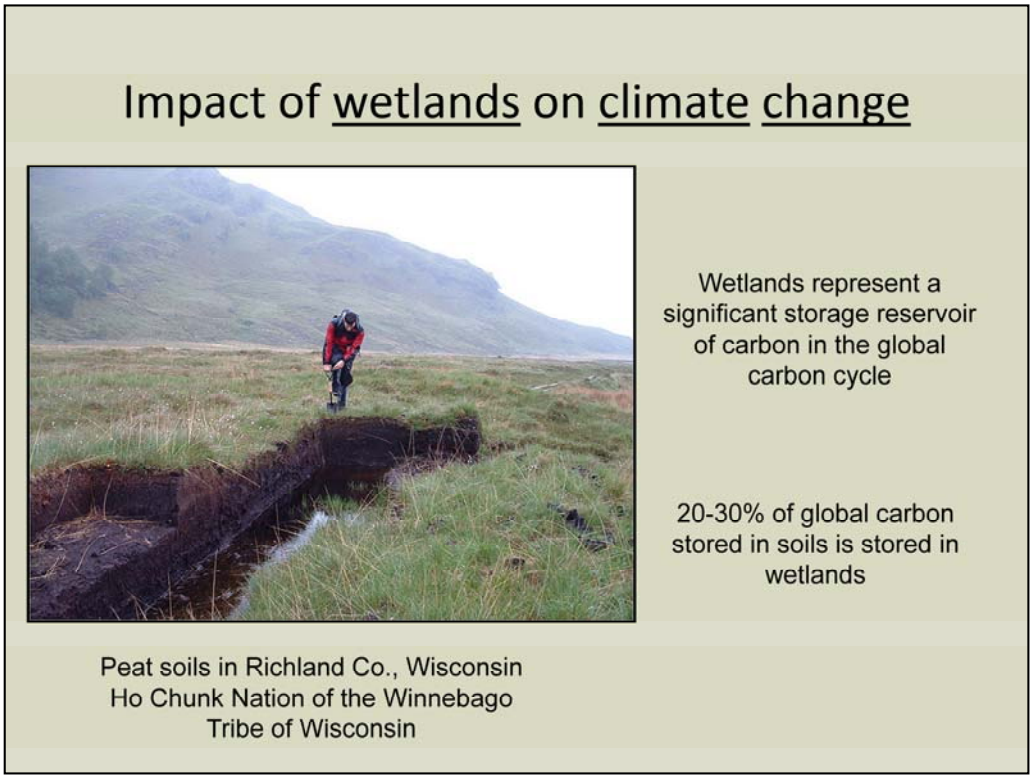
Image credit: Adapted from Mitsch and Gosselink (2007)



Second to CO_2, methane is an important greenhouse gas of anthropogenic origin. Increases in atmospheric carbon dioxide concentration have been well-studied and have been reported elsewhere. Methane has not received as much attention. Methane concentrations have more than doubled since pre-industrial times – from an estimated 700 ppb to about 1774 ppb in 2005. Since wetlands are a source of methane (as described earlier), wetlands might be cited as a contributor to global climate change. However, if we have witnessed over a 50% decrease in wetlands since the late 1700s while methane concentrations have increased over that same time frame, clearly the increase in methane levels cannot be due to wetlands and other sources must be identified.

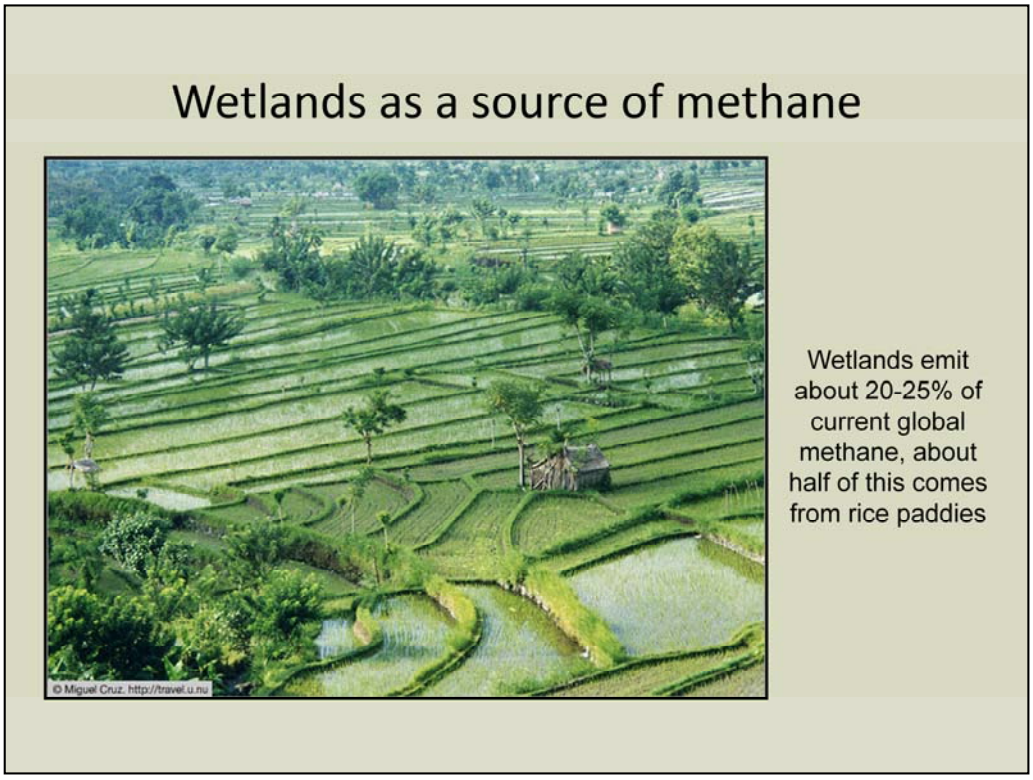
Wetlands also produce nitrous oxide (N_2O), which is also a greenhouse gas. N_2O is produced as a byproduct of the denitrification process and has increased about 16% since 1780.

Image credit: U.S. Global Change Research Program (www.globalchange.gov).



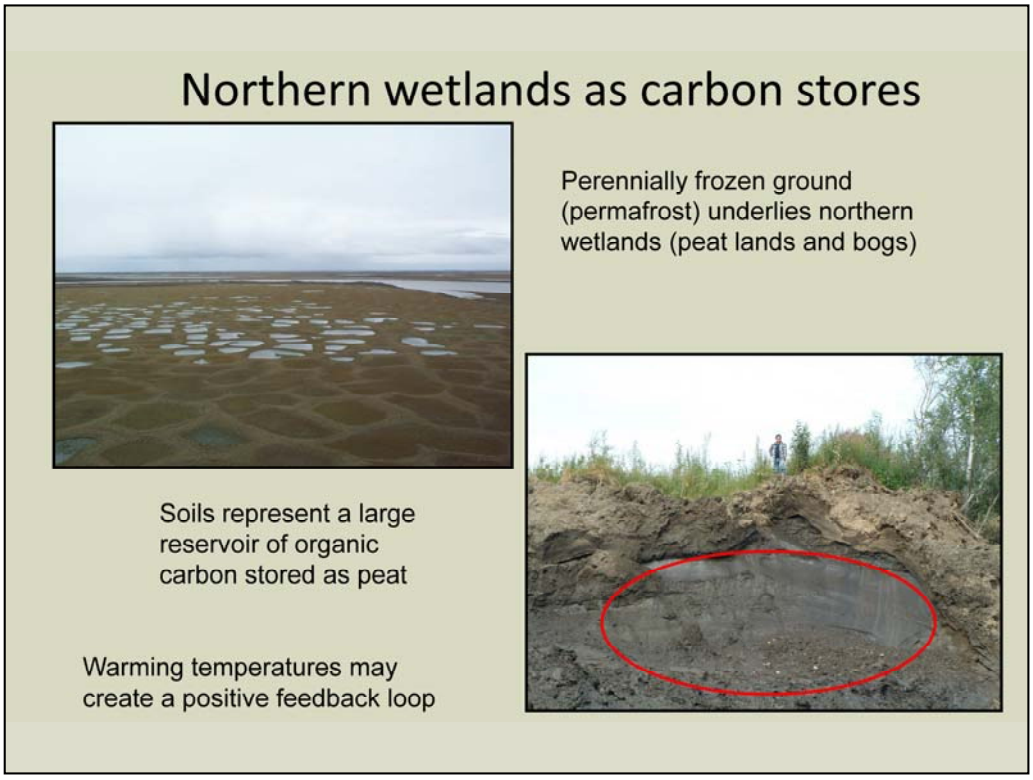
Wetlands represent a significant storage reservoir of carbon in the global carbon cycle. Of the total storage of carbon in the earth's soils (1400-2300 Pg, where 1 Pg=10^{15} g), about 20-30% is stored in wetlands, much as peat in wetland soils. About 0.08 Pg/year are stored as peat in wetlands, a small percent of the 6.3 Pg/year that are produced by humans. Disturbance of peat deposits can influence global carbon budgets – combustion and oxidation of peat deposits and drainage of wetlands also can release carbon back into atmosphere (could be 45-89% of the carbon being sequestered by wetlands). Created and restored wetlands have the potential to play an important role in carbon sequestration. Rates of 180-190 g C/m^2/yr have been reported for created wetlands in Ohio.

