Interagency Partnership to Assess and Restore a Degraded Urban Riverine Wetland: Dyke Marsh Wildlife Preserve, Virginia

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Introduction

The narrow-leaved cattail wetland (Hopfensperger and Engelhardt 2007) known as Dyke Marsh formally became a land holding of George Washington Memorial Parkway (GWMP, a unit of the national park system) in 1959, along with a congressional directive to honor a newly-let 30-year commercial sand and gravel dredge-mining lease at the site (Litwin et al. 2013; Figure 1). Dredging continued until 1974 when Public Law 93-251 called for the National Park Service and the United States Army Corps of Engineers to "implement restoration of the historical and ecological values of Dyke Marsh." By that time, about 83 acres of the marsh remained, and no congressional funding accompanied the passage of the law to effect any immediate conservation or restoration. Decades of dredge mining had severely altered the surface area of Dyke Marsh, the extent of its tidal creek system, and the shallow river bottom of the Potomac River abutting the marsh. Further, mining destabilized the marsh, causing persistent erosion, shoreline retreat, and tidal channel widening after mining ceased (Litwin et al. 2013). Erosion has continued unchecked until the present; approximately 50 acres of the original marsh are now estimated to remain (Figure 2). The specific cause of persistent erosion had been unknown prior to this collaborative study (Litwin et al. 2013) but previously was assumed to be due to flooding by the Potomac River.

GWMP needed to (1) quantify the magnitude of acreage loss, (2) determine the most significant causal agents of marsh erosion, and (3) understand the initial environmental conditions in place prior to dredging, in order to comply with Public Law 93-251 and restore Dyke Marsh to a more naturally sustainable geological and biological system. In 2009, the National Park Service (NPS) entered into partnership with the US Geological Survey (USGS) to investigate the causes and rates of unabated marsh erosion; the results of that part-

The George Wright Forum, vol. 31, no. 2, pp. 116–128 (2014).

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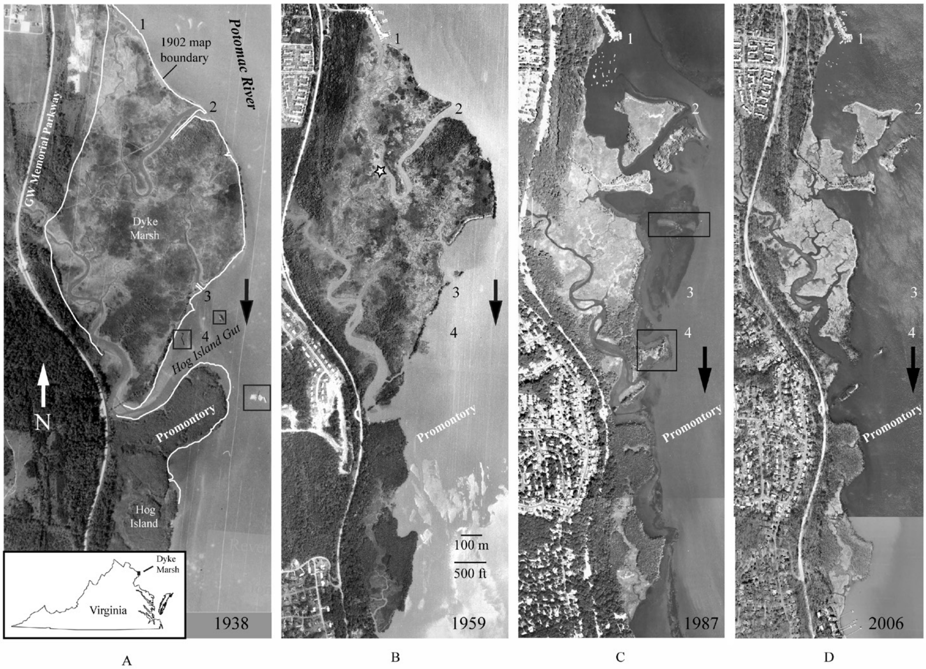

