Chapter 21

CONSERVATION OF TIDAL FRESHWATER WETLANDS IN NORTH AMERICA

Dennis F. Whigham, Andrew H. Baldwin & Christopher W. Swarth

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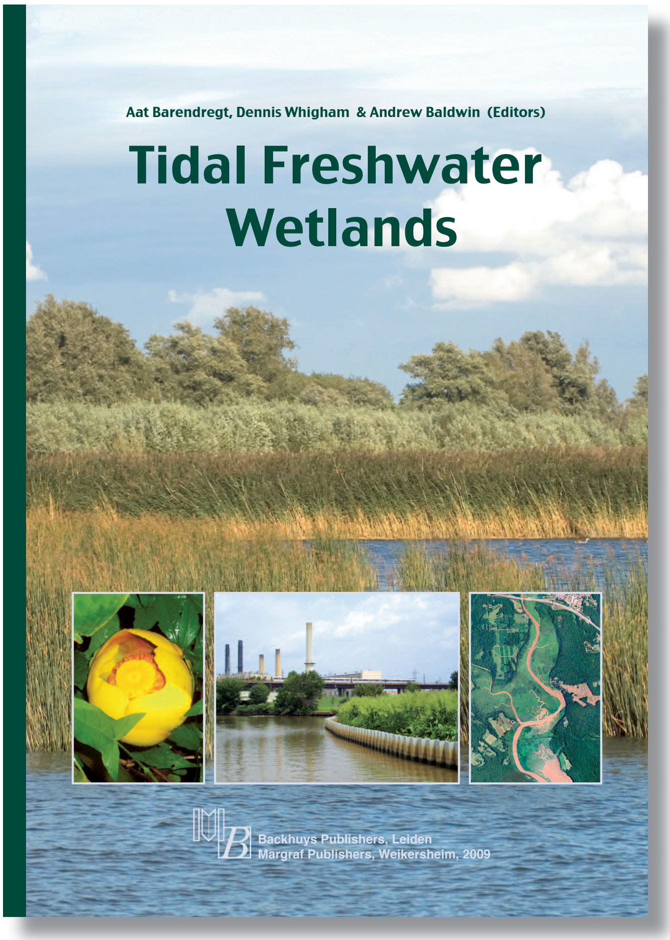

Tidal Freshwater Wetlands, edited by Aat Barendregt, Dennis Whigham & Andrew Baldwin
2009, viii + 320pp.; (incl. 16 colour plates), 21 x 29,7 cm, hardbound
ISBN 978-3-8236-1551-4
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Backhuys Publishers, Leiden
Margraf Publishers, Weikersheim, 2009

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Chapter 21

CONSERVATION OF TIDAL FRESHWATER WETLANDS IN NORTH AMERICA

*Dennis F. Whigham *, Andrew H. Baldwin & Christopher W. Swarth*
** corresponding author - e-mail: whighamd@si.edu*

Abstract: In the USA, significant losses of tidal and non-tidal wetlands occurred until legislation at various levels of government began to slow the rate of losses. Primarily because of their location in the upper reaches of tides in estuaries, large areas of tidal freshwater wetlands were destroyed or degraded prior to the establishment of regulatory controls. Similar to other types of wetlands, a variety of public and private organizations have directly or indirectly had a positive influence on the conservation of the remaining tidal freshwater wetlands. National public (e.g., National Estuarine Research Reserves, National Wildlife Refuges) and private (e.g., The Nature Conservancy) funding efforts designed to conserve rare or threatened habitats or species have resulted in the conservation, and restoration, of tidal freshwater wetlands in many estuaries. In some instances, conservation efforts were directed toward specific tidal freshwater wetlands while in others, conservation resulted from efforts to protect larger areas that included tidal freshwater wetlands. While conservation of individual tidal freshwater wetlands is important, effective conservation requires a broader view. More recently, it has been recognized that protection of individual sites requires effective management, and often restoration, of watersheds that have historically been the sources of nutrients, sediments, and toxics that have had negative impacts on tidal freshwater wetlands. In this chapter we describe examples of public and private efforts that have resulted in successful conservation of tidal freshwater wetlands, with a focus on eastern North America. We also describe threats to the long-term sustainability of conserved tidal freshwater wetlands.

Nomenclature for plants follows the U.S. Department of Agriculture Plant List (http://plants.usda.gov/)

Keywords: conservation, invasive species, National Estuarine Research Reserves, North America, sea level rise

INTRODUCTION

The aerial extent of tidal freshwater wetlands (hereafter referred to as TFW) in North America that exist today is not precisely known (Odum et al. 1984) but it is clear that, with the exception of Alaska (see: Chapter 16), the total extent of TFW is only a fraction of the original area that they once occupied. In the 18th and 19th centuries TFW were lost as a result of dam construction on rivers and diking for purposes of converting wetlands to agricultural lands (Odum et al. 1984, Hackney & Yelverton 1990, Meador 1996, see: Chapter 13). Many TFW were lost in urban areas as a result of filling or the establishment of port facilities and navigation channels (e.g., Philadelphia, Washington D.C., Richmond) (Baldwin 2004). Historically, there were originally fewer TFW on the west coast (e.g., Washington, Oregon, California), but many that were present in the western USA were also diked and converted into other land-uses (e.g., Atwater et al. 1979, Reed 2002, Tanner et al. 2002, Brown & Pasternack 2005).

