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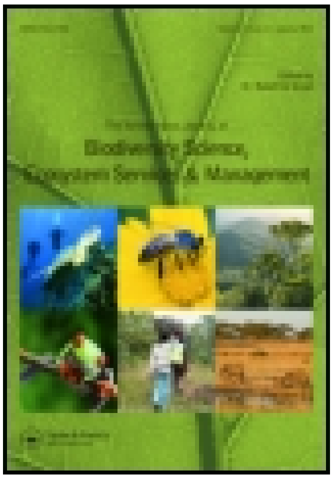

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EDITORIAL

Ecosystem services of wetlands

Wetlands are among the most valuable ecosystems on the planet. As described in Mitsch and Gosselink (2015, pp. 3–4) and earlier editions:

> 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.

Wetlands continue to be cited as the most valuable parts of our landscape in ecosystem service assessments (Costanza et al. 1997, 2014; Mitsch & Gosselink 2000; De Groot et al. 2012; McInnes 2013). Costanza et al. (1997) used ecosystem unit estimators that showed that wetlands, especially inland swamps and floodplains, were considerably more valuable than lakes and rivers, forests, and grasslands (Table 1). Only coastal estuaries had higher unit values than inland and coastal wetlands from the 1997 study. Costanza et al. (2014) revisited the calculations of the 1997 paper, using some revised unit values from De Groot et al. (2012). The new unit values for selected ecosystems are given in the last column in Table 1. The inland swamps/floodplain values stayed approximately the same as they were in the 1997 paper, while the tidal marsh/mangroves unit value increased 14-fold, 'largely due to new studies of the storm protection, erosion protection, and waste treatment values' of these coastal wetlands (Costanza et al. 2014, p. 155).

Wetland ecosystem services can be categorized in a number of ways. For its first 21 years, the Mitsch and Gosselink's (2015) textbook categorized wetland values into three levels of biological hierarchy: population, ecosystem, and global. Population values include those related to specific ecological populations: providing habitats for animals harvested for pelts, waterfowl and other hunted and watched birds, fish and shellfish production, timber and peat harvesting, and support of endangered and threatened species. Ecosystem values require the entire wetland ecosystem, not just a few species of plants, animals, or microbes, to improve water quality, mitigate storm and flood damage, recharge aquifers, and even sustain human cultures. Global values include maintaining water and air quality influences on a much broader scale than that of the ecosystem level, especially in regional and global cycles of nitrogen, sulfur, and carbon.

With the publication of the Millennium Ecosystem Assessment (2005) came an alternative categorization for ecosystem services, whereby the services are described as being provisioning, regulating, cultural, and supporting.

(1) *Provisioning ecosystem services* include products obtained from ecosystems, such as food, water, timber, fiber, or genetic resources.
(2) *Regulating ecosystem services* include air quality regulation, climate regulation, water purification, disease regulation, pest regulation, pollination, and natural hazard regulation.
(3) *Cultural ecosystem services* include benefits that people obtain from ecosystems related to spiritual enrichment, recreation, ecotourism, aesthetics, formal and informal education, inspiration, and cultural heritage.
(4) *Supporting ecosystem services* include basic ecosystem processes of nutrient cycling and primary productivity that may, in turn, lead to the other three services listed above.

A summary of many of the ecosystem services provided by wetlands, using these Millennium Ecosystem Assessment (2005) categories, is listed in Table 2. Several of these ecosystem services of wetlands are described in more detail in the papers in this special issue.

Content of this special issue

The seven papers in this special issue of *International Journal of Biodiversity Science, Ecosystem Services & Management* mostly resulted from the presentations at EcoSummit 2012 in Columbus, Ohio, USA, in early October 2012. EcoSummit 2012, the fourth EcoSummit since 1996, hosted 1622 delegates from 73 countries presenting 1329 papers (Mitsch 2013). This special issue is the final of a series of seven journal special issues

Table 1. Comparison of unit values of selected ecosystems including wetlands in 1997 and revised in 2011, as given in Mitsch and Gosselink (2015). All numbers are normalized to 2007 US$.

Ecosystem	1997 estimate unit value (US$ ha^{-1} yr^{-1})	2011 estimate unit value (US$ ha^{-1} yr^{-1})
Estuaries	31,509	28,916
Inland swamps/ floodplains	27,021	25,681
Tidal marshes/ mangroves	13,786	193,843
Lakes/rivers	11,727	12,512
Forests	1338	3800
Grasslands	321	4166

Data sources: 2011 estimates are from Costanza et al. (2014); 1997 estimates are from Costanza et al. (1997), but revised to 2007US$.