Image credit: Natural Resource Conservation Service. Peat soils in Richland County, Wisconsin. Ho Chunk Nation of the Winnebago Tribe of Wisconsin



Wetlands emit about 20-25% of current global methane, about half of this comes from rice paddies (a form of man-made wetlands). Although in lower concentrations than CO_2, methane is a concern in global climate change because it is far more effective as a greenhouse gas. By some accounts methane is 12X more effective than CO_2. However, it does break down more rapidly in the atmosphere than CO_2. Rates of methane release vary widely depending on wetland type.

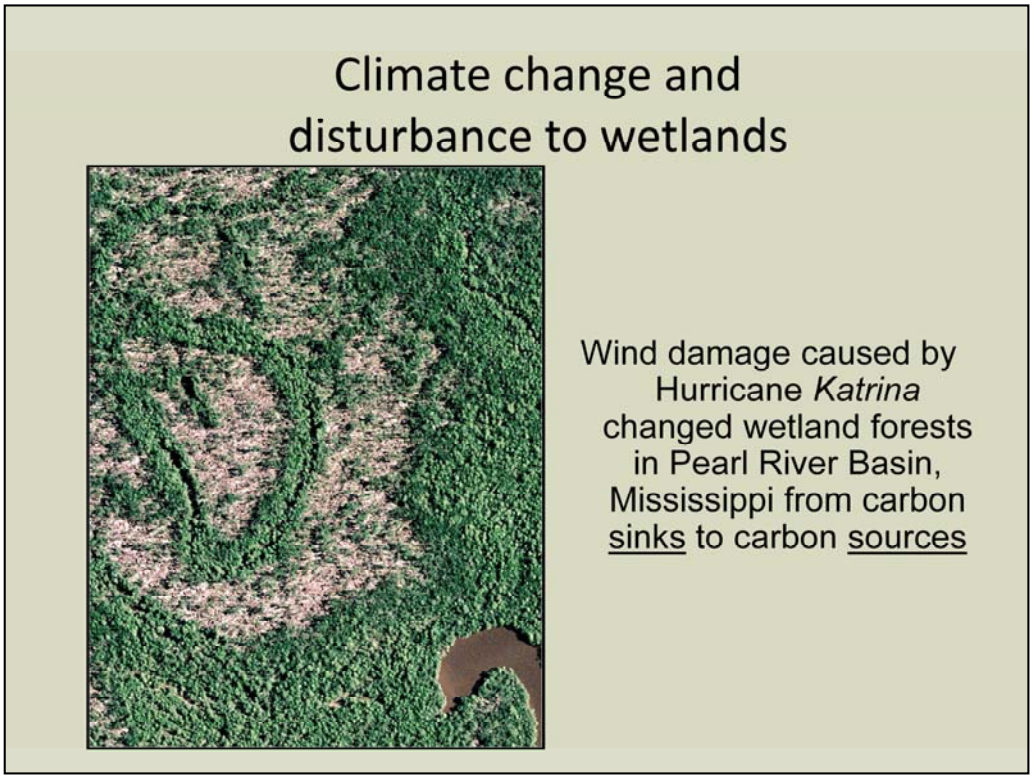
Image credit: Miguel Cruz



In northern latitudes, perennially frozen ground (permafrost) underlies wetlands such as northern peat lands and bogs. Global climate models project future warming to be strongest in these regions, with some models predicting a 7-8 C warming by the end of the 21st century. Due to the large reservoir of organic carbon (stored as peat) in these soils, warming temperatures have the potential to create a positive feedback loop in which warming temperatures thaw large stores of carbon, which are acted upon by microbes to release more carbon (as both carbon dioxide and methane), driving further warming. Schuur, et al. (2008) evaluated the implications of climate change to the carbon store in permafrost and the global carbon cycle. They conclude that the thawing of permafrost exposes organic carbon to increased microbial decomposition. Although there are other processes that increase carbon uptake and sequestration in a warming scenario (e.g., increased growing season length, increased plant growth rates) these processes apparently will not compensate for carbon release from thawing permafrost. The authors conclude that the net effect of widespread permafrost thawing will be a positive feedback loop that results in a warmer climate.

In addition to thawing and decomposition, warming and drying in peatlands raises the potential for peat fires. The release of carbon dioxide from extensive peat fires has the potential for another positive feedback loop in which global climate change increases the amount of carbon dioxide which in turn increases the effects of global climate change.

Photo credit (both images): Photos courtesy of Vladimir Romanovsky



See notes slide 9 (page 19)

Photo credit: Louisiana State University

Notes slide 9 (page 19)

Disturbances to wetlands can have an impact on carbon budgets. When Hurricane Katrina hit the Gulf Coast in 2005, vast areas of wetland forests dominated by baldcypress and water tupelo were impacted by the high winds. Researchers at Tulane University and the University of New Hampshire estimated that the hurricane destroyed or severely damaged some 320 million large trees, thus changing the role that many Gulf Coast forests play in the global carbon budget.

Forests differ in their ability to store carbon. Young and growing forests, such as those that had flourished along the Gulf Coast, are particularly effective in pulling carbon dioxide from the air and storing it as carbohydrates in plant tissues and soils. Young, rapidly growing forests, thus act as carbon sinks. After a disturbance like a hurricane, millions of trees are killed and branches and trunks are broken. Photosynthesis slows and less carbon dioxide is extracted from the atmosphere. In addition, bacteria and fungi decompose the dead vegetation, releasing large amounts of carbon dioxide into the atmosphere. Large scale disturbances like hurricanes have the potential to convert wetland forests from carbon sinks to carbon sources. Researchers estimated that the carbon released by Gulf Coast forests after Hurricane Katrina approximated 60 to 100 percent of the carbon stored by all the forests in the United States in an average year.

An interesting consideration:

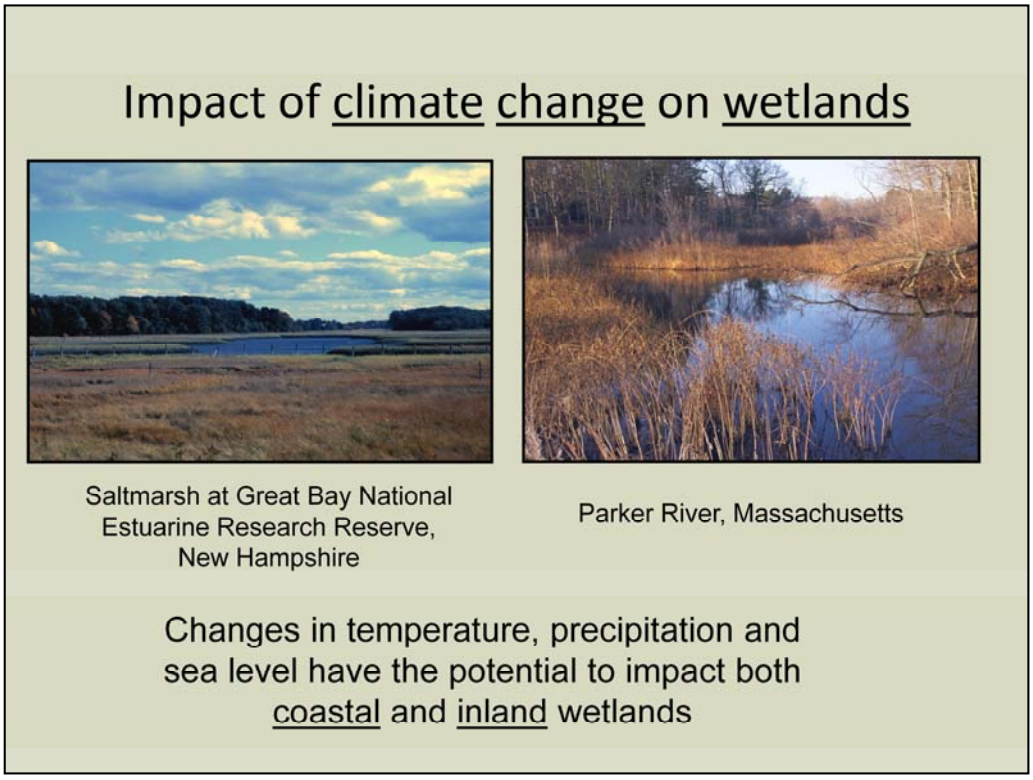
The relationship described here has the potential to cause a positive feedback loop in which warming temperatures caused by greenhouse gas emissions increase the likelihood of more powerful storms. As storm-damaged forests release more carbon into Earth's atmosphere, global warming is enhanced.

References

Chambers, J.Q., Fisher, J.I., Zheng, H., Chapman, E.L. Baker, D.B., and Hurtt, G.C. (2007). Hurricane Katrina's carbon footprint on U.S. Gulf Coast forests. *Science*, 318(5853): 1107. doi:10.1126/science.1148913.

Cook-Anderson, G. (2007, November 15) Forests damaged by Hurricane Katrina become major carbon source. NASA. Accessed December 28, 2007.

Pearl River Basin. U.S. Geological Survey. Accessed December 28, 2007.