The rate of loss of all types of tidal wetlands has been reduced dramatically in North America (Dahl & Johnson 1991, Dahl 2000, 2006), primarily due to national, state, and local laws and regulations (Votteler & Muir 1996). A corollary to the cessation of wetland losses has been concerted efforts to conserve and restore large and small areas of TFW on both coasts of North America (see: Chapter 19).

In this chapter we focus on examples of public and private efforts to protect TFW for purposes of conserving biodiversity and improving water quality as well as providing opportunities for research and education. We begin with an example of a national program (National Estuarine Research Reserve System) that was not specifically intended to conserve TFW but has resulted in the conservation of important sites in several states. We then give examples of joint public and private programs that have resulted in the conservation of TFW on the east coast of North America. The third section deals with a more recent approach that focuses on the protection of wetlands, including TFW, through management of watersheds that historically have been the sources of nutrients, sediments, and toxic materials that have degraded TFW. We conclude with a discussion of the sustainability of wetlands that have been conserved given the increasing

Tidal Freshwater Wetlands, pp. 233-240
Edited by A. Barendregt, D.F. Whigham, A.H. Baldwin; © 2009 Backhuys Publishers, Leiden, The Netherlands

potential of a variety of factors to threaten their long-term integrity. Among the most important threats are the effects of global climate change (e.g., sea level rise) and the subsequent movement of brackish water further upstream and into the fresh water portion of rivers. The threat of invasive species is also discussed.

NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM (NERRS)

National and state partnerships like NERRS provide a degree of protection for coastal wetlands, including TFW. NERRS is a network of 26 reserves developed as partnerships between the National Oceanic and Atmospheric Administration (NOAA) and coastal states. The locations and descriptions of the current NERRS sites can be found through linkages on the NOAA web site[1]. An objective of NERRS was to establish a 'protected areas program created by the Coastal Zone Management Act, of 1972, to provide a system of representative estuarine ecosystem areas suitable for long-term research, education, and stewardship'. The system currently protects more than 400,000 hectares of tidal wetlands in the USA, principally saline and brackish tidal wetlands.

While NERRS was not specifically designed to conserve TFW, they were included in NERRS reserves in Maryland, New York, Virginia, Georgia, and South Carolina. In Chesapeake Bay, the largest estuary in North America, two of the three NERRS sites in Maryland (Jug Bay, Otter Point Creek) were established in areas dominated by TFW. In the Virginia NERRS, the 353-ha Sweet Hall Marsh is the only one of the four reserve sites in which TFW is the dominant wetland type. All of the TFW reserves in Maryland and Virginia have become the focus of education and research activities. Sweet Hall Marsh, for example, has been the site of a number of research projects, primarily by scientists at the Virginia Institute of Marine Sciences[2]. The Jug Bay[3] and Otter Point Creek[4] sanctuaries in Maryland also have extensive education and research programs. Examples of publications from the Maryland NERRS sites include studies of vegetation (e.g., Weiner & Whigham 1988, Verhoeven et al. 2001), nutrient cycling (Fogel & Tuross 1999, Verhoeven et al. 2001, Ziegler & Fogel 2003), paleoecology (e.g., Khan & Brush 1994), geomorphology (see: Chapter 4), and management (Haramis & Kearns 2007a).

Figure 1. Overview of one portion of the Jug Bay Wetlands Sanctuary, a National Estuarine Research Reserve site in Maryland. In the foreground is a low marsh habitat dominated by *Nuphar lutea* and *Zizania aquatica* var. *aquatica* (light colored inflorescences clearly shown). The area in the background, beyond the main channel of the Patuxent River, is primarily high marsh habitat that is dominated by a diversity of species including *Peltandra virginica*, *Typha latifolia*, *Zizania aquatica* var. *aquatica,* and several annual *Polygonum* species. Photo by D.F. Whigham.