Figure 1. Aerial photos of Dyke Marsh, within George Washington Memorial Parkway. All were taken at approximately low tide conditions. (A) 1938 photo of marsh showing its historical "pre-mining" configuration. By 1940 deep-water access had been dredged from the Potomac River's main channel to the promontory (the approximate initiation of shoreface mining; Litwin et al. 2013, their Appendix 1F). By 1949 the promontory and its wetland forest were mined out (Litwin et al. 2013, their Figure 3). A white line showing the 1902 marsh boundary is overlain on this photo for comparison, to illustrate "pre-mining" landform stability at the marsh. Tidal creeks (mouths) are numbered north to south; the original positions of those creek mouths are shown in all four photos. Black boxes indicate first dredge barges (mining) along periphery of Dyke Marsh. Black arrows indicate direction of Potomac River flow (southward). (B) 1959 photo showing the initial mining-out of the promontory that formed the southern shoreline of tidal creek #4, Hog Island Gut. The locality of the first samples ever analyzed (1963) to estimate marsh age is starred, along tidal creek #2. This is the marsh configuration that existed when the NPS was first delegated oversight of this wetland by Congress. (C) 1987 photo showing marsh conditions about one decade after commercial dredging ended at the marsh. The tidal creek networks are mostly mined out. Black boxes indicate several land areas that disappeared since 1987. (D) 2006 photo showing continued erosion along its southern and western shorelines (Hog Island Gut and its tributaries are now eroding the marsh. The four island remnants of the once-intact wetland also are aggressively eroding away. Figure modified from Litwin et al. 2013.

nership (hereafter referred to as the "interagency study") are the subject of this paper. USGS took the lead on geological research (Litwin et al. 2013) that provided a synthesis of existing knowledge and yielded new data on historical marsh configuration, function, and degrada-

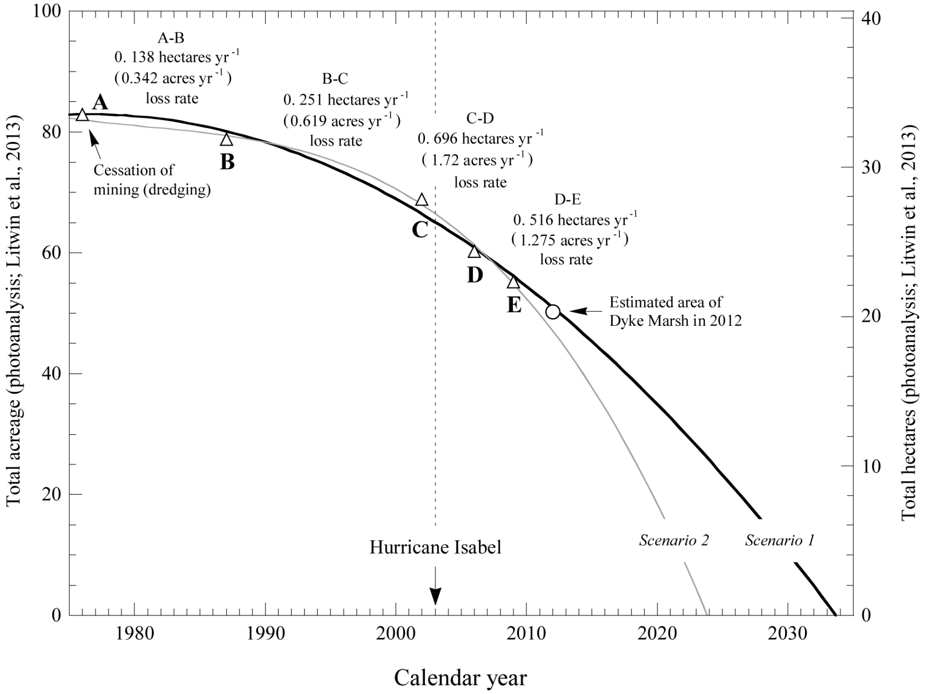

Figure 2. Photo-based acreage estimates of Dyke Marsh (1976–2009), showing marsh size versus time. Note that marsh loss rate is nonlinear. Two equally valid numerically modeled solutions (scenarios 1 and 2) suggest that, without NPS land management remediation, acreage loss rates will increase and lead to the demise of this wetland by 2035 at the latest. Figure from Litwin et al. 2013.