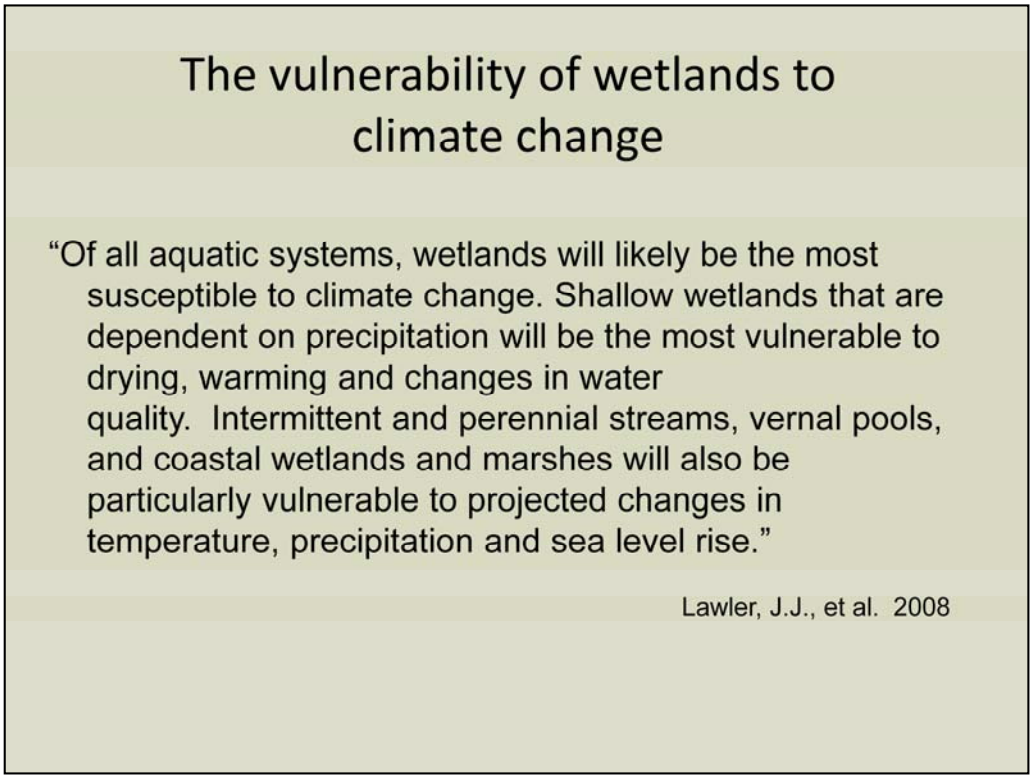


Temperature, precipitation and sea level changes have the potential to impact wetlands – both coastal and inland.

Photo credits:

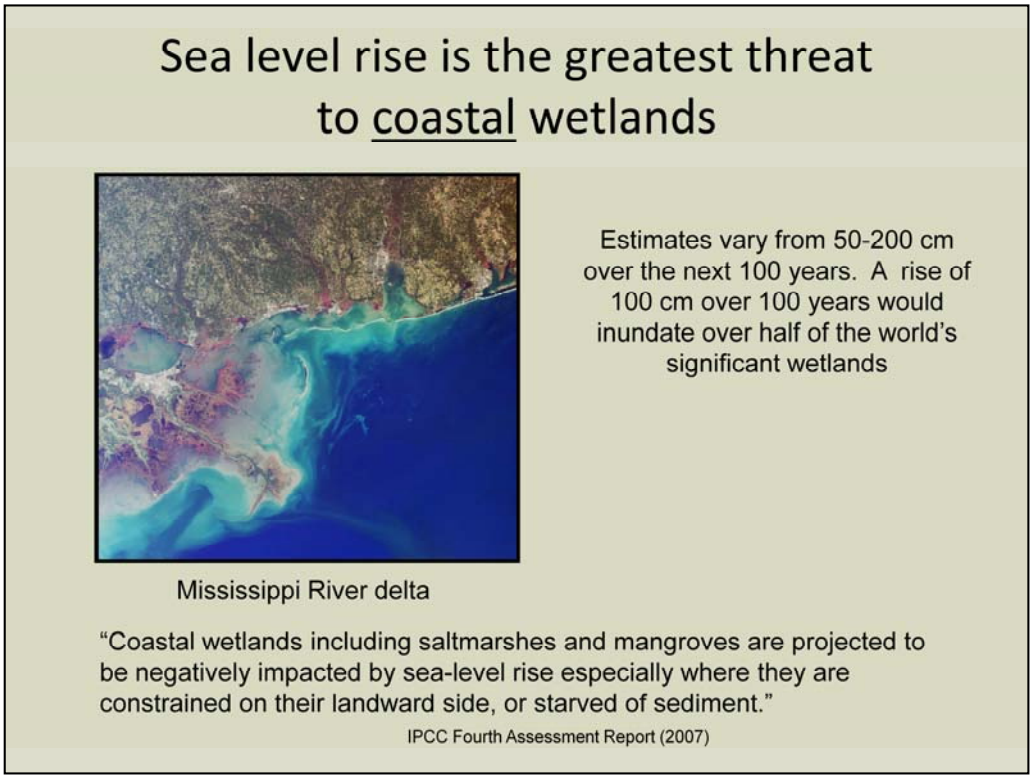
Left – saltmarsh: Sean Linehan, National Oceanic and Atmospheric Administration/Department of Commerce

Right – Park River: Louise Kane, National Oceanic and Atmospheric Administration/Department of Commerce, Restoration Center.



Climate change is perhaps the greatest challenge facing wetland managers because "Of all aquatic systems, wetlands will likely be the most susceptible to climate change. Shallow wetlands that are dependent on precipitation will be the most vulnerable to drying, warming and changes in water quality. Intermittent and perennial streams, vernal pools, and coastal wetlands and marshes will also be particularly vulnerable to projected changes in temperature, precipitation and sea level rise."

Lawler, J.J., et al. 2008



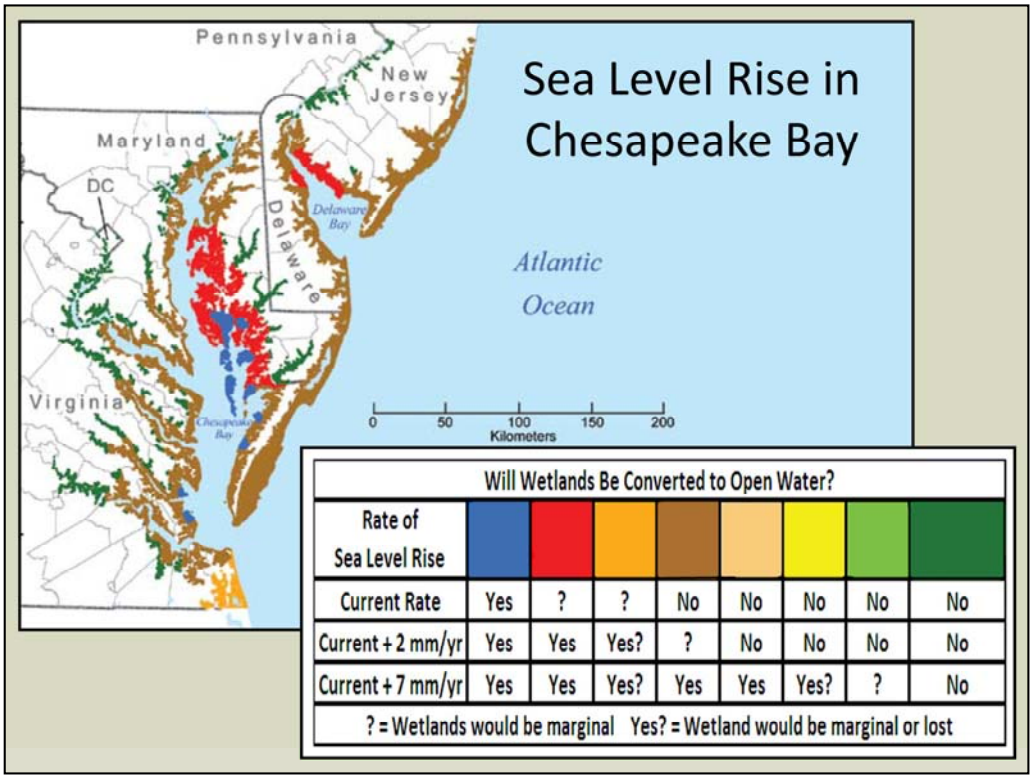
Sea level rise is the greatest threat to coastal wetlands. The Mississippi River Delta, already an area of wetland loss due to subsidence, is typical of those areas likely to be most affected.

Estimates of sea level rise range from 50-200 cm over the next 100 years. If sea levels rise 100 cm over 100 years, half of the world's significant wetlands would be inundated and lost. For coastal marshes, if sea levels rise at a rate that exceeds the accumulation of substrate (marsh sediments) then coastal wetlands break down due to inundation, erosion and intrusion by salt water. Also, human structures put coastal wetlands in a "coastal squeeze." Since many of the coastal areas are dominated by human efforts to protect upland areas (dikes, sea walls, bulkheads, development, etc.) coastal wetlands are trapped between a rising sea and protected dry land. Thus, the rate of loss of coastal wetlands will be determined by both the rate of seal level rise and the degree to which the upland areas are protected. These protections are likely to increase as anticipation of and the reality of sea level rise becomes apparent. Comprehensive long-range planning will be required to mitigate the effects of sea level rise on both human structures and natural wetlands.