OTHER PUBLIC AND PRIVATE APPROACHES TO TFW CONSERVATION

While national laws and programs such as NERRS provide protection for tidal wetlands, the degree of protection varies from one state to another because of differences in how wetland regulations are enforced and differing patterns of ownership of tidal lands. In some states (e.g., Maryland), all land below the mean high tide line is the property of the state, while in others (e.g., South Carolina, Connecticut, and Maine), tidal lands are managed as private property. Given the differences in state laws, it is not surprising that a variety of programs have been employed to protect tidal wetlands, including TFW. Some TFW have been conserved through Federal ownership within the national network of wildlife refuges that is administered by the U.S. Fish and Wildlife Service[5]. An example of a refuges that includes TFW is the Savannah River National Wildlife Refuge in South Carolina and Georgia[6], which includes more than 11,000 ha of bottomland hardwood forests and TFW. The John Heinz National Wildlife Refuge at Tinicum preserves 32 ha of TFW in the Delaware River estuary. The Refuge is within one mile of the international airport in Philadelphia, PA. Another large refuge with extensive TFW is the ACE Basin National Wildlife Refuge in South Carolina.

In addition to Federal agencies, TFW have also been conserved through the actions of other public entities. One example of the types of partnerships that have developed among public agencies is a 2,400 ha network of wetland and upland sites along the Patuxent River in Anne Arundel and Prince George's counties in Maryland. One component

[1] http://www.nerrs.noaa.gov
[2] http://www.vims.edu/cbnerr/research/01June02_research_biblio.PDF
[3] http://www.jugbay.org
[4] http://www.otterpointcreek.org
[5] http://www.fws.gov/refuges/
[6] http://www.fws.gov/savannah/

of this network is the Jug Bay Wetlands Sanctuary (Fig. 1) that is owned and managed by Anne Arundel County, a local government entity. As described above, Jug Bay is now part of NERRS. Another component of this network is the Jug Bay Natural Area that includes 120 ha of TFW that are also within the Jug Bay NERR.

Connecticut is another state where TFW have been preserved through a variety of public and private partnerships. The Connecticut chapter of The Nature Conservancy (TNC; the largest private non-profit land conservation organization in the USA[7]) has protected many upland and wetland sites throughout the state[8] with public and private funding. The lower Connecticut River was identified as one of the 'last great places' by TNC. At least three TNC preserves (Whalebone Cove, Selden Creek Preserve, Chapman Pond) include TFW and there are ongoing efforts to preserve other sites (N. Frohling pers. comm.).

TNC activities have also resulted in the conservation of TFW in other states including the Santee River Delta in South Carolina; (E. Krueger pers. comm.) and four other reserves in Maryland; Parker Creek watershed and wetland complex[9], Kings Creek on the Choptank River[10], and sites on the Nanticoke[11] and Wicomico[12] rivers. In Virginia, TNC preserves (i.e., Cumberland Marsh Preserve, Holt's Creek[13]) contain TFW.

CONSERVING INDIVIDUAL WETLANDS IS OFTEN NOT ENOUGH

Conserving TFW through a variety of public and private efforts such as those described above have been an effective conservation strategy but they are not the only methods. Because TFW are degraded by runoff from upstream watersheds (Barendregt et al. 2006), it is increasingly apparent that it is also important to include watershed management as an element for developing long-term conservation strategies. Another issue to consider is the long-term stability and dynamics of conserved TFW in the context of susceptibility to damage by invasive species and the impacts of saltwater intrusion associated with three often interrelated factors. The three factors are sea level rise, reduced freshwater inflow resulting from river management and global climate change, and the deepening of navigation channels in harbors and estuaries that allow saltwater to advance further upstream.

Watershed management

TFW are always located at the interface between tidal and non-tidal segments of rivers; areas that typically have poor water quality due to nutrient inputs from wastewater treatment facilities (Simpson et al. 1983a, Barendregt et al. 2006), high inputs of sediments (Orson et al. 1990; see: Chapter 4), and heavy metal loading (Simpson et al. 1983b), from urban runoff. Consequently, an important management strategy for TFW should be watershed protection and restoration with a long-term goal of improving water quality by reducing nutrients, sediments, heavy metals, and toxics that reach TFW habitats. Water quality improvement can result from two related management approaches. First, point sources of pollution can be identified and eliminated or reduced. Second, non-point sources of contaminants can be identified and managed to reduce pollution. Examples of both strategies are currently being employed in eastern North America, resulting in additional protection of conserved TFW.

Example 1: Source pollution reduction

A wastewater treatment plant in Upper Marlboro (Maryland) discharges into Western Branch, which flows into the Patuxent River within the Jug Bay NERRS site (described in previous sections of the chapter). In 1991, the wastewater treatment plant was upgraded to an advanced wastewater treatment facility (removal of N and P). Staff and volunteers at the Jug Bay Wetland Sanctuary were monitoring water quality within the NERRS site prior to and subsequent to the upgrading of the wastewater treatment plant in Upper Marlboro (Fig. 2). The initial impact of upgrading the wastewater treatment facility was that nitrate concentrations declined in the main channel of the Patuxent River (top diagram). Decreases in nitrate concentration were even more pronounced in water samples collected at high tide in a tidal creek that connected the Patuxent River with a large emergent TFW within the NERRS site (middle diagram). At the same sampling location, nitrate concentrations were, on average, also lower in ebbing water following the upgrading of the wastewater treatment facility. While the wetland clearly removed nitrate from tidal water (compare middle and lower diagrams in Fig. 2), this example demonstrates that management of point sources can result in a positive improvement of water quality in areas where TFW are conserved.

