*Potential impacts of accelerated sea level rise on*
*Maryland's coastal wetlands and their ecosystem services*

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## Introduction

Coastal wetlands are among the most valuable ecosystems in the world (Feagin et al. 2010). They are also among the most vulnerable ecosystems to a changing global climate (IPCC 2007). This is especially apparent in Maryland and throughout the Mid-Atlantic, a "hotspot" of accelerated sea level rise (Sallenger et al. 2012). With many Mid-Atlantic tidal wetlands having already declined as a result of rapid coastal development, the threat of further loss has critical implications. Many of the ecosystem services tidal wetlands provide, including storm surge protection, nitrogen and carbon sequestration, and habitat for diverse species, are vital for moderating the impacts of global change. Conservation and restoration of tidal wetlands, as well as actions to reduce the rate of sea level rise, are crucial for the sustainability of Maryland's coastal ecosystems and communities.

## Global and regional sea level trends

Reconstructions of past global sea levels suggest that sea level has risen an average of 1.7 ± 0.5 $mm/yr^{-1}$ throughout the $20^{th}$ century (IPCC 2007). Globally, sea levels are projected to rise 180 mm - 330 mm (B1 scenario) to 260 mm – 590 mm (A1F1 scenario) by the end of the $21^{st}$ century (IPCC 2007). During the past century, sea levels along the Maryland coast increased at a rate of approximately 3.05 $mm/yr^{-1}$, due to the simultaneous subsidence of coastal lands (MCCC 2008) and, possibly, due to sea level variations associated with ocean currents (Sallenger et al. 2012). Relative sea level rise – sea level rise compounded by land subsidence – along the Maryland coast could exceed 1 m during the $21^{st}$ century (MCCC, 2008). This projection is significantly higher than the global expectation, underscoring the unique vulnerability of

Maryland's coastal communities. Table 1 (see Appendix) shows global and regional sea level rise in the 20th century and projections for the 21st century.

**Sea level rise and Maryland's coastal communities**

Maryland has more than 3,000 miles of coastline and, consistent with national and global trends, a growing coastal population (NOAA 2011). Coastal communities already experience hazards associated with storm events, shore erosion, coastal flooding, storm surge, and inundation (MCCC 2008). In adapting to these challenges and mitigating their effects, Maryland's tidal wetlands play a crucial role. However, the conservation of coastal wetlands is a complex challenge in the context of rapid sea level acceleration and coastal population growth. Today, fewer than 40% of the historic wetlands within the Chesapeake Bay persist, and accelerated sea level rise threatens further loss (NOAA 2012).

**Response of tidal wetlands to sea level rise**

In response to sea level rise, coastal wetlands have the potential to 1) migrate landward via vertical accretion or 2) experience drowning (Gedan et al. 2009). Accretion is the process by which tidal wetlands build vertically to maintain their elevation relative to sea level (USCCSP 2009). It is facilitated by the deposition of mineral sediments during wetland inundation as well as the accumulation of organic matter through plant growth and decomposition (Schuerch et al. 2012). Tidal wetlands may be able to migrate landward if sediment supply is sufficient and inland conditions are conducive for migration. In the presence of accelerated sea level rise associated with high carbon dioxide concentrations, the ability to accrete vertically is crucial for the persistence of tidal wetlands. Coincidentally, increased carbon dioxide concentrations may have the potential to stimulate this process: as carbon dioxide enhances plant growth and increases root biomass, the elevation of marsh soils may increase to facilitate accretion (Najjar et al. 2010). However, this benefit is contingent on a sufficiently slow rate of sea level rise that enables the gradual accretion process to keep pace with rising water levels.

Drowning of tidal wetlands occurs when vertical accretion does not keep pace with rising water levels, rendering wetlands unable to maintain their elevation relative to sea level (USCCSP 2009). As wetland inundation occurs, responses may vary by marsh type. Salt marshes are likely to be converted to open water; tidal freshwater marshes are likely to decline in area as saltwater intrudes, with brackish marshes potentially migrating inland to replace them (Craft et al. 2009). Kirwan et al. (2010) emphasized that wetland submergence is not an inevitable outcome of sea level rise. Wetland response will depend largely on the magnitude of global temperature increase and the pace of sea level acceleration, as well as a suite of geological and ecological factors.