In their most recent assessment of the risk that climate change presents to coastal wetlands, the International Panel on Climate Change states that:

"Coastal wetlands including saltmarshes and mangroves are projected to be negatively impacted by sea-level rise especially where they are constrained on their landward side, or starved of sediment."
IPCC Fourth Assessment Report (2007)

Image credit: Image courtesy NASA/GSFC/LaRC/JPL, MISR Team

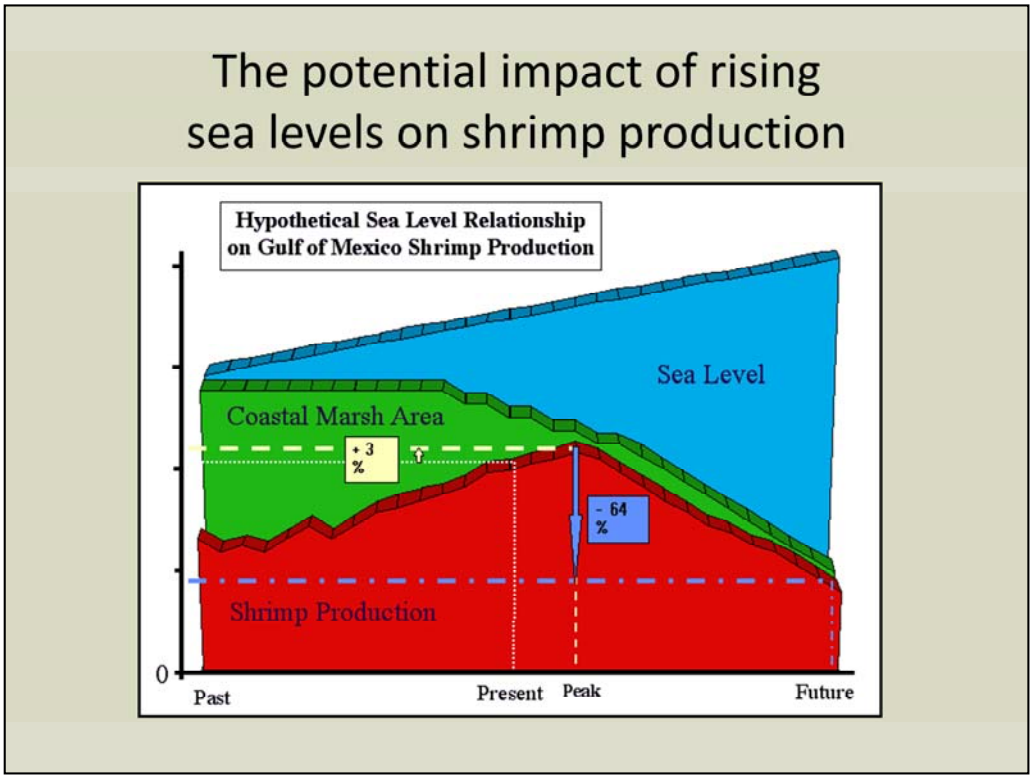


Coastal wetlands of the Mid-Atlantic are particularly vulnerable to the effects of sea level rise. Impacts on wetlands are driven by relative sea level rise, determined by two factors – the rate at which sea levels rise worldwide and the rate of land subsidence. Current relative sea level rise in the Mid-Atlantic region (3-4 mm per year) is approximately twice the global average of relative sea level rise of 1.7 mm/year due primarily to relatively high subsidence rates in the region. Climate change is expected to substantially increase these rates caused by both the melting of ice sheets and glaciers and the expansion of ocean water. The most recent (2007) report by the Intergovernmental Panel on Climate Change predicted global sea level rise of up to 59 cm over the next century. More recent studies that have taken into account accelerated melting of glaciers and ice flows have projected a global sea level rise over the same time frame of 100 cm or more. This would increase the rate of sea level rise in the Mid-Atlantic region to as much as 12 mm per year.

The implications for wetlands in the Mid-Atlantic region for three different sea level rise rates are shown in this diagram. This region is characterized by thousands of miles of coastline, large and unique estuaries (Delaware and Chesapeake Bays) and a wide variety of wetland habitats. As sea level rises, coastal wetlands are converted into open water habitats. Obviously, with higher rates of sea level rise, larger areas of coastal wetlands become inundated and lost to erosion. Note that under current rates of sea level rise, the relatively small area in blue will be inundated. A modest increase in the rate of only 2 mm/year results in a significantly larger area being impacted (much of the eastern shorelines of both Chesapeake and Delaware Bays). Increases in the rate of 7 mm/year (well within the predicted range) make it likely that most coastal wetlands in the region would be inundated along with the loss of associated wetland functions.

Wetlands may "migrate" inland where low-lying land is available; however, if existing wetland cannot keep pace with sea level rise, large areas of wetlands will be lost.

Image Credit: Adapted from EPA



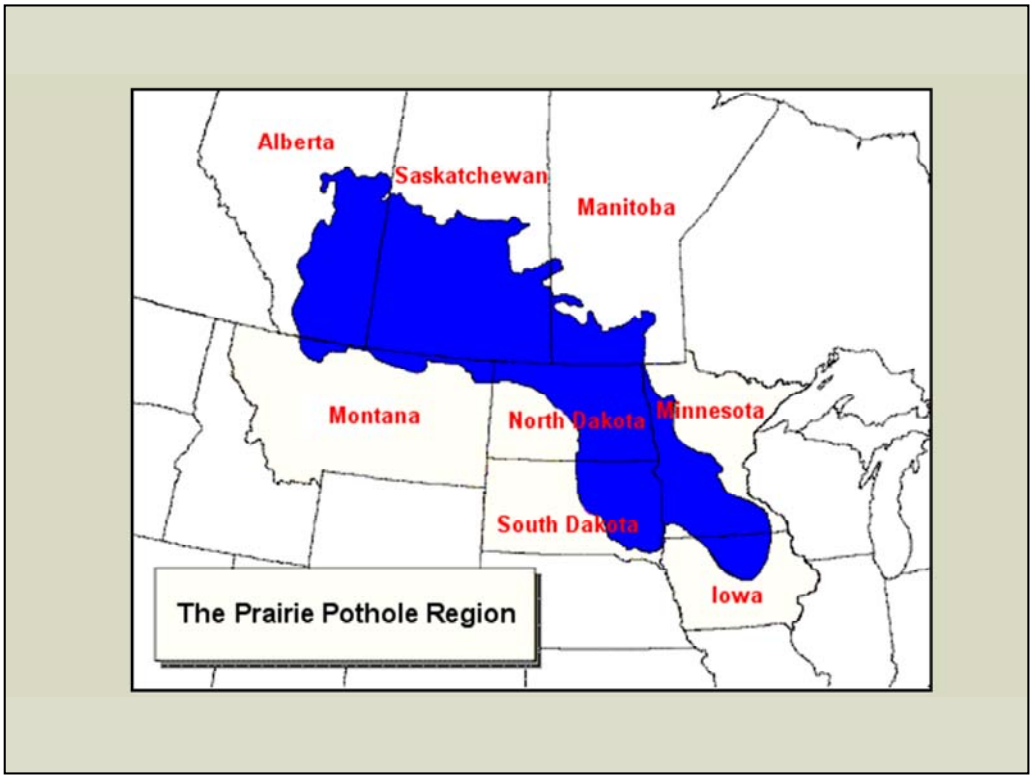
The figure illustrates a potential impact of global climate change on the Gulf Coast shrimp fishery. Most global climate change scenarios predict increases in sea level in the Gulf of Mexico. Rising sea levels result in the inundation of coastal marshes, which can temporarily provide beneficial conditions for the growth and reproduction of shrimp. Continued inundation however, results in the degradation of marsh habitat and the conversion to more open water habitats. The availability of marsh habitat declines with a resulting decline in shrimp populations. This model predicts a 64% decline in shrimp production below peak levels (dashed blue line in figure).

Image credit: NOAA - Pacific Fisheries Environmental Laboratory

Inland wetlands:

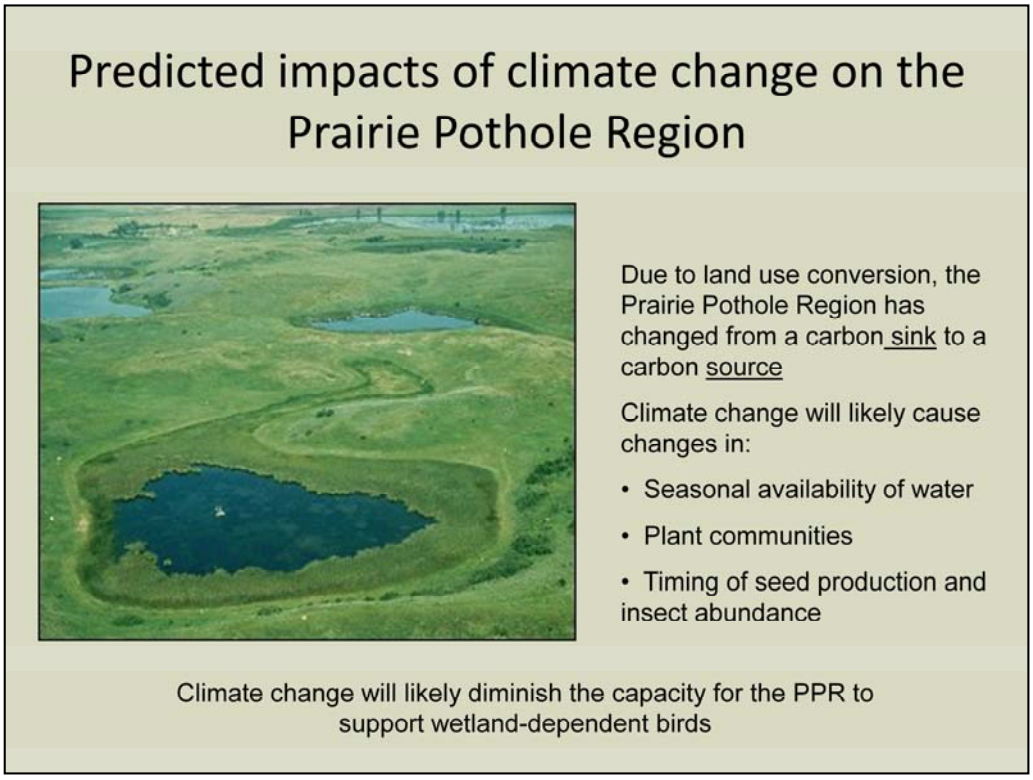
Changes in temperature will be the major impact on inland wetlands. The melting of permafrost in tundra, for example, will result in wetland loss. Changing rainfall patterns in boreal and temperate areas will affect the nature and distribution of wetlands there. A decrease in precipitation or an increase in evaporation result in less frequent flooding conditions and a change in plant species that are able to survive.