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[7] http://nature.org/aboutus/
[8] http://nature.org/wherewework/northamerica/states/connecticut/preserves/
[9] http://www.acltweb.org/naturalresources/land/land.cfm
[10] http://nature.org/wherewework/northamerica/states/maryland/preserves/art134.html
[11] http://nature.org/wherewework/northamerica/states/maryland/preserves/art150.html
[12] http://nature.org/wherewework/northamerica/states/maryland/preserves/art141.html
[13] http://www.nature.org/wherewework/northamerica/states/virginia/preserves/art1232.html

Example 2: Watershed protection at a relatively small scale

The original acquisition that eventually became the Jug Bay Wetland Sanctuary (approximately 134 ha) was purchased in 1974 and included upland habitats immediately adjacent to the TFW and a relatively small part of a watershed that discharged into the TFW though a tributary stream. At the time the site was purchased, managers recognized that more land was needed to provide a larger habitat buffer and to eliminate potential sources of nutrients flowing into the TFW. Between 1985 and 1997 an additional 112 ha were purchased, and by 2003 other adjacent parcels comprising 360 ha had been added to bring the total to over 600 ha. With the additional land purchases, the sanctuary now controls significant portions of the three local watersheds (Galloway Creek, Two Run Creek, and Pindell Creek) that discharge into TFW at Jug Bay. The conservation of additional land has also resulted in the removal of sources of non-point source pollution by restoring some land-uses (a horse farm and several active agricultural fields) back to native vegetation.

Example 3: Watershed restoration at a large scale

Because successful restoration of TFW habitats may be constrained by the environmental conditions of the surrounding watershed (Baldwin 2004), restoration of TFW in urban areas is closely linked to watershed restoration. For purposes of this discussion, the main point to emphasize is that in highly degraded urban settings (e.g., Schlekat et al. 1994, Velinsky et al. 1994, Wade et al. 1994), successful management of conserved and restored TFW can only be accomplished through a large-scale watershed restoration effort such as the ongoing Anacostia River restoration effort[14] in Maryland and Washington, DC. The Anacostia River, which has a 45,584 ha watershed that lies in Maryland and Washington, DC, joins the Potomac River in Washington, DC and is the focus of several TFW restoration and conservation activities. There are more than 600,000 inhabitants within the highly urbanized watershed and most of the original 400 ha of TFW in the Anacostia River were destroyed by historical dredging and filling activities. The sites that remain today are in a degraded condition and the target of ongoing conservation and restoration activities (Neff 2002, Baldwin 2004). Approximately 30 ha of TFW in the Anacostia River are conserved as part of the Kenilworth Aquatic Gardens, a site administered by the National Park Service[15]. Additionally, wetland restoration efforts have occurred at Kingman Lake and along "fringe" areas of the Anacostia River (Neff 2002, A. Baldwin pers. comm.). While ongoing restoration activities are directed toward reestablishment of TFW, a major component of the Anacostia River efforts focuses on the highly urbanized watershed with a long-term goal of improving water quality, including a reduction of sedimentation within the tidal fresh water zone. Since 1987 millions of dollars have been spent on various restoration activities in the watershed,