tion. That interagency study focused on (1) quantifying the historical and present-day rates of marsh erosion, (2) determining the natural ("post-mining") causes of marsh erosion, and (3) identifying any human-induced causes that contributed to marsh destabilization and ultimately, to erosional loss of wetland acreage and adjacent river bottom. In turn, NPS provided NRPP (Natural Resource Preservation Program) funding towards the research and logistical support (boat access and GWMP natural resources personnel) to facilitate the necessary site work.

The interagency study integrated radiometric dating, sedimentary textural analysis, field examination of erosional features, analysis of past vegetation (pollen analysis), photoanalysis of past marsh photographic datums, and comparison of navigation maps versus instrumental bathymetry records (i.e., maps from1862 to 2010, versus sonar bathymetry from 1992 and 2009).

The overall research results put into context several geologic factors that likely could diminish the ongoing erosion at the wetland. It also helped park managers to understand the increasing pace of marsh erosion (Figure 3), as well as all of its attendant geologic and ecologic consequences.

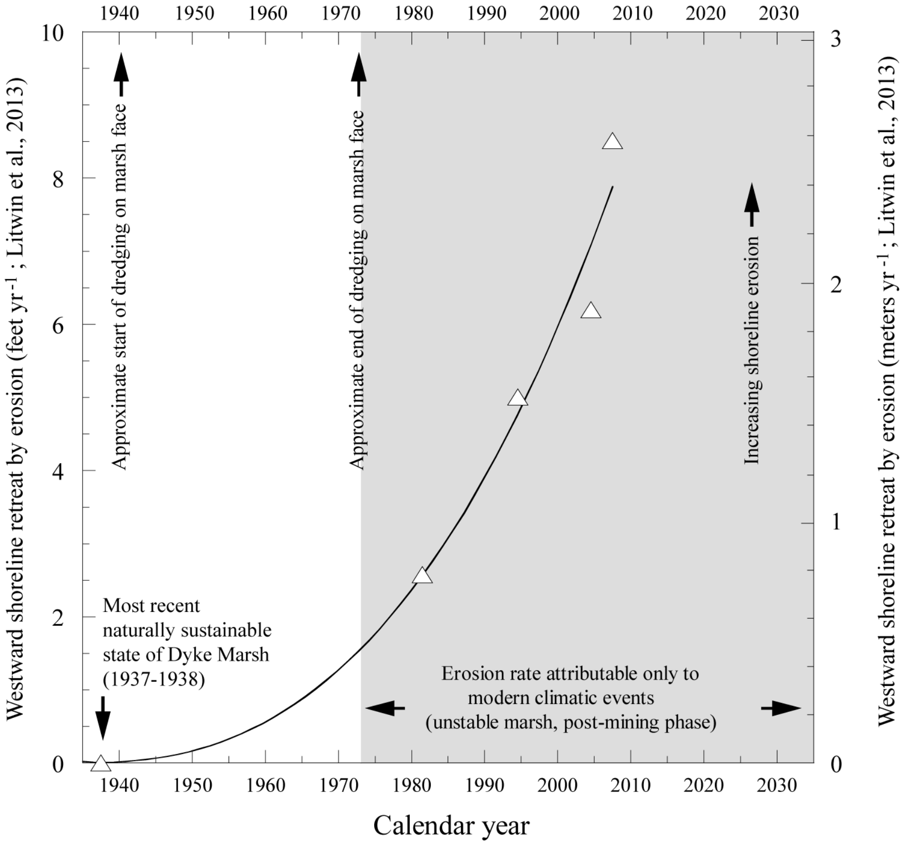

Figure 3. Westward shoreline erosion rates at Dyke Marsh, based on median values measured along 25 fixed reference stations for each of four analyzed time intervals after mining ceased (1976–1987, 1987–2002, 2002–2006, and 2006–2009), with comparison to naturally sustainable "pre-mining" shoreline (1937–1938). This quantifies the increasing erosion of the face of the marsh by northbound storms tracking up the Potomac River valley. Figure from Litwin et al. 2013.