Photo credit: U.S. Army Corps of Engineers



The Prairie Pothole Region (PPR) in the Midwest is the single most productive habitat for waterfowl in the world. The productivity of the region is highly dependent on climate and it is suspected to be vulnerable to climate change. Climate model simulations have been used to predict the impact of climate change on this unique habitat. These models suggest that the most productive waterfowl areas would shift under a drier climate scenario from the historic center of the Prairie Pothole Region in North and South Dakota and SE Saskatchewan to the wetter eastern and northern fringes. The majority of wetlands in these areas have already been drained. Restoration and protection of these habitats is a priority as insurance for waterfowl against the effects of climate change.

Image credit: U.S. Fish and Wildlife Service



Research conducted by the U.S. Geological Survey in the Prairie Pothole Region (PPR) suggests that wetlands in this region historically functioned as carbon sinks, but conversion to agricultural land use has shifted their function to now be sources of atmospheric carbon. These studies suggest that greater amounts of atmospheric carbon can be stored in restored wetlands rather than croplands even though the acreage of wetlands is significantly smaller. In addition to providing carbon storage, these restored wetlands would also provide habitat for wildlife in the region, particularly migrating birds.

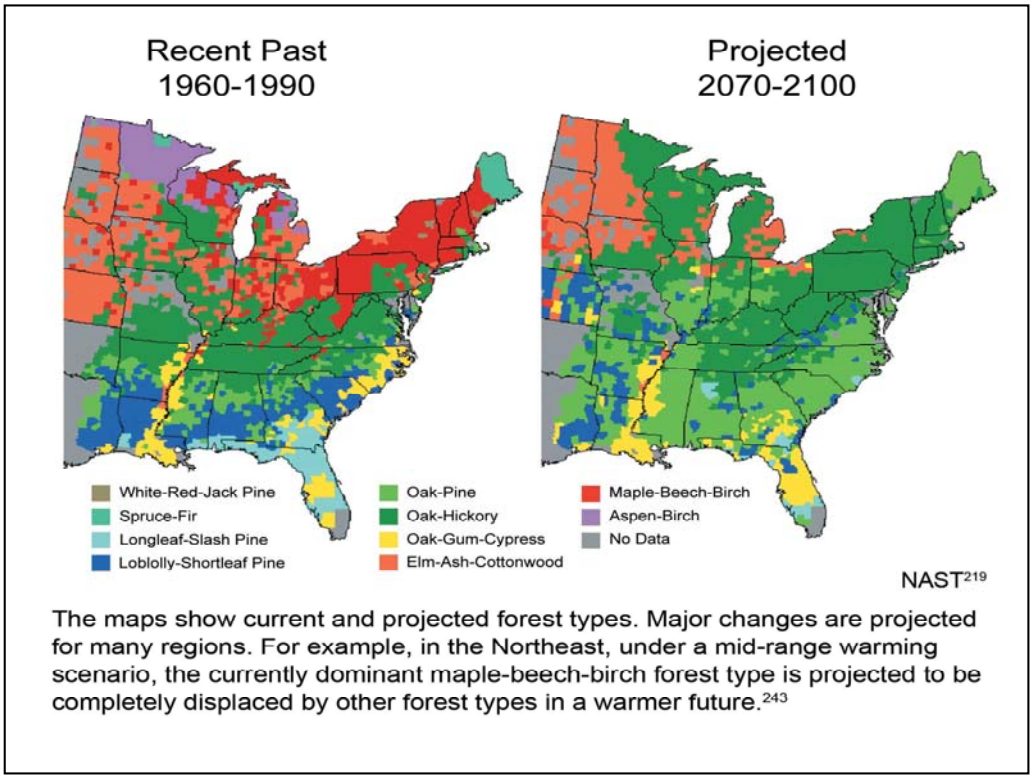
The PPR supports millions of resident and migrating wetland-dependent birds. The landscape is now dominated by intensive agriculture. Remaining wetlands have been impacted by altered hydrology, sedimentation and changes in plant communities. The USGS predicts that the northern and central portions of the PPR may warm by 3-6 C by the end of this century. This change in climate is likely to cause further impacts - for example:

1. changes in the seasonal availability of water
2. plant community changes
3. changes in the timing of seed production and insect abundance

These changes will likely diminish the capacity for the region to support wetland-dependent birds.

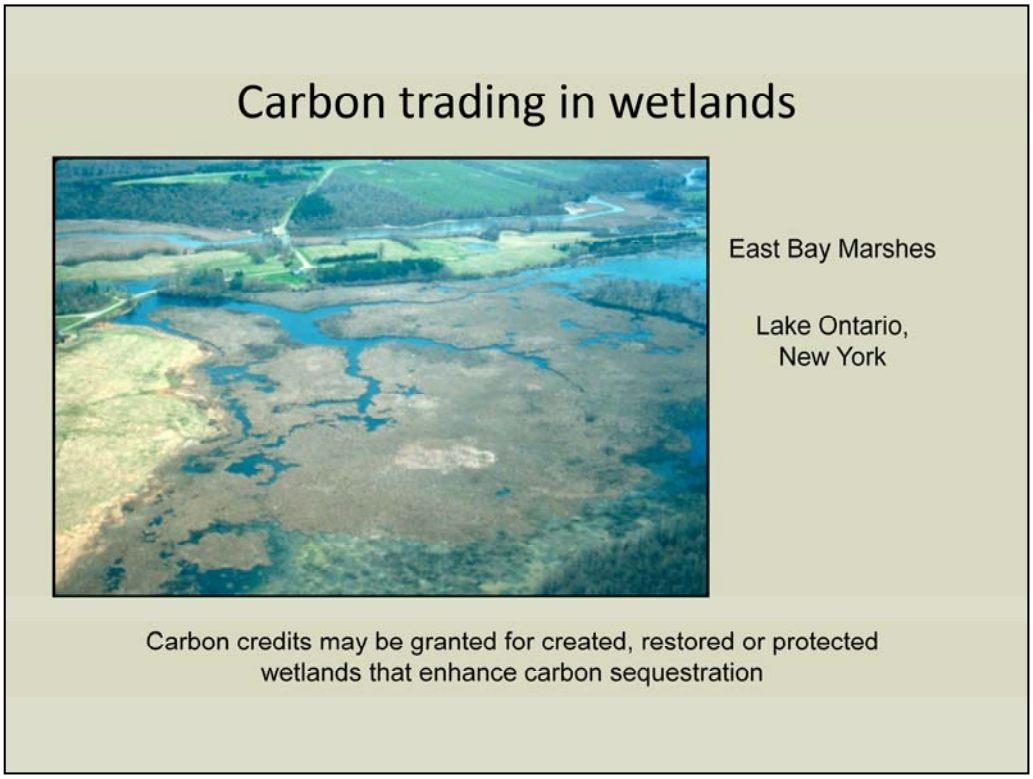
In 2011, the USGS began a research program to address the potential impacts of climate change on birds in the PPR (see Skagen and Melcher, 2011 for details).

Photo Credit: U.S. Geological Survey, Northern Prairie Wildlife Research Center



This slide illustrates projected changes in the distribution of major forest types in eastern United States under a mid-range warming scenario. Two of the forest types represented are typically forested wetlands – “Oak-gum-cypress” in southern U.S. (in yellow) and “Elm-ash-cottonwood” (in orange) in north central states and in the Midwest. Note changes in the distribution of forested wetlands and climate change advances. For example, oak-gum–cypress remain mostly unchanged in the Mississippi River Basin, but disappear completely from the Carolinas.

Image credit: U.S. Global Change Research Program (www.globalchange.gov).



A **carbon offset** is a reduction in greenhouse gas emissions (or increase in long-term carbon storage) by one entity that can compensate for emissions by another entity. In this system, the second party can continue "business as usual" and avoid directly reducing its own emissions. These "offsets" can be bought and sold as carbon credits in a carbon trading market. Offset projects are usually certified by a third party, which instills confidence that the offsets that are achieved are real. Carbon offsets require additionality, meaning that carbon benefits occur directly as a result of an action deliberately taken to store more carbon. That is, the increase in carbon storage takes place above and beyond what would have occurred under traditional management.

Carbon trading markets have been proposed (and are beginning to be developed) as a way to assign value to either reductions in carbon release or increases in carbon storage. Energy conservation measures and the storage of carbon in forests are among the most common methods of gaining carbon credits. Wetlands have now entered the discussion. There are plans to develop a protocol for granting credits to created, restored, or protected tidal wetlands that enhance carbon sequestration. In carbon trading markets, carbon credit trading will be used to help fund tidal wetland restoration. See, for example, "Restore America's Estuaries" at www.estuaries.org.