Table 2. Ecosystem services of wetlands based on the Millennium Ecosystem Assessment (2005) categories.

- Provisioning services
  - Fisheries support
  - Peat production for fuel and horticulture
  - Furbearer and other animal harvesting
  - Timber production
  - Direct food production
- Regulating services
  - Water quality improvement
  - River flooding mitigation
  - Protection of coastlines from tsunamis, cyclones, and other coastal storm surges
  - Carbon sequestration
  - Habitat for rare and endangered species
- Cultural services
  - Landscape aesthetics
  - Sites for human relaxation
  - Ecology education
  - Sustenance of human cultures
  - Ecotourism, bird-watching
- Supporting services
  - Wetland functions such as hydric soil development, primary productivity, serving as chemical sources, sinks, and transformers, and water storage

resulting from EcoSummit 2012 (Table 3). The special issues have mostly focused on ecosystem restoration, ecosystem services, ecological engineering, and ecohydrology.

The first three papers in this special issue by Hernandez et al. (2015), Villa and Mitsch (2015), and Estrada et al. (2015) address the ecosystem service carbon sequestration provided by wetlands. The papers focus on the importance of addressing natural or anthropogenic changes in the wetland landscape when accounting for soil carbon pools and fluxes. These manuscripts focus on subtropical and tropical regions (Mexico, Florida, and Brazil, respectively), a part of the world where studies on carbon sequestration in wetlands are relatively scarce. Carbon sequestration in wetland ecosystems is an important service that benefits humans greatly by mitigating climate change (Fisher & Turner 2008; Watanabe & Ortega 2011; Mitsch et al. 2013). However, using wetlands or any other potential carbon-sequestering ecosystem as a tool to abate climate change requires accurate quantification of this service. Slow organic matter decomposition rates due to waterlogged soils and large organic matter accumulation due to high biomass productivity make wetland soils significant sinks of carbon as opposed to other ecosystems with transient carbon pools such as biomass (Mcleod et al. 2011; Mitsch & Gosselink 2015).

Hernandez et al. (2015) found that land-use change from forested natural wetlands to managed flooded grasslands entails a carbon loss (the average organic matter content was 284 ± 15 g kg^{-1} in the forested wetlands and 134 ± 6 g kg^{-1} in the flooded grasslands). The authors point out the need of better policies in Mexico to protect coastal wetlands to avoid positive feedback to climate change. Villa and Mitsch (2015) found that wetland communities that are permanently flooded have high carbon sequestration rates (98 ± 9 g C m^{-2} yr^{-1}, vs. 22 ± 5 g C m^{-2} yr^{-1} in the reference upland) and act as net sinks. However, the sequestration in transition communities did not follow a hydrological gradient and thus, the authors point out other factors beyond inundation frequency that need to be addressed when defining the conditions that favor carbon sequestration over emissions. Estrada et al. (2015) did an economic valuation of the carbon stocks in Brazilian mangrove communities under different settings, following the Reducing Emissions from Deforestation and Forest Degradation (REDD) and the Clean Development Mechanism (CDM) valuations. Estrada et al. point out the need to account for spatial variability as different mangrove types differ in their efficiency sequestering carbon and thus in their economic value, ranging from US$ 19 ± 10 ha^{-1} yr^{-1}in basin mangrove forests to US$ 82 ± 32 ha^{-1} yr^{-1} in fringe mangroves. The authors point out that this economic value, if acknowledged by REDD and CDM projects, could help local communities of developing countries.

Four additional papers explore the ecosystem services of water purification, watershed stabilization by forested and urban wetlands, and coastal protection by mangrove wetlands. Marton et al. (2015) investigated the variability and spatial patterns of denitrification in natural and restored depressional wetlands in northern Indiana, USA. They found that restored wetlands had greater denitrification rates and higher spatial variability than did natural wetlands. The authors suggest that soil properties and denitrification should be considered when assessing the effectiveness of restored wetlands at providing ecosystem services, such as nitrogen removal.

Wahlroos et al. (2015) describe the ecosystem services of two small flow-through wetlands, which were constructed in Baltic Sea catchments in southern Finland over 2010 to 2014. The values described include water

Table 3. Scholarly journal special issues resulting from EcoSummit 2012 held in Columbus, Ohio, USA.