Collaborative study findings

Estimated natural marsh longevity. NPS needed to understand accurately the longevity of the marsh as a persistent landscape feature and the variation in its resident floral communities through time to gain insight on the marsh's past ability to respond to changes in environmental conditions. The first study to estimate the longevity of this wetland (Myrick and Leopold 1963) primarily characterized tidal creek hydrology in the northern half of the marsh. In that study, Estella Leopold[1] analyzed pollen from subsurface channel-bank samples taken from that same tidal creek (creek #2, Figure 1B, indicated by star). The report noted that her field samples yielded pollen assemblages that were similar in character to those found in a Delaware marsh (and which previously had been dated by radiocarbon evidence as 5,000 to 7,000 years old; Myrick and Leopold 1963). This informal comparison became the only known estimate of marsh longevity, and stood for over 40 years, as it was founded on the best available evidence at that time.

USGS researchers took shallow and deep sediment core samples across Dyke Marsh transects, and dated multiple organic samples taken directly from those same cores to get a best approximate age of marsh establishment at the site. The oldest radiometric evidence was obtained from a percussion core taken from the southern marsh, which indicated that marsh probably had developed at this site by the Early Woodland Period (~2,200 BP, or late Holocene). This refined the initial age estimate (Myrick and Leopold 1963), and gave the park updated knowledge of how long the marsh had been in existence and responding naturally to fluctuating environmental conditions. A follow-up high-resolution study of the marsh's paleoclimate history (vegetation response to climate shifts) is in progress. Preliminary results suggest that the forest structure surrounding the marsh has been highly sensitive to climatic warmings and coolings during the past millennium, at short time-scales. In addition, preliminary results suggest the presently observed dominance of narrow-leaf cattail in the Dyke Marsh wetland likely first developed < 1,000 years ago.

Natural and human-induced stressors to the Dyke Marsh tidal wetland system. Multiple factors were implicated in determining why Dyke Marsh is eroding aggressively today, but did so less visibly prior to 1938, based on archival photographic and cartographic evidence. First, the study found no correlation between historical Potomac River flooding frequency and marsh erosion, as had been suspected initially. The study instead determined that other natural processes contributed to the observed persistent marsh erosion. The study noted that by 1949, a long-forested promontory that had existed immediately south of the marsh had been fully removed by the dredge mining. This promontory was underlain by high-quality sand and pea-gravel, making it among the first areas within Dyke Marsh to be targeted for commercial dredging. The study found that elimination of this adjacent forested promontory consequently exposed the marsh to wave energy generated by episodic cyclonic storms (tropical storms and hurricanes) tracking upriver from the south. Prior to 1940, under "pre-mining" conditions and with an intact southern promontory, the maximum linear fetch[2] that potentially would permit waves propagating from the south to be delivered (shoaled) against the southern marsh was close to zero. By 1949, southerly linear fetch exceeded 3 miles, because the promontory that protected the south end of the marsh had been mined out. The removal of the promontory as a buffer gave wind fields of subsequent northbound storm systems a much greater travel path (and opportunity) to build surface waves, and therefore enabled greater potential wave energy to be expended directly against the marsh's southern shoreface.