Photo credit: New York State Department of Environmental Conservation

Summary

- Wetlands are significant sources and sinks of greenhouse gases and thus, play an important role in global climate change
- Wetlands are particularly vulnerable to the effects of global climate change
- Increases in global temperatures may release large carbon stores in northern wetlands, creating a positive feedback loop.
- Sea level rise driven by climate change is the greatest threat to coastal wetlands
- Increases in temperature pose the greatest threat to inland wetlands
- Carbon trading in wetlands has been proposed as one mechanism to enhance carbon sequestration

Photo Credits

- Environmental Protection Agency
- Louisiana State University
- Miguel Cruz
- Mitsch and Gosselink (2007)
- NASA/GSFC/LaRC/JPL, MISR Team
- Natural Resource Conservation Service. Peat soils in Richland County, Wisconsin. Ho Chunk Nation of the Winnebago Tribe of Wisconsin
- New York State Department of Environmental Conservation
- NOAA - Pacific Fisheries Environmental Laboratory
- National Oceanic and Atmospheric Administration/Department of Commerce: National Estuarine Reserve Research System, Louise Kane, Sean Linehan
- U.S. Army Corps of Engineers
- U.S. Fish and Wildlife Service
- U.S. Geological Survey, Northern Prairie Wildlife Research Center
- U.S. Global Change Research Program (www.globalchange.gov)
- Vladimir Romanovsky
- Wikipedia

Wetlands and Climate Change – Resources

Anderson, K.E., et al. 2009. Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic Region (Executive Summary). Environmental Protection Agency. Washington, D.C. pp. xiii-viv.
www.climatescience.gov/Library/sap/sap4-1/final-report/sap4-1-final-report-all.pdf.

Bridgham, S.D. , et al. 1995. Potential feedbacks of northern wetlands on climate change. BioScience 45:262-274.

Chambers, J.Q., et al. 2007. Hurricane Katrina's carbon footprint on U.S. Gulf Coast forests. Science 318:1107.

Environmental Protection Agency. 2011. The impact of climate change on the Mid-Atlantic Region.
www.epa.gov/reg3artd/globalclimate/ccimpact.html

Johnson, W.C. 2010. Prairie wetland complexes as landscape functional units in a changing climate. BioScience 60:128-140.

Johnson, W.C., et al. 2005. Vulnerability of northern prairie wetlands to climate change. *BioScience* 55:863-872.

This article provides an excellent overview of the vulnerability of wetlands in the Prairie Pothole Region to climate change. A map (Figure 11) depicts the distribution of optimal wetland conditions for waterfowl breeding under historic conditions as compared to three different climate change scenarios.

Karl, T.R., et al. (eds.). 2009. Global climate change impacts in the United States. U.S. Global Change Research Program. Cambridge University Press. 188 pp.
www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/full-report

This federal program coordinates and integrates research being conducted on global environmental change and its implication for society. This report summarizes the science of climate change and its impact on the U.S. including wetland ecosystems.

Kusler, J. 2007. Common questions: Wetland, climate change, and carbon sequestering. Association of State Wetland Managers, Inc. 27 pp.

This is a collection of common questions about the relationship between wetlands, climate change and carbon sequestering. It also includes an extensive list of resources and suggested readings.
http://www.aswm.org/pdf_lib/11_carbon_6_26_06.pdf

Lawler, J.J., et al. 2008. Oregon's Biodiversity in a Changing Climate, Report prepared for the Climate Leadership Initiative,University of Oregon.
www.sustainable.uoregon.edu/

Nash, S. 2008. Wetlands, icecaps, unease: Sea-level rise and Mid-Atlantic shorelines. BioScience 58:919-923.

NASA. 2007. Forests damaged by Katrina become major carbon source. www.nasa.gov/mission_pages/hurricanes/archives/2007/katrina_carbon.html

This is a NASA summary of the research conducted by Chambers, et al (2007) (cited above) that evaluates the impact of Hurricane Katrina on global carbon budgets.

Parry, M.L., et al. (eds.). 2007. IPCC fourth assessment report: Climate change 2007 (AR4). Working group II report – Impacts, adaptation and vulnerability. Cambridge University Press, New York.
www.ipcc.ch/publications_and_data/ar4/wg2/en/contents.html

Restore America's Estuaries
www.estuaries.org.

"Restore America's Estuaries" is developing a protocol for granting credits to created, restored, managed or protected tidal wetlands that enhance carbon sequestration. In carbon trading markets, carbon credit trading will be used to help fund tidal wetland restoration.

Schuur, E.A.G., et al. 2008. Vulnerability of permafrost carbon to climate change: Implications for the global carbon cycle. BioScience 58:701-714.

Skagen, S.K. and C.P. Melcher. 2011. Avian conservation in the Prairie Pothole Region, Northern Great Plains – Understanding the links between climate, ecosystem processes, wetland management, and bird communities. U.S. Geological Survey Fact Sheet 2011-3030. 4 pp.
http://pubs.usgs.gov/fs/2011/3030/pdf/FS11-3030.pdf

Twilley, R.R. 2007. Coastal wetlands and global climate change – Gulf Coast sustainability in a changing climate. Pew Center on Global Climate Change. Arlington, VA. 24 pp.
www.pewclimate.org/regional_impacts
www.pewclimate.org/docUploads/Regional-Impacts-Gulf.pdf

U.S. Geological Survey. 2004. Prairie wetlands are important for carbon storage. Northern Prairie Wildlife Research Center. USGS Fact Sheet Number FS-067-02.
www.npwrc.usgs.gov/about/factsheet/carbon.htm

U.S. Geological Survey. 2006. Prairie wetlands and climate change – Droughts and ducks on the prairies. Patuxent Wildlife Research Center. USGS Fact Sheet. 2 pp.
www.pwrc.usgs.gov/products/factsheets/climate change fssm.pdf

Wetlands and Climate Change - Video Resources

Crash: A tale of two species. Public Broadcasting Service. NATURE . DVD - 55 min.
www.shopPBS.org

This PBS video examines the ecological role and economic importance of the horseshoe crab, a marine species that has remained essentially unchanged for 350 million years. The timing of reproductive behavior of the species is intricately connected to the migration and survival of coastal wading birds. This relationship serves as a good example of interconnectedness in coastal wetlands.

Wetlands International
www.wetlands.org

This international wetlands conservation organization produces a number of short videos that are available for download from their web site. The following titles provide some interesting perspectives on the relationship between wetlands and climate change:

1. Adapting to climate change: Mangrove forests (5 min.)
2. Palm oil production, peatland loss and carbon dioxide emissions (5 min.)
3. Tierra Del Fuego peatlands and climate change (10 min.)

General and Comprehensive Resources

The following resources cover a broad range of wetlands-related topics. Several are comprehensive web sites that contain a variety of information on wetlands that may be relevant to instructors. More detailed descriptions of the content of these web sites are provided in a separate section entitled "Detailed Descriptions of Comprehensive Resources" that follows. These resources have been identified with an asterisk (*) in the list below. More specific resources that cover one or few aspects of wetlands are provided in the module that is most relevant to those topics.

Association of State Wetland Managers (*)
www.aswm.org

The Association of State Wetland Managers is a nonprofit membership organization established to promote and enhance protection and management of wetland resources, to promote application of sound science to wetland management and to provide wetland training and education.

Batzer, D.P. and R.R. Sharitz. 2007. Ecology of freshwater and estuarine wetlands. Univ. of Calif. Press. 581 pp.
www.ucpress.edu

This is a comprehensive undergraduate text in wetland ecology. It is appropriate for a course devoted entirely or primarily to wetlands. Otherwise, it would be a useful reference for instructors who incorporate wetlands topics into a broader course in ecology.

Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998-2004. U.S. Fish and Wildlife Service, Washington, D.C. 112 pp.
http://www.fws.gov/wetlands/StatusAndTrends/

Environmental Protection Agency (*)
www.epa.gov/wetlands

The EPA wetlands site provides some good introductory information on wetlands. Wetlands definitions, types, status and trends, functions and values and wetlands management (including mitigation) and protection are all covered.

Hammer, D.A., ed. 1989. Constructed wetlands for wastewater treatment. Lewis Publishers, Inc., Chelsea, MI . 831 pp.

Kusler, J.A. and T. Opheim. 1996. Our national wetland heritage: A protection guide, 2nd ed. Environmental Law Institute, Washington, D.C. 149 pp.

This is a comprehensive guide to the protection and restoration of wetlands by local governments, private citizens, conservation organizations and landowners.

Maltby, E. and T. Barker (eds.). 2009. The wetlands handbook. Wiley-Blackwell, Inc. San Francisco, CA. 800 pp.
www.wiley.com

At $300 this text is probably only for the most serious wetlands instructors. It is a comprehensive analysis of ecosystem-based approaches to wetlands management. The emphasis is on maintaining/restoring ecological functions in freshwater wetlands.

Marks, R. 2006. Ecologically isolated wetlands. Natural Resources Conservation Service and Wildlife Habitat Council. Fish and Wildlife Habitat Management Leaflet #38. 8 pp.

This brief document is an excellent introduction to wetlands and is suitable to assign for student reading. Wetland processes and functions, ecological and economic benefits and issues associated with wetland loss and degradation are covered. As the title suggests, management issues emphasize what can be done to reduce the effects of wetland isolation.

Millennium Ecosystem Assessment. 2005. Ecosystems and human wellbeing: Wetlands and water – Synthesis. World Resources Institute, Washington, D.C.
www.millenniumassessment.org/documents/document.358.aspx.pdf

http://www.maweb.org/documents/document.358.aspx.pdf

This is a global assessment of wetlands resources with recommendations for future management.

Mitsch, W.J. and J.G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold Co., Inc. New York, NY. 539 pp.

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

A potential choice for a textbook for a course on wetlands, but designed for junior/senior level students and for those with some background in ecology.