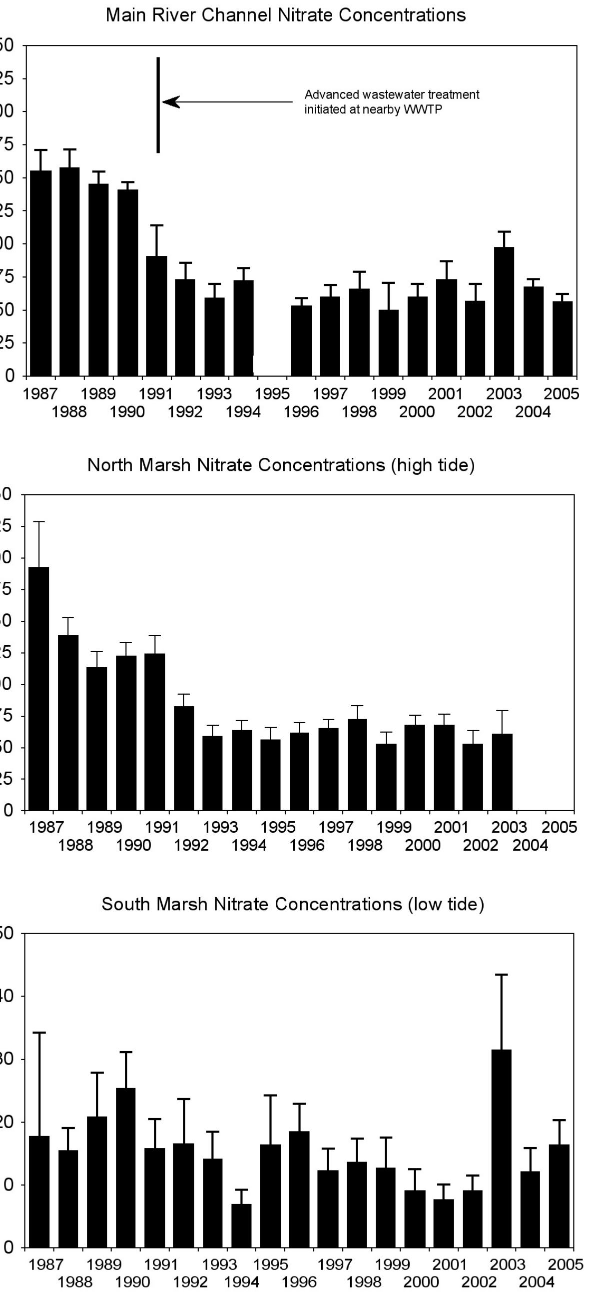

Figure 2. Nitrate concentration (N in mg/L, mean +/- SE) in monthly or bi-weekly surface water samples at three sites in the Jug Bay Wetlands Sanctuary on the Patuxent River (Maryland). Top graph shows NO_3 concentrations in the main river channel, the year (1991) when an advanced wastewater treatment system went on line at the WWTP, and the resultant lowered NO_3 concentrations. Middle graph shows the high NO_3 concentrations in waters that typically flood the wetland during high tide. Lower graph shows the much lower NO_3 concentrations in ebbing waters that flow off the high marsh during low tide. (C. Swarth pers. comm.; 1987-1990 main river data courtesy of Maryland Department of the Environ-

[14] http://www.anacostia.net/download/highlights.pdf
[15] http://www.nps.gov/kepa/

including storm water flow reductions, stream restoration, wetland restoration, land purchases for conservation, and stream riparian buffer restoration[16]. The restoration of the watershed[17] will eventually result in the long-term conservation of biodiversity and ecosystem function in conserved and restored TFW in the Anacostia River.

THREATS TO ALREADY CONSERVED TFW

Invasive species

The impact of invasive plant and animal species are topics of concern globally and in the USA there are clear examples of situations in which invasive species have altered ecosystem structure and function, including wetlands (e.g., Farnsworth & Ellis 2001). There have been few studies of the impacts of invasive plant and animal species in TFW and available results suggest that invaders have little or no quantitative impacts in some instances and clear negative impacts in others (see: Chapters 7 and 9).

One example is the recent expansion of a non-native haplotype of *Phragmites australis* into saline, brackish, and TFW along the east coast of North America (Minchinton & Bertness 2003, Silliman & Bertness 2004, Philipp & Field 2005, Vasquez et al. 2005, King et al. 2007). *Phragmites* is common in many of the conserved TFW described in this chapter (e.g., Perry & Hershner 1999) and it is actively managed with herbicides in conserved TFW owned and managed by The Nature Conservancy (e.g., Findlay et al. 2003, D. Barbour pers. comm.). The long-term negative effects of *Phragmites* on biodiversity and ecological processes are, however, not clear in TFW (Findlay et al. 2003) or other types of coastal wetlands (Otto et al. 1999, Weis & Weis 2003, Silliman & Bertness 2004).

Trapa natans (water chestnut) and *Lythrum salicaria* (purple loosestrife) are two additional non-native plant species that have invaded TFW in conserved sites in New England. In Tivoli Bay, a NERRS site on the Hudson River in New York, the long-term impacts of *Trapa* invasion are ambiguous. Findlay et al. (1989, 1990), for example, found that *Trapa*-dominated sites supported a diverse invertebrate fauna. He also determined that decomposition rates of *Trapa*-dominated sites were higher than the rates of decomposition in sites dominated by *Typha* but the impacts of the differences on ecosystem nutrient dynamics were not clear.

Tidal freshwater portions of the Hudson River have also been colonized by an aquatic non-native animal species, the Zebra mussel (*Dreissena polymorpha*) but there appear to have been few demonstrable impacts on ecosystem processes (e.g., Findlay et al. 1998a). There is evidence, however, from recent research at the Jug Bay NERRS site in Maryland (Baldwin & Pendleton 2003, Haramis & Kearns 2007a) that increased population density of a non-migratory Canada goose (*Branta canadensis maxima*; see: Chapter 7) had dramatic impacts on vegetation. Wild rice (*Zizania aquatica* var. *aquatica*) is a common species in TFW along the east coast of North America (e.g., Whigham & Simpson 1977, Odum et al. 1984) and it is an important food resource for resident animals as well as migratory birds (Meanley 1996). Wild rice began to decline in abundance in Jug Bay wetlands in the 1990s (C. Swarth pers. comm.) and the decline coincided with an increase in the abundance of non-migrating Canada geese. Haramis and Kearns (2007a) conducted a series of exclosure experiments and clearly demonstrated that the decline in wild rice was the result of herbivory by nesting pairs of adults, broods of goslings, and non-breeding subadults that roosted on the river at night (Fig. 3). Management of the geese by harvest of adults and addling eggs and re-establishment of wild rice by fencing and planting has resulted in the restoration of wild rice populations to levels similar to those that were present prior to geese herbivory. The wild rice example clearly demonstrates that active management of existing conserved TFW sites is important and that adaptive management can minimize the impacts of invasive non-native animal species. Similar issues are also relevant in other types of tidal wetlands that have been invaded by non-native species such as the nutria (*Myocastor coypus*) and migratory birds that begin to develop non-migrating populations (Willner et al. 1979, Van den Wyngaert 2001, Johnson & Foote 2005).