Prior to dredging, wave energy from the south also had been partly dissipated by the shallow western river bottom along the Potomac River, immediately south of the wetland; historical shallow river depths were confirmed by bathymetry (navigation) maps dating back to 1862. The collaborative study therefore also examined the effects of dredging on the Potomac river bottom adjacent to and south of the marsh. The study found that dredging during the mining phase had occurred to depths extending 30 feet below mean low water in areas that were formerly shallow (2-to-4-foot) river bottom and even previously emergent wetland. This significant change in the depth profile of the Potomac River adjacent to Dyke Marsh continues to have a large impact on how wind-driven waves approach the shoreface of the marsh. On the "pre-mining" marsh the broad shelf of shallow water in conjunction with the forested promontory acted as dual erosion buffers, by causing larger waves to crest and to shoal well before reaching the marsh shoreface. By contrast, the "post-mining" Potomac River bottom profile provides little to no wave-base barrier for maximum-sized waves to shoal against until they reach the marsh shoreface. Furthermore, the 30-foot-deep submerged mining scars within the historical GWMP boundary, observed in recent park bathymetry surveys, are now the loci of aggressive river bottom scour, destabilizing the previously shallow river bottom. As a result, the marsh is increasingly unable to absorb and dissipate storm energy, specifically the wind-driven wave energy from northward-tracking cyclonic summer storms (and probably also cold-season northeasterly storm events, i.e., winter nor'easters).

But even non-storm conditions at the marsh now contribute to persistent erosion. Dredging altered the hydrology by destroying most of the tidal channel network that historically existed on the marsh (based on archival aerial photographs, Figure 1). This original channel network had developed to be approximately in balance for dissipating the energy delivered by daily (non-storm) tides on the Potomac (presently ~3-foot tide range). The "pre-mining" tidal channel network on the marsh directed rising tides and their suspended sediments back into and onto the interior marsh surface through highly sinuous, dendritic, and shallow tidal channels, dissipating that tidal energy, and consequently trapping that formerly suspended sediment onto the marsh surface with each successive tidal cycle. By this process, riverine wetlands along the Potomac served as important natural filters to improve water quality, in conjunction with the tidal cycles. Since dredging began on the marsh, normal tidal flows increasingly exceeded the diminishing marsh remnant's ability to dissipate this non-storm tidal energy and to trap its incoming suspended sediment load. As a result, marsh acreage growth was progressively inhibited. This relatively constant diurnal tidal energy is now being expended across a rapidly diminishing (eroding) marsh acreage, which steadily and notably increases the marsh-tide imbalance, and increasingly impedes the marsh's ability to conserve its acreage. As a result, non-storm tidal energy is now slowly stripping sediment from the interior of the marsh and from its distributaries, rather than adding sediment, as would be predicted under undisturbed and balanced tidal marsh conditions. This non-storm sediment loss is confirmed by modern field observations of deepening and widening tidal channels, tidal channel bank steepening, and shallow nickpoint[3] erosion at the heads of the distributaries, along with surface erosion scour on the interior marsh platform. The USGS study noted that the rate of acreage loss and shoreline loss is now nonlinear, and has become an accelerating feedback loop. The study determined that marsh shoreline erosion (measured due westward) was occurring at a rate of approximately 6–8 feet per year just prior to 2010, and is increasing (Figure 3). From 1976 to 2009, overall marsh acreage loss to erosion has increased from 0.3 acres per year to over 1.2 acres per year, and also is increasing (Figure 2). As a consequence, the study determined that Dyke Marsh likely will disappear within the next 20 years if marsh-tide equilibrium is not restored. These Dyke Marsh wetland erosion rates were unexpectedly high, and found to be comparable in magnitude to wetland erosion rates documented directly along marine coasts of the Mid-Atlantic region, the latter of which suffer the initial impact of landfall hurricanes and tropical storm systems in this area.

Discussion

Other ongoing research at Dyke Marsh (NPS National Capital Region Office of Natural Resources and Science) is yielding independent results that are consistent with these findings, especially regarding an increasing loss of acreage. Since 2006, NPS has been actively monitoring permanent rod surface elevation tables (RSETs; per Cahoon et al. 2002) across the marsh: (1) along the marsh shoreface, (2) along the marsh tidal channels, and (3) on the undissected interior marsh platform (a total of 9 stations). These permanently fixed stations measure the total elevation change of the marsh surface, relative to the bottom of the deep benchmark to which they are attached. The RSET locations also incorporate feldspar marker horizons[4] (Cahoon and Turner 1989) as time datums, along with "frozen-finger"[5] technology (Cahoon et al. 1996) to penetrate the marsh and to get accurate serial measurements of vertical marsh growth due to tides and flood depositional events. Data analyzed to date suggest that average elevation change (including vertical aggradation) of the marsh surface has been keeping pace with relative sea level increases in the Mid-Atlantic region over the past ~80-year trend (NOAA 2014; G. Sanders unpublished data 2014). However, two of the three permanent RSET stations placed parallel to—but inland of—the marsh shoreface are now *at* the retreating edge of the marsh shoreline, and soon will be unusable for monitoring due to aggressive shoreline erosion.