Journal	Special issue editors	Title of special issue	EcoSummit session	Publication citation
Ecological Engineering	Ed Glenn	Colorado Delta wetlands	Symposium 22	*Ecological Engineering* 59: 1–184 (Oct 2013)
Ecohydrology & Hydrobiology	Maciej Zalewski, Michael McClain, and Paul DuBowy	Ecohydrology for harmonization of societal needs with the biosphere potential I	Symposium 49	*Ecohydrology & Hydrobiology* 13: 1–96 (2013)
Ecohydrology & Hydrobiology	Maciej Zalewski, Michael McClain, and Paul DuBowy	Ecohydrology for harmonization of societal needs with the biosphere potential II	Symposium 49	*Ecohydrology & Hydrobiology* 13: 97–172 (2013)
Landscape Ecology	Louis Iverson, Cristian Echeverria, Laura Nahuelhual, and Sandra Luque	Ecosystem services in changing landscapes	Symposium 55	*Landscape Ecology* 29: 181–358 (February 2014)
Ecological Engineering	Mike Weinstein and John Day	Sustainable restoration	Symposium 63	*Ecological Engineering* 65: 1–158 (April 2014)
Ecological Engineering	William Mitsch, Julie Cronk, and Li Zhang	The Olentangy River Wetland Research Park: two decades of research on ecosystem services	Parts of symposia 6, 35, 59, 65	*Ecological Engineering* 72: 1–142 (November 2014)
International Journal of Biodiversity Science, Ecosystem Services & Management	William Mitsch, Blanca Bernal, and Maria Hernandez	Ecosystem services of wetlands	Various sessions	*International Journal of Biodiversity Science, Ecosystem Services & Management* 11(1): x–xxx (February 2015)

pollution mitigation, amphibian and bird population enhancement, and urban enhancement. Most of the activity was related to water quality sampling with several continuous probes and auto-samplers that created a wealth of data on urban stormwater pulses. Ten percent phosphorus retention was realized on average through the wetlands with up to 70% retention during summer storm and winter snowmelt events. Wahlroos et al. (2015) also point out, not surprisingly, that the public found the wetland parks appealing because of the plant and animal, especially avian, diversity. The pattern of nutrient retention, a diverse flora and fauna, and public appreciation of a 'wetland park' is similar to the ecosystem services that have been demonstrated over 20 years at the urban Olentangy River Wetland Research Park in Columbus, Ohio, USA (Mitsch et al. 1998, 2012, 2014).

Barksdale and Anderson (2015) investigated the impact of land use and land cover on canopy tree density, diameter, species cover, importance values, and soil value/chroma in headwater wetlands in coastal Alabama, USA. The authors found that exotic species cover was significantly related to land-use change. Increases in exotic shrubs were associated with decreases in watershed forest cover. Increases in shrub/sapling prevalence index (a measure of hydrophytic vegetation) and soil chroma were positively correlated to increased watershed conversion to agriculture (and concurrent loss of forest cover). The authors recommend that strategies for conserving ecosystem services associated with the studied wetlands should include minimizing surrounding forest loss and maintaining groundwater inflow.

Marois and Mitsch (2015) provide a literature review on the ecosystem services of coastal protection from tsunamis and cyclones provided by mangrove wetlands along tropical and subtropical coastlines of the world. They discuss and contrast the results from different approaches that have been used to evaluate the capacity of mangrove forests for coastal protection. These approaches include observational studies, numerical model studies, and physical model studies. The authors conclude that observational studies have not provided conclusive results on the extent of coastal protection provided by mangroves from extreme natural disasters. However, results from several recent numerical and physical models support the mitigating capabilities of mangroves for cyclone storm surges and small tsunamis. They also highlighted that coastal protection can account for a major portion of total economic value calculated for mangrove forests.

Conclusions

The seven papers in this special issue present a diverse but by no means a total summary of the many ecosystem services provided by wetlands. Wetlands were one of the first ecosystems to be recognized in the early 1970s for their implicit values, probably because they had been viewed for such a long time, particularly in the western world, as systems that needed to be drained for human progress. In fact, early recognition and quantification of the many values of wetlands, especially when those values were translated to monetary values, led to an 'ecosystem envy' by those who studied other ecosystems such as grasslands, forests, and lakes. For example, as the formal mitigation of wetland losses by creating and restoring new wetlands in the USA in the 1980s has now been copied for mitigation policies for streams, floodplains, and even farmland. Ecologists and economists alike should both recognize and be pleased for all the efforts of those who did the pioneering work in illustrating and quantifying ecosystem services of wetlands. It is now important that we not lose sight of those services that wetlands provide.

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