Figure 3. Jug Bay Wetland Sanctuary photo showing the impacts of excluding non-migrating Canada geese (*Branta canadensis*) from areas where wild rice (*Zizania aquatica* var. *aquatica*) grows. Wild rice inside exclosures was larger and produced more seeds (Haramis & Kearns 2007a). Photo courtesy of M. Haramis.

Among many land managers there is a belief that non-native species should be eradicated or controlled at any cost, and that their eradication will without question be ecologically and environmentally beneficial. However, there is increasing evidence that the non-native species may not have severe negative impacts on the structure and function of TFW (see

[16] http://www.anacostia.net/download/2004_AnnualReport_Final.pdf
[17] http://www.anacostia.net/

examples above) and control measures need to be weighed carefully (D'Antonio & Meyerson 2002). First, there is the issue of the high cost of species removal, and a general lack of funds available for post-removal monitoring and re-vegetation. Secondly, many exotic species are valuable ecologically and may be beneficial to native species. For example, *Phragmites australis* is effective in trapping and stabilizing sediments in eroding wetlands (Rooth & Stevenson 2000), may increase nitrogen uptake and immobilization (Windham & Ehrenfeld 2003), and is used preferentially by some wetland birds over shorter vegetation (Benoit & Askins 1999). A third concern is damage to non-target species resulting from control efforts; in one study (Kay 1995) wipe-on application of aquatic herbicides to *Phragmites australis* damaged adjacent native emergent plants including *Leersia oryzoides* and *Eleocharis quadrangulata*. Presumably direct application to plant leaves would cause less impact to other species than backpack or aerial spraying, other common methods of control. Fourth, it may be beneficial to introduce non-native species to assist with restoration of some degraded sites, for example for soil erosion control (D'Antonio & Myerson 2002). And fifth, indirect environmental impacts in the form of greenhouse gas emissions and natural resource depletion may result from energy and materials costs of manufacturing herbicides, helicopter use for spraying, and other energy-intensive activities. Indirect impacts like these are rarely considered in determining the cost-effectiveness of non-native species control.

These and other considerations suggest that plans to control non-native species need to be subjected to a careful, systematic analysis of ecological and socioeconomic benefits, costs, and impacts before they are implemented as part of a conservation strategy. Once plans are implemented it is then important to follow the progress of the management project in order to make subsequent adjustments when monitoring demonstrates that the original goals have not been attained.

Salt water intrusion

Any natural or anthropogenic activities that result in the movement of brackish water in the direction of TFW have the potential to trigger dramatic changes. At least three interrelated factors may influence the limit of brackish water in estuaries, and subsequently into portions of estuaries where TFW occur: sea level rise, dam construction, and river dredging. Each of these has the potential to create negative impacts on TFW on the east coast of North America.

Sea level rise

Accelerated sea level rise, caused by global warming, can impact tidal wetlands by increasing tidal submergence time (hydroperiod), by pushing saline and brackish water further into estuaries, or by a combination of both (Hull & Titus 1986, see: Chapter 23). Many species that occur in TFW are sensitive to small salinity changes and to an increase in the depth of flooding that would be associated with increasing rates of sea level rise (Baldwin et al. 2001). Increased salinity also can exacerbate the deleterious impacts of increased flooding (McKee & Mendelssohn 1989).

The intrusion of brackish water into tidal fresh water areas will also alter patterns of nutrient cycling. The biogeochemistry of phosphorus, for example, changes dramatically along the salinity gradient in estuaries. In the Parker River and the Potomac River estuaries, efflux of dissolved PO_4^{3-} from sediments is much faster in brackish waters than in tidal fresh waters where FeOx sequesters PO_4^{3-} in the surface sediments (Callender 1982, Callender & Hammond 1982, Hopkinson et al. 1999).