The Maryland coastline, with its low elevation and ongoing land subsidence, contains more land vulnerable to sea level rise than other sections of the Atlantic coast (Wu et al. 2009). Particularly in areas where elevation change is gradual, such as Maryland's Eastern Shore, the submergence of large areas of land – including tidal wetlands – is already occurring and is projected to continue in response to accelerated rates of sea level rise (MCCC 2008; USCCSP 2009). Further, an increase in tidal wetland area over the next century is very unlikely, given current rates of loss and few observed instances of new wetland formation (USCCSP 2009).

**Tidal wetland ecosystem services and potential effects of their loss**

Human populations are fundamentally dependent on ecosystem services, the provisioning, regulating, cultural, and supporting benefits that ecosystems provide (MEA 2005). Tidal wetlands provide more ecological services to human populations than any other coastal environment (Gedan et al. 2009). They regulate disturbance in the form of storm and shoreline protection, filter wastewater runoff and sequester nitrogen, function as important carbon sinks, and provide habitat for commercial and other beneficial species (Gedan et al. 2009; Craft et al. 2009; Scavia et al. 2010; Engle 2011). The wellbeing of communities and ecosystems along the Maryland coast depend on the continued provision of these services.

*Disturbance regulation and storm protection.* Costanza et al. (2008) described tidal wetlands as “valuable, self-maintaining ‘horizontal levees’” (p. 247). Their shallow depth and emergent vegetation can protect coastlines from storm surges by providing frictional resistance that absorbs storm energy. The average storm protection value of coastal wetlands in the U.S. is estimated to be $23.3 billion per year (Costanza et al. 2008). Recent intense storms have illustrated the adverse effects of tidal wetland loss and the reduction of their storm protection services. Wetland loss in Louisiana prior to (480,000 ha) and during (20,000 ha) Hurricane Katrina led to a lost storm protection value of $28.3 billion (Costanza et al. 2008). In Maryland, sea level rise combined with wetland loss is having detectable impacts on storm protection. Storm waves are extending further inland, increasing the risk of property and infrastructure damage (MCCC 2008). Since nearly 97,000 homes in Maryland have the potential to be affected by storm surge damage (III 2012), the storm protection services of tidal wetlands are vital.

*Waste treatment and nitrogen sequestration*. The aerobic and anaerobic regimes of wetland soils and their rapid biomass production rates foster the process of denitrification in wetlands (Jordan et al. 2010). Nitrogen may be sequestered in biomass and buried wetland soils, improving water quality in receiving waters. However, potential negative impacts are also associated with the denitrification services of wetlands, including the release of the greenhouse gas nitrous oxide (Engle 2011). The role of wetlands for sequestering pollutants becomes even more critical in the midst of land use change and climate change (Kaushel et al. 2010). Extreme weather events and increased flooding carry pollutants through watersheds, amplifying the risk of aquatic ecosystem degradation. For example, drought conditions in 2002 followed by Tropical Storm Isabel in 2003 increased pulses of pollutants entering the Chesapeake Bay, leading to one of the most severe cases of hypoxia ever recorded (Kaushel et al. 2010). For a region that is expected to gain 25% more impervious surface area (Boesch and Greer 2003) accompanied by increased nitrogen loading, these types of events underscore the value of tidal wetlands for maintaining water quality. The compromised state of tidal wetlands in the Bay, combined with climate-induced losses, has already diminished their waste treatment services (Najjar 2010).