NPS site remediation planning. A restoration and long-term management plan / environmental impact statement (EIS) currently is in final draft form and its completion is anticipated in late 2014. This will provide the National Environmental Policy Act documentation that will guide the site restoration process. The National Park Service and the US Army Corps of Engineers will collaborate on the design and construction of the marsh restoration, with USGS as a scientific advisory partner. The most desirable restoration scenario is to re-balance any natural depositional processes that enable Dyke Marsh to sustain itself in a resilient state. The USGS research helped NPS to understand the geologic processes that build and erode the marsh, and the geologic consequences of human modifications to the marsh's historical configuration. This enabled NPS to select the most effective strategies to mitigate shoreline erosion, as well as strategies to abate the storm-induced degradation and persistent foreshortening of the marsh's largest remaining tidal channel remnant that dissipates tidal energy at this wetland (Hog Island Gut).

Replacement of a promontory in its historical position along the south shore of Hog Island Gut, which had been completely removed by mining between 1938 and 1949 (Litwin et al. 2013), should provide significant protection and stabilization to the marsh, enabling any natural marsh-building processes to increase in effectiveness. Reconstruction of the promontory is a common feature among all alternatives presented in the EIS. It is considered to be an essential requirement for any restoration scenario. The plan includes placing heavy, deep-water fill in the dredge scars near the marsh edge, creating a breakwater at the site of the promontory that was lost to dredging, installing containment cells that will be filled with dredge material to elevations proper for supporting marsh vegetation, and planting native wetland species within those containment cells. Highly sinuous and shallow tidal distributaries for dissipating tidal energy will be created on the new graded surface as part of the remediation, along with continued monitoring of natural sediment deposition rates on the marsh. The active NPS monitoring stations (RSETs) will provide important data on changes in the marsh's ability to trap sediment and to aggrade naturally, as the marsh's acreage and tidal channel network are restored.

The National Capital Region (NCR) of the NPS proposed to Ronald Reagan Washington National Airport in 2013 that Dyke Marsh reconstruction could serve as an acceptable mitigation to counterbalance the loss of ~2 acres of Potomac River bottom upriver (within NCR boundaries), slated to be removed in an upcoming runway extension. The FAA is in favor of this proposed NPS "improvements-in-kind" offer, and has now included that task formally in the airport runway extension project.

Present-day ecosystem services. Despite the erosion and destabilization that currently affects Dyke Marsh, the remaining ~50 acres still provide valuable ecosystem services. Dyke Marsh is located along the scenic GWMP (on the route to Mount Vernon). Approximately 7.4 million vehicles travel the parkway annually (2012 figures), making it a major transportation corridor within the Washington metropolitan area, and it crosses the western edge of the marsh. The marsh acts as a physical storm buffer between the Potomac River and the parkway. At the same time, it provides important green space within a densely populated urban area. GWMP trails at the marsh receive more than 438,000 day-users (foot traffic) annually. Dyke Marsh provides opportunities to enhance the economic productivity of the region through boating, bird watching, fishing, hiking, jogging, biking, and nearby hunting activities. A popular marina and sailing school exists just north of Dyke Marsh. Restoration of this urban wetland will improve each of these diverse public-use services.