There is already evidence of the effects of brackish water intrusion at Sweet Hall Marsh, a TFW in Virginia (Perry & Hershner 1999). Perry and Hershner (1999) compared vegetation patterns over a 13-year period and found evidence for an increase in species that tolerate brackish conditions (e.g., *Spartina cynosuroides*) and a decrease in the abundance and biomass of freshwater species such as *Peltandra virginica*. There is also evidence from long-term salinity measurements in the Patuxent River estuary (Maryland) that there is more frequent intrusion of brackish water into the Jug Bay NERRS site (Fig. 4).

In addition to salinity increases, some studies of wetland deterioration suggest that TFW may not accrete sediment at a rate sufficient to keep pace with relative sea level rise. A study of wetlands at Jug Bay reported a decrease in surface elevation of 1.4 mm/yr over a 2.5 yr period, suggesting that accretion was insufficient to keep pace with relative sea level rise (Childers et al. 1993). On the other hand, TFW may not be as susceptible to increases in sea level as brackish and saline wetlands, possibly due to high sedimentation rates in the tidal fresh water zone of tidal rivers. In a study of wetland loss in the Nanticoke River estuary (Maryland and Delaware) between 1938 and 1985, TFW appeared to be accreting sufficiently to keep pace with relative sea level rise and were more stable than brackish wetlands farther downstream in the estuary (Kearney et al. 1988). Given the importance of sediment accretion to the integrity of TFW in the face of sea level rise, efforts to increase the input of sediments into wetland systems may help maintain the extent of TFW despite increasing water level.

Several approaches to increasing sediment input to wetlands have been pioneered in the delta plain of the Mississippi River in coastal Louisiana. Two promising approaches are the diversion into wetlands of fresh water containing entrained sediment from rivers and the spraying or pumping of dredged sediment onto the wetlands (see: Chapter 19). Fresh water and its accompanying sediment have been diverted from the Mississippi River into Breton Sound at the Caernarvon diversion, downstream of New Orleans, Louisiana. This diversion increased wetland vertical accretion, accumulation of mineral sediment and organic matter, and nutrient availability (DeLaune et al. 2003). Additionally, fresh water

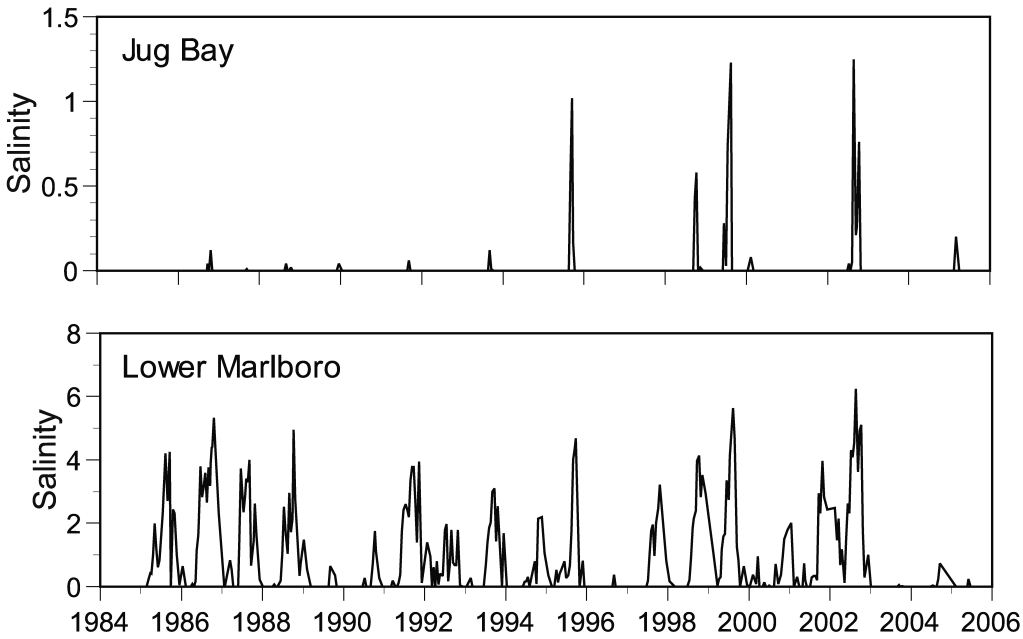

Figure 4. Biweekly surface water salinity (parts per thousand) in fresh water (Jug Bay) and brackish (Lower Marlboro) sections of the Patuxent River estuary (data from the web site of the Chesapeake Bay Program[18]). Tidal freshwater wetlands occur at the Jug Bay site and brackish wetlands occur in the Lower Marlboro portion of the Patuxent River estuary. Figure prepared by and made available by Tom Jordan, Smithsonian Environmental Research Center, Edgewater, MD.

plant species are replacing wetlands formerly occupied by salt-tolerant species, and an increase in soil organic matter was attributed to increased plant productivity (the source of organic matter) (DeLaune et al. 2003). A smaller-scale method of introducing sediments is a technique called thin-layer deposition, which involves spraying a thin layer of dredged sediment onto the wetland surface. In a study in the Birdsfoot Delta at the mouth of the Mississippi River, thin-layer deposition of sediment increased the growth of the salt marsh plant *Spartina alterniflora* by a factor of three over pre-application conditions (Ford et al. 1999). However, while higher sediment accretion occurred in sprayed areas, elevation did not increase significantly. Nonetheless, this study suggests that sediment addition might also improve growth conditions in TFW that are deteriorating due to high rates of relative sea level rise. Sediments contain nutrients, and they also contain iron, which may precipitate sulfides, thus reducing phytotoxicity in the plants that are subjected to the increased salinity (DeLaune et al. 2003).