*Carbon sequestration*. Wetlands, which store more than one third of the total world pool of soil carbon, sequester more carbon than any other soil ecosystem (Choi and Wang 2004). The unique properties of tidal wetlands become particularly valuable in the context of climate change and increased atmospheric carbon dioxide concentrations. Unlike inland wetlands, which may contribute to greenhouse gas emissions through the production of methane, coastal wetlands serve as carbon sinks without emitting significant amounts of methane (Choi and Wang 2004). Further, Choi and Wang (2004) noted that the landward expansion of coastal wetlands as a result of sea level rise could potentially increase carbon sequestration if wetlands are replacing other ecosystem types that are less efficient at storing carbon. However, wetland loss has jeopardized this service. A study of coastal wetland loss in Louisiana indicated that destruction of large areas of marsh triggered large losses of sequestered soil carbon, and concluded that proposed coastal restoration efforts would be insufficient for wetlands to regain their role as net carbon sinks (Delaune and White 2012). However, wetland restoration offers potential for maintaining these services. Studies at Maryland's Blackwater Wildlife Refuge have shown that both natural and restored marshes can serve as carbon sinks, suggesting the crucial role of wetland conservation and restoration as concentrations of atmospheric $CO_2$ increase (Strebel et al. 2010).

*Habitat.* Wetlands provide habitat for more than one-third of threatened and endangered species in the U.S. (U.S. EPA 2003). They also provide important habitat and refuge for migratory bird species, as well as many commercial species. In Maryland, wetlands serve as nurseries and spawning habitat for more than two-thirds of the state's commercial fish and shellfish (MCCC, 2011). Salt, brackish, and freshwater wetlands each provide habitats to unique assemblages of species. The high amount of plant biomass in salt marshes supports a wide variety of fish, birds, and invertebrates. Brackish marshes support many of the same species, as well as andromodous fish species, like shad and herring, that move between salt and freshwater habitats to spawn. Tidal freshwater marshes provide forage, shelter, and spawning habitat for estuarine fish and shellfish to complete their life cycles, and may also support higher plant and bird diversity than other marsh types (USCCSP 2009). As sea levels rise, the inland migration of wetlands will entail shifts in vegetation composition and changes in salinity (Burkett 2008). This has the potential to impact species composition and diversity in wetlands, especially as brackish marshes begin to replace freshwater marshes, the most biologically diverse wetland type (MD DNR 2008). It could also impact fisheries by changing habitat suitability for commercial species.

**Recommendations**

The conservation of coastal wetlands is critical for the sustained provision of ecosystem services. As sea level rise accelerates, wetland conservation becomes increasingly urgent and complex. Fortunately, wetlands are resilient and potentially adaptable ecosystems, provided that changes are sufficiently gradual and conditions are conducive to adaptation. Select conservation, management, and outreach strategies are offered below (see also Table 2):

*Limit greenhouse gas emissions.* Since wetlands may adapt to sea level rise if the rate of change is sufficiently slow, a key recommendation is to maintain greenhouse gas emissions levels at or below the IPCC's (2007) low emissions (B1) scenario. Under a high emissions scenario, greater temperature increase, and rapid sea level rise, many tidal wetlands – especially in highly vulnerable areas like the Mid-Atlantic coast - will be unable to persist (MCCC 2008).

*Prevent and reduce stress on wetlands.* Added stressors such as pollution, exotic vegetation, and biodiversity loss can reduce the resiliency of wetland ecosystems and compromise their ability to respond to climate change (Erwin 2009; MCCC 2011). Continued efforts to reduce pollution from stormwater runoff, monitor invasive species abundance, and prevent habitat destruction can assist wetlands in maintaining their functionality.

*Retain open space for wetland migration.* The ability of tidal wetlands to respond to climate change by vertical accretion depends on the availability of space to migrate inland. The presence of barriers such as coastal roads and pavement can slow or stop the retreat of wetlands to higher ground (MCCC 2011). Adaptation strategies should ensure that land use on and near coastlines limits development to provide sufficient space for vertical accretion.

*Restore tidal wetlands*. Given their potential to save costs associated with storm damage alone, wetland restoration is an extremely cost-effective investment for coastal communities (Costanza et al. 2008). Because coastal ecosystems are extremely difficult to restore after being lost to open water (Scavia et al. 2002), it is critical that restoration efforts stay ahead of coastal inundation by rising sea levels.

*Educate public and policymakers about the value of tidal wetlands*. The impacts of sea level rise on Maryland's coastal ecosystems have the potential to affect diverse stakeholders, including commercial watermen, farmers, property owners, and municipal governments (Najjar 2010). Fostering awareness of the ecological and economic benefits of coastal wetlands can support stakeholders in making informed conservation decisions.