Such freshwater wetlands are diminishing nationally as a public and natural resource. Dyke Marsh is the last large remnant of a series of once extensive and numerous tidal freshwater marshes that were lost to expanding development of the Washington area (Updegraff et al. 1954). It has been the focus of many studies of marsh biodiversity and ecology (e.g., Hopfensperger et al. 2006; Mitchell et al. 2007; Barrows et al. 2008; Hopfensperger and Engelhardt 2008; Hopfensperger and Baldwin 2009; Kjar 2009; Steury 2011; Steury et al. 2012, 2013; Cavey et al. 2013; Palinkas et al. 2013). Even in its diminishing state, Dyke Marsh hosts the only breeding population of marsh wrens in the Washington area and provides habitat for a breeding population of the least bittern (rare in the state of Virginia) and state-rare plant species such as river bulrush and rough avens.

Additionally, ~239 species of birds (site nesters, extralocal residents, and transcontinental migratory species) have been documented at this wetland (Johnston 2000; GWMP unpublished data 2014), a diversity that is similar to that observed at other Mid-Atlantic Region coastal sites along the Atlantic Flyway. For example, Prime Hook and Bombay Hook national wildlife refuges (in Delaware, under the jurisdiction of the US Fish and Wildlife Service) document approximately 288 total bird species and 274 total bird species, respectively. If diversity comparisons are made only among total "migratory" (extralocal and non-nesting) species at these three sites, Dyke Marsh hosts ~166 non-nesting species, Prime Hook ~174, and Bombay Hook ~171. By that measure, Dyke Marsh appears to support a *minimum* of ~95–97% of the total non-nesting bird diversity observed at Prime Hook or Bombay Hook, which are two major migratory habitats along the Atlantic Flyway. Preliminary comparisons to Chincoteague National Wildlife Refuge and Assateague Island National Seashore (Virginia), also located along the Atlantic Flyway, yield similar results. Chincoteague hosts ~295 total species (excluding their exceptionally rare taxa such as puffin and jaeger) and ~204 non-nesting species. Assateague hosts ~294 total species, of which 46 taxa are not unequivocally documented and therefore are not counted here (note: nesting species data were unavailable from that site). Based on currently available figures, Dyke Marsh hosts ~81% of the total non-nesting diversity observed at Chincoteague, and ~96% of the presently *confirmed total species* diversity at Assateague. Although the actual component species differ among these five sites, these "non-nesting species diversity" comparisons provide evidence that Dyke Marsh is a similarly significant migratory resource (and urban corridor habitat) along the Atlantic Flyway in the Mid-Atlantic Region.

Impacts of study collaboration

The impacts of this successful NPS–USGS collaboration are grouped into long- and short-term categories below, yielding multiple tangible results from this interagency effort within the US Department of Interior.

Improved ecosystem services. Long-term impacts of restoring Dyke Marsh will include stabilizing two miles of Potomac River shoreline (including along the GWMP, which is, as noted above, a major metropolitan transportation corridor), protecting ~50 acres of existing freshwater tidal wetland, and adding 150 acres of restored wetland in areas where it was lost to dredging. Restoration will help in attenuating tidal energy on the wetland to re-enable natural marsh deposition and in buffering storm energy (to help protect adjacent park and private real estate interests); creating additional economic opportunities for local businesses. Other positive impacts include restoring "urban corridor" wildlife habitat, restoring and increasing historical refugial habitat for endangered species, improving spawning and nursery grounds for (game and bait) fish, and restoring historical habitat for migratory waterfowl (including Arctic-wintering and -migratory species such as the tundra swan and lesser scaup, which have been documented at the marsh). Societal impacts include (1) enhancing natural water filtration along the Potomac River (the source of drinking water for over 4 million people) and in the Chesapeake Bay, (2) increasing natural vegetation-driven denitrification processes to help increase water quality and diminish eutrophication within the Potomac River (Brush 2009; Hopfensperger et al. 2009), (3) helping to reduce sediment transport towards the Chesapeake Bay, (4) increasing local metropolitan carbon storage (carbon sequestration), and (5) improving public recreation and youth natural-science field education opportunities. In these ways, restoration of Dyke Marsh will improve multiple regional-scale ecosystem services and address the NPS Call to Action's Goal #32 ("Crystal Clear").[6]