Mitsch, W.J., et al. 2009. Wetland ecosystems. John Wiley and Sons, Inc., Hoboken, NJ. 285 pp.

Earlier editions of the Mitsch and Gosselink Wetlands *classic wetlands text (described above) included seven "ecosystem" chapters that described the structure and function of wetland ecosystems found in North America. In the interest of reducing the size of this text, the authors decided in the most recent edition to pull out these chapters and develop a separate text.* Wetland Ecosystems *is the result of that effort.*

National Research Council (NRC). 1995. Wetlands: Characteristics and boundaries. National Academy Press, Washington, D.C. 306 pp.

National Research Council (NRC). 2001. Compensating for wetlands losses under the Clean Water Act. National Academy Press, Washington, D.C. 158 pp.

Oregon Wetlands Explorer (*)
www.oregonexplorer.info/wetlands/

This joint project of Oregon State University, The Wetlands Conservancy and Oregon Division of State Lands is primarily designed for wetlands professionals, but educators (especially those in Oregon) will find some useful information here.

Payne, N.F. 1992. Techniques for wildlife habitat management of wetlands. McGraw-Hill, Inc., New York, NY. 549 pp.

Ramsar Convention on Wetlands
www.ramsar.org

The Ramsar site is most useful for international wetlands information. The Ramsar Convention is an intergovernmental treaty that commits its member countries to maintain the ecological character of "wetlands of international importance." The site provides digital photos and other media for instructor use including a 4-minute introductory You-tube video that introduces Ramsar and describes the value of wetlands.

Society of Wetland Scientists (*)
www.sws.org

The Society of Wetland Scientists (SWS) is the premier professional organization for wetland scientists and other professionals in the field. SWS publishes, Wetlands*, the leading journal on wetlands science and issues. Their web site has a number of resources that educators will find useful.*

Tiner, R.W. 2005. In search of swampland: A wetland sourcebook and field guide. Rutgers University Press, New Brunswick, NJ
http://rutgerspress.rutgers.edu

This resource is an excellent introduction to wetlands issues written for the "average citizen."

U.S. Army Corps of Engineers (*)
www.usace.army.mil/CECW/Pages/techbio.aspx

The Army Corps of Engineers has primary responsibility for waterways in the U.S. and is the primary agency that regulates wetlands at the federal level. As a focal point for federal wetlands management, this site has links to lots of wetlands resources with an emphasis on wetland delineation and classification, wetland functions and values, mitigation banking, and wetland plants and soils.

U.S. Fish and Wildlife Service - National Wetland Inventory (*)
www.fws.gov/wetlands

This site, maintained by the U.S. Fish and Wildlife Service, provides a wealth of useful information and tools including wetland status reports (national and regional), Google Earth with wetlands maps overlay and digitized wetlands maps.

U.S. Geological Survey – National Wetlands Research Center
www.nwrc.usgs.gov

Wetlands International
www.wetlands.org

The mission of this international conservation organization is "to sustain and restore wetlands, their resources and biodiversity for future generations." The organization uses science-based information to promote the protection and restoration of wetlands. Instructors looking for an international perspective on wetlands issues, especially those related to climate change and wetland bird conservation, will find Wetland International publications to be useful resources. The organization also produces a number of short (5-15 min.) videos available for download on their web site. Topics include the impacts of climate change on mangrove forests, wetland restoration and carbon dioxide storage in peatland forests.

Details on Comprehensive Web Sites (*)

Association of State Wetland Managers
www.aswm.org

The Association of State Wetland Managers is a nonprofit membership organization established to promote and enhance protection and management of wetland resources, to promote application of sound science to wetland management and to provide wetland training and education. Their web site has lots of resources related to all wetlands topics including:

A wetlands glossary:
http://www.aswm.org/watersheds/wetlands-and-watershed-protection-toolkit/887-wetlands-and-watershed-protection-toolkit?start=15

An excellent collection of publications that examine the relationship between wetlands and climate change:
www.aswm.org/science/climate_change/climate_change.htm

A collection of publications that examine the Gulf Oil Spill and its impact on wetlands. Includes coverage of wetland legal issues such as the Rapanos decision, "navigability," landmark legal cases,"takings." Instructors may also want to subscribe to "Wetland Breaking News" a newsletter on up-to-date wetlands issues and new publications.
http://aswm.org/wetland-science/2010-gulf-oil-spill

Environmental Protection Agency
www.epa.gov/wetlands
http://water.epa.gov/type/wetlands/index.cfm

The EPA wetlands site provides some good introductory information on wetlands. Wetlands definitions, types, status and trends, functions and values, wetlands management (including mitigation) and protection are all covered. The "Fact Sheets" are concise, 1-2 page summaries of various wetlands topics. Specific EPA sites of interest to instructors include:

This EPA wetlands module outlines the various values assigned to wetlands and describes how they are measured.
www.epa.gov/watertrain/wetlands/index.htm

This is an EPA site dedicated to wetland mitigation.
www.epa.gov/wetlandsmitigation

This EPA fact sheet is an excellent introduction to wetland mitigation banking.
www.epa.gov/owowwtr1/wetlands/facts/fact16.html

This is a short (approx 15 min.) video designed for a general audience that emphasizes the importance of providing outdoor, nearby nature, experiences for children – emphasis is on wetlands and includes interviews with wetlands scientists and environmentalists. Web site has directions for saving/ downloading video.
www.epa.gov/wetlands/education/wetlandsvideo/

A series of wetlands fact sheets on most aspects including an overview of wetland types, functions and values, threats, restoration, and monitoring and assessment.
www.epa.gov/owow/wetlands

The EPA wetlands helpline
http://water.epa.gov/type/wetlands/wetline.cfm

U.S. Fish and Wildlife Service – National Wetlands Inventory
www.fws.gov/wetlands

The U.S. Fish and Wildlife Service is the principal federal agency that provides information to the public on the extent and status of the nation's wetlands. This site provides a wealth of useful information and tools including wetland status reports (national and regional), Google Earth *with wetlands maps overlay and digitized wetlands maps. Perhaps the most useful tool is the "Wetlands Mapper," which visually displays the results of the national wetlands inventory, based primarily on an analysis of aerial photographs. Wetlands are identified, mapped and then superimposed on topographic maps. The inventory does not identify all wetlands in an area, but probably the most significant ones. The "Wetlands Mapper" allows viewing of identified wetlands either on-line or hard copy maps can be ordered for every state (see "Hard Copy Orders"). Each map is mapped as a polygon with an imbedded code that indicates the specific wetland type and other information related to this site.*

The WetlandsMapper shows the location of wetlands identified on National Wetlands Inventory (NWI) maps and integrates digital map data with other resource information. The following links provide a useful introduction to this feature:

- Wetlands Mapper Documentation and Instructions Manual (www.fws.gov/wetlands/_documents/gData/WetlandsMapperInstructionsManual.pdf)
- Frequently Asked Questions: Wetlands Mapper (www.fws.gov/wetlands/_documents/gData/QuestionsAnswersAboutNewMapper.pdf)
- Frequently Asked Questions web page (www.fws.gov/wetlands/FAQs.html)

NWI wetlands data can also be viewed with Google Earth. Instructions and a link to do so are included at the NWI web site.

This U.S. Fish and Wildlife site also includes Wetlands Status and Trends Reports, *which provide long-term trend information about specific changes and places and the overall status of wetlands in the United States. The historical database provides photographic evidence of land use and wetlands extent dating back to the 1950s. This provides an accurate record to assist in future restoration efforts.*

Status and Trends Reports available on the web site include:

- NOAA/USFWS joint report on Coastal Wetland Trends 1998-2004 (www.fws.gov/wetlands/_documents/gSandT/NationalReports/StatusTrendsWetlandsCoastalWatershedsEasternUS1998to2004.pdf)

- Status and Trends of Wetlands in the Conterminous United States 1998 to 2004 (Dahl, 2006) (www.fws.gov/wetlands/_documents/gSandT/NationalReports/StatusTrendsWetlandsConterminousUS1998to2004.pdf)
- Status and Trends of Wetlands in the Conterminous United States 1986 to 1997 (www.fws.gov/wetlands/_documents/gSandT/NationalReports/StatusTrendsWetlandsConterminousUS1986to1997.pdf)
- Wetlands Status and Trends in the Conterminous United States, Mid-1970's to Mid-1980's (www.fws.gov/wetlands/_documents/gSandT/NationalReports/WetlandsStatusTrendsConterminousUS1970sto1980s.pdf)
- Status and Trends of Wetlands and Deepwater Habitats in the Conterminous United States 1950's to 1970's (www.fws.gov/wetlands/_documents/gSandT/NationalReports/StatusTrendsWetlandsDeepwaterHabitatsConterminousUS1950sto1970s.pdf)

Links to other resources such as the National Wetlands Plant List and an EPA evaluation of the impact of climate change on coastal wetlands are also available.