## Appendix

| | Estimated increase during the 20th century | Projected increase during the 21st century – IPCC B1 (lowest emissions) scenario | Projected increase during the 21st century – IPCC A1F1 (highest emissions) scenario |
|---|---|---|---|
| Global sea level rise (SLR)$_1$ | 170 mm | 180-380 mm | 260-590 mm |
| Relative Sea Level Rise (RSLR) in Maryland$_2$ | 305 mm | (up to*) 823 mm | (up to*) 1036 mm |

**Table 1.** Global sea level rise (SLR) and relative sea level rise (RSLR) in Maryland - 20th and 21st centuries
Data sources: $_1$IPCC 2007; $_2$MCCC 2008
*The MCCC (2008) does not provide exact figures for the lower bound of the projected relative sea level rise range (RSLR) estimates. The figures provided here represent the upper ends of the range estimates.

| ***Recommendation*** | ***Existing strategies to promote in Maryland*** | ***Strategies that may serve as potential models for Maryland*** |
|---|---|---|
| Limit greenhouse gas emissions | • The Maryland Greenhouse Gas Reduction Act was passed in 2009, requiring the state to develop a plan to reduce its emissions levels from 2006 by 25% by the year 2020 (MDE 2012). | • The UN Environmental Program's Bridging Gaps report suggests "doable actions" for bridging the emissions gap (current emissions levels compared with 2020 targets), including scaling up renewable energy programs, investing in green buildings, and promoting the use of fuel efficient vehicles (UNEP 2012). |
| Prevent and reduce stress on wetlands | • Maryland's Stormwater Management Act of 2007 (MGA 2007) has promoted redevelopment projects focused on reducing impervious surface area. Maryland laws and regulations require Environmental Site Design (ESD) as maximally as possible to control stormwater from new and redevelopment (MDE 2010). | • The Wisconsin Wetlands Association launched a statewide Wetlands Threats Analysis to identify threats to natural processes fundamental to maintaining wetlands and their services (e.g., destruction, altered species composition, habitat fragmentation) to help prioritize conservation actions (WWA n.d.). |
| Retain open space for wetland migration | • The Chesapeake and Atlantic Coastal Bays Critical Areas Act limits development within 300 m of tidal wetlands (Titus et al. 2009), identifying as critical areas "all lands within 1,000 feet of the landward edge of tidal waters or adjacent wetlands, as mapped on the 1972 State Wetlands Maps or designated private tidal wetlands" (MD DOT, 2012). | • Rolling easements (Titus 2011) to preserve ecosystem structure and function by allowing wetlands to migrate inland and preventing the construction of sea walls and barrier structures; *Example* - Rhode Island's coastal zone management program (Higgins 2008). Rolling easements have also been implemented in Maine, Massachusetts, and South Carolina (IPCC 2007). |
| Promote coastal wetland restoration | • The Wetlands Reserve Program (USDA NRCS, 2012) supports Maryland landowners technically and financially in protecting, restoring and enhancing wetlands on their properties, toward the goal of achieving the greatest wetland functions and values. | • Marsh creation projects as part of the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) in Louisiana's Gulf Coast build land by removing sediment from a "borrow site" and pumping it to a restoration site to accelerate the natural land-building process of wetlands (CWPPRA n.d.). |

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|---|---|---|
| Educate the public and policymakers about the value of wetlands and their ecosystem services | • The Maryland Commission on Climate Change develops strategy reports synthesizing research for the public and policymakers, including information on the ecosystem services of coastal wetlands (MCCC 2011, ch. 4).<br>• The Maryland and Delaware Climate Change Education, Assessment, and Research program (MADE CLEAR) promotes public understanding of climate change and its impact on local ecosystems through formal and informal education (MADE CLEAR 2012). | • The Delaware Department of Natural Resources and Environmental Control commissioned and published a report for policymakers outlining the economic value of Delaware wetlands ecosystem services (DNREC 2011).<br>• The U.S. EPA program office in New England operates an adopt-a-wetland program encouraging teachers to engage their students in wetland education and stewardship activities (EPA 2012). |

**Table 2.** Recommended actions for conserving coastal wetlands and maintaining their ecosystem services; existing strategies in Maryland and strategies that could serve as models for Maryland

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