Restoration appropriations. Short-term impacts include several funding allocations resulting from this research, appropriations that followed an invited congressional briefing by the NPS–USGS collaborators (January 2012) and our published study (Litwin et al. 2013). The initial funds planned for Dyke Marsh reconstruction, as 'improvements-in-kind' in association with upcoming Reagan National Airport runway expansion, will total between $1.7

and 2.5 million. On 29 October 2013, Secretary Jewell held a national press conference at GWMP, announcing that NPS is to receive an additional $24.9 million in Dyke Marsh restoration funds through a competitive grant administered by the Department of the Interior, as part of the 2013 Disaster Relief Appropriations Act (see photo on the cover of this issue). The Dyke Marsh fiscal component alone comprised fully 15% of the national total of $165 million in this storm-relief funding package. These two allocations collectively will enable the restoration of the Dyke Marsh wetland landscape to approximate its "pre-mining" configuration along the Potomac River, and will help to restore part of the extensive riverine wetlands that historically once lined the tidal portions of the Potomac River. Restoring Dyke Marsh's degraded and destroyed wetlands also will help NPS meet the longer-term goal of net gain of wetlands across the national park system (NPS Environmental Policies 2006, section 4.6.5, "Wetlands").

Conclusions

Geology, climatology and meteorology, ecology, and biology are best understood when approached as integrated disciplines. This collaboration was successful because we combined agency expertise, thereby allowing us to understand the interaction of the physical and biological components of this wetland ecosystem. The success of this study also resulted from regular communication with other federal, state, district, local, and nongovernmental entities, including private citizens' groups (e.g., Friends of Dyke Marsh). All were stakeholders in this effort to determine the underlying problems affecting this imperiled wetland. This collaboration demonstrated that a fundamental understanding of geological processes was an important prerequisite to understanding marsh system function (and dysfunction) at this site. Understanding the geologic processes at work on the present marsh remnant helped USGS and NPS to identify appropriate and effective ways to resolve causal problems, rather than only addressing the problematic symptoms generated by a persistently eroding natural, cultural, and recreational resource. Most importantly, this effort highlights the practical value of applying interagency cooperative science to public land management issues, and underscores the benefits of engaging other federal, state, and local stakeholders during that process.

Acknowledgments

This project was supported by the US Geological Survey Climate and Land Use Change Research and Development Program (Landscape Response to Quaternary Climate Change Project, M. Pavich), and the NPS Natural Resource Preservation Program. Diane Pavek, NPS National Capital Region, reviewed a draft of this article and provided helpful comments and edits. We most gratefully acknowledge the strong support that former GWMP Superintendent Dottie Marshall and Deputy Superintendent Jon James provided during the course of our study. We gratefully acknowledge the help of Stacey Underwood (US Army Corps of Engineers, Baltimore District) during the early stages of interagency restoration planning for Dyke Marsh. We thank Susan Guiteras (US Fish and Wildlife Service) for providing bird species data from the Prime Hook and Bombay Hook wetlands. We thank Michael Dixon (US Fish and Wildlife Service) for providing bird species data from Chincoteague National

Wildlife Refuge. We thank Larry Cartwright, Kurt Gaskill, Katherine Wychulis, and Ed Eder (Friends of Dyke Marsh) for verification of bird diversity data at Dyke Marsh.

Endnotes

1. Daughter of late naturalist Aldo Leopold, and sister of the 1963 study's coauthor.
2. The distance across open water over which surface waves can be generated by sustained winds.
3. The point of abrupt slope change in the longitudinal profile of a stream or tributary.
4. Powdered white feldspar is applied to the marsh surface, and is buried in place with sediment supplied by consecutive incoming tides.
5. Liquid nitrogen is dispensed into a hollow probe driven directly downward into the moist marsh surface at the SET station each year. The mud in contact with the tube freezes from the liquid nitrogen, and the probe is pulled; the bright white feldspar (now buried, but visible along the probe) allows vertical deposition on the marsh to be measured (per unit time).
6. "Protect the health of our watersheds by improving water quality, aquatic habitat, and ensuring adequate flows for public enjoyment …" (http://inside.nps.gov/calltoaction/pdf/C2A_2013_screen.pdf).

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