Oregon Wetlands Explorer
www.oregonexplorer.info/wetlands/

This joint project of Oregon State University, The Wetlands Conservancy and Oregon Division of State Lands was first launched in 2009 as "a useful tool for anyone doing wetland work in Oregon." It is primarily designed for wetlands professionals, but educators (especially those in Oregon) will find some useful information here. The following are included:

1. *Statewide database of wetlands maps, hydric soils, FEMA flood zones, Wetland Reserve Program (WRP) sites, wetland mitigation banks. Local wetland inventories and recommended priority sites for conservation*
2. *A tool for rapid assessment for wetlands*
3. *Oregon-related information on various wetland topics*
4. *Wetland GIS and vegetation plot data*

Society of Wetland Scientists
www.sws.org/

The Society of Wetland Scientists (SWS) is the premier professional organization for wetland scientists and other professionals in the field. SWS publishes, Wetlands*, the leading journal on wetlands science and issues. Their web site has a number of resources that educators will find useful. Several are described below:*

This newly developed web page was designed to document the impact of the Deepwater Horizon oil spill in the Gulf of Mexico on wetlands. It includes insights from wetland scientists, links top pertinent resources and digital photographs.
www.sws.org/oilspill/

This page lists links to specific short courses in wetlands training – delineation, hydric soils, plant identification, restoration, mitigation, and constructed wetlands.
www.sws.org/training/

This is a directory of wetland-related academic programs at U.S. colleges and universities.
www.sws.org/colleges/

These "position papers" on various wetlands topics are designed to "increase public understanding of wetlands issues and to promote sound public policy." They are written by experts in the field and are based on the best available science. Topics include oil effects on wetlands, mosquito control, mitigation banking, performance standards for wetland restoration and creation, and definitions of wetland restoration. The papers are brief, well-referenced and provide excellent background for educators with a particular interest in specific wetland issues. They are also suitable to assign as student reading to provide a basis for discussions on wetland issues.
www.sws.org/wetland_concerns/

The SWS also publishes the "SWS Research Brief," which helps translate wetland research results for a non-technical audience. The research of selected wetlands scientists is highlighted in each brief. These make excellent student reading and serve to familiarize students with the process of science – how scientists formulate questions, collect data, present their findings and draw conclusions from them.
www.sws.org/ResearchBrief/

Some topics include:

- *Restoration of mangroves*
- *Invasive plants in wetlands*
- *Impact of elevated CO_2 levels on wetlands*
- *Impact of hurricane Katrina on wetlands*
- *Relationship between marshes, mosquitoes and malaria*

The SWS education page is designed with the college educator in mind and is intended "to facilitate sharing of techniques, skills, tools and ideas on and about wetlands education." See for educational resources including labs, field activities, courses, links to other web sites, etc. The Society of Wetlands Scientists also maintains a list of colleges and universities that offer courses or programs in wetland science or ecology.
www.sws.org/education/

Here are some examples of materials that college instructors will find most useful:

1. *Links to general information on wetlands*
2. *Syllabi, lab exercises and exams for wetlands courses*

NOTE: Instructors with an interest in teaching wetland concepts using digital imagery and aerial photography will find the "Wetland Education Through Maps and Aerial Photography" (WETMAAP) site to be particularly useful.

3. *Digital images collection for wetlands education*

U.S. Army Corps of Engineers
www.usace.army.mil/CECW/Pages/techbio.aspx

The Army Corps of Engineers has primary responsibility for waterways in the United States and is the primary agency that regulates wetlands at the federal level. As a focal point for federal wetlands management, this site has links to lots of wetlands resources. Those that are most relevant to this series of modules include the following:

Wetlands delineation and classification

- Corps Wetlands Delineation Manual (www.el.erdc.usace.army.mil/elpubs/pdf/wlman87.pdf)
- Regional Supplements to the Corps Delineation Manual (www.usace.army.mil/CECW/Pages/reg_supp.aspx)
- USFWS National Wetlands Inventory (www.fws.gov/wetlands/)
- Classification of Wetlands & Deepwater Habitats of the U.S. (www.npwrc.usgs.gov/resource/wetlands/classwet/index.htm)
- Recognizing Wetlands - An Informational Pamphlet (www.usace.army.mil/CECW/Documents/cecwo/reg/rw_bro.pdf)

Wetlands functions and values

- Current HGM Information and Guidebooks (http://el.erdc.usace.army.mil/wetlands/hgmhp.html)
- Hydrogeomorphic Approach to Assessing Wetland Functions (http://el.erdc.usace.army.mil/wetlands/hgmhp.html)
- National Plan to Implement the Hydrogeomorphic Approach to Assessing Wetland Functions (www.usace.army.mil/CECW/Documents/cecwo/reg/hydro_geo.pdf)
- Wetland Functions & Values - A Report by the National Science Foundation, 1995 (www.usace.army.mil/CECW/Documents/cecwo/reg/wet_f_v.pdf)
- Consequences of Losing or Degrading Wetlands
- U.S. Environmental Protection Agency Wetlands Information Website http://water.epa.gov/type/wetlands

Mitigation banking

- Federal Guidance for the Establishment, Use and Operation of Mitigation Banks (http://water.epa.gov/lawsregs/guidance/wetlands/mitbankn.cfm)
- National Wetland Mitigation Banking Study: Technical and Procedural Support to Mitigation Banking Guidance, 1995 (www.iwr.usace.army.mil/index.php?option=com_content&view=category&layout=blog&id=7&Itemid=3/iwrreports/WMB-TP-2.pdf)
- National Wetland Mitigation Banking Study: Model Banking Instrument, 1996 (www.iwr.usace.army.mil/index.php?option=com_content&view=category&layout=blog&id=7&Itemid=3/iwrreports/WMB-TP-1.pdf)
- National Wetland Mitigation Banking Study: The Early Mitigation Banks: A Follow-up Review, 1998 (www.iwr.usace.army.mil/index.php?option=com_content&view=category&layout=blog&id=7&Itemid=3/iwrreports/98-WMB-WP.pdf)

- National Wetlands Mitigation Action Plan (www.usace.army.mil/CECW/Documents/cecwo/reg/Mit_Action_Plan.pdf)
- IWR - Wetlands and Regulatory (www.iwr.usace.army.mil/index.php?option=com_content&view=category&layout=blog&id=7&Itemid=3/publications.cfm)

Plants and soils

- NRCS Soils Website (www.soils.usda.gov/)
- Field Indicators of Hydric Soils in the U.S. ftp://ftp-fc.sc.egov.usda.gov/NSSC/Hydric_Soils/FieldIndicators_v7.pdf
- National List of Vascular Plant Species that Occur in Wetlands:
    - 1996 (www.usace.army.mil/CECW/Documents/cecwo/reg/plants/list96.pdf)
    - 1988 (www.usace.army.mil/CECW/Documents/cecwo/reg/plants/list88.pdf)
    - National Wetland Plant List (NWPL) https://rsgis.crrel.usace.army.mil/apex/f?p=703:1:2631898853215485
- NRCS Plants Database (www.plants.usda.gov/java/)
- Center for Aquatic and Invasive Plants - University of Florida (www.plants.ifas.ufl.edu/)
- Global Invasive Species Database (www.issg.org/database/welcome/)
- Interactive Key to Wetland Monocots of the U.S. (www.npdc.usda.gov/technical/plantid_wetland_mono.html)

Sources for Digital Images

Barras, J.A. 2007. Satellite images and aerial photographs of the effects of Hurricanes Katrina and Rita on coastal Louisiana. U.S. Geological Survey Data Series 281.
www.pubs.usgs.gov/ds/2007/281

Bureau of Land Management Image Library
www.blm.gov/wo/st/en/bpd.html

Most of the images in this web site are "public domain" and can be used without further authorization from the BLM.

The Integration and Application Network (IAN)
www.ian.umces.edu/imagelibrary/

The Integration and Application Network (IAN) is an initiative of the University of Maryland Center for Environmental Science. IAN emphasizes environmental problems in the Chesapeake Bay and its watershed. Although registration is required, there is no cost to download images.

The Natural Resources Conservation Service Photo Gallery
www.photogallery.nrcs.usda.gov

The Natural Resources Conservation Service Photo Gallery provides a comprehensive collection of natural resources and conservation-related photos from around the U.S. They are available for non-commercial use, free-of-charge with proper acknowledgement (described on web site).

NBII Life – Library of Images From the Environment
www.life.nbii.gov/dml/home.do

The National Biological Information Infrastructure (NBII) Library, Images from the Environment (LIFE), provides high-quality environmental images that are freely available for educational use. The collection includes images of plants, animals, fungi, microorganisms, habitats, wildlife management, environmental topics, and biological study/fieldwork. Images are annotated with background information(context, scientific names, location, habitat classifications, etc.), greatly improving their use as educational materials.

NOAA Photo Library/NERR Collection
http://www.photolib.noaa.gov/nerr/index.html
This collection includes images of estuaries in the National Estuarine Research Reserve System. Collection contains more than 1000 photos with images of landscapes, habitats, and individual specimens with descriptions.

U.S. Department of Agriculture PLANTS Database
www.plants.usda.gov

Plant images may be used for non-commercial use although copyrighted images require notification of the copyright holder.

The Society of Wetland Scientists
www.sws.org/regional/pacificNW/photo.html

The Ramsar Convention on Wetlands
www.ramsar.org/cda/en/ramsar-media-photos/main/ramsar/1-25-126_4000_0__

Has a good collection of photos from sites that have met Ramsar criteria.

U.S. Environmental Protection Agency Image Gallery
www.epa.gov/newsroom/pictures.htm

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U.S. Fish and Wildlife National Digital Library
www.fws.gov/digitalmedia/

The U.S. Fish and Wildlife Service's National Digital Library is a searchable collection of public domain images, audio/video clips and publications. Permission is not required for use; however you are asked to give credit to the photographer or creator and the U.S. Fish and Wildlife Service.

U.S. Forest Service
www.fs.fed.us/photovideo/

USDA Forest Service's "Find-a-Photo" site allows access to thousands of copyright- free wildlife, fish, wildflower and environmental education photographs, donated by Forest Service employees, their partners and volunteers.