In the long-term, even with sediment additions there may be little that can be done to avoid the impacts of projected sea level rise on TFW. In terms of salinity impacts, preserved sites that are located near the existing interface between the tidal freshwater and oligohaline zones in estuaries are likely at greatest risk. An effective approach for adaptive management of these TFW would be to identify and conserve sites that are as far as possible beyond the limits of brackish water intrusion. It would take longer before sites in those types of locations are impacted by salt water intrusion. In terms of rising water level, it may be beneficial to preserve topographically flat upland areas adjacent or upstream of currently existing TFW so that wetlands can migrate landward. Such a scenario is not unforeseeable, as sea levels are expected to rise on the scale of meters during the next centuries.

Dam construction

A factor that resulted in the historical loss of TFW in New England states (e.g., Maine, Rhode Island) and states on the south Atlantic coast (Georgia, South Carolina) is dam construction. In New England, elevation gradients between non-tidal rivers and tidal estuaries are typically steep and dams were historically placed at the boundary between non-tidal and tidal areas, i.e., the location where TFW occur. If TFW were not destroyed as part of the dam construction process, sites upstream were destroyed by flooding. Downstream of dams, brackish water intruded further upstream because of altered flows (less fresh water input into the estuary) resulting in the loss of TFW. Few new dams are being constructed in New England and dam removal is beginning to occur, a process that potentially will result in the restoration of TFW in some systems.

In the southeastern USA, there are plans to construct dams in non-tidal rivers such as Pamunkey River in the Chesapeake Bay portion of Virginia (P. Megonigal pers. comm.) for purposes of water supply. Water supply reservoirs typically result in a decreased flow of fresh water into downstream estuarine systems and a subsequent movement of brackish water further upstream. These conditions poten-

[18] http://www.chesapeakebay.net/data_waterquality.aspx

tially have negative impacts on TFW. The negative effects of dam construction on TFW can, however, be reduced by regulation of discharges from dams to ensure that fresh water flows are adequate to impede the intrusion of brackish water further up the estuary.

River dredging

Dredging for navigation channels and harbors results in changes in the tidal regime (Hackney & Yelverton 1990) and upstream movement of brackish water. Hackney and Yelverton (1990) quantified significant losses of TFW in response to a combination of sea level rise and dredging activities in the Cape Fear River (North Carolina). Areas that were historically dominated by TFW became brackish wetlands. As coastal ports and rivers are expanded to accommodate increased ship traffic, the effects of managing harbors and rivers on upstream tidal wetlands needs to be determined and evaluated in the decision making processes.

SUMMARY

Many TFW in North America have been heavily impacted by human activities but the rate of loss of TFW has decreased significantly and there are now many efforts to restore and conserve these wetlands (see: Chapter 19). In this chapter we have offered an overview of conservation activities on the east coast of North America in the context of both public and private conservation efforts. TFW have been conserved in most states where they occur, resulting in a significant number of publicly owned, protected areas that focus on conservation, research, and education. TFW are, however, susceptible to a range of natural and anthropogenic factors that could impact them negatively. We suggest that management options need to be regularly addressed at each TFW reserve to ensure that any negative impacts of runoff from adjacent and more distant watersheds, invasive species, and salt water intrusion can be avoided or mitigated. The continued survival and conservation of TFW will, however, require a more proactive approach. Additional sites need to be conserved in estuarine systems where the currently conserved sites are near the upper limit of brackish water. A desirable goal of TFW conservation would be to consider the current distribution of conserved areas and to develop a plan to ensure that a network of additional sites will exist in the future to assure the continued persistence and ecological integrity of this unique type of wetland ecosystem.

ACKNOWLEDGEMENTS

We thank the following individuals who provided information on the status of TFW in their states and regions that was otherwise difficult to obtain: Frank Golet (Rhode Island), Tom Kutcher (Rhode Island), Eric Kruger (South Carolina), Deborah Barber (Maryland), Wiley Kitchens (Florida), William Conner (South Carolina), Rebecca Sharitz (South Carolina), Mike Kennish (New Jersey), Greg Kearns (Maryland), Ken Moore (Virginia), Nathan Frohling (Connecticut), Ralph Tiner (Massachusetts), Sandra Upchurch (South Carolina), Michelle Dionne (Maine), Peter Wellenberger (New Hampshire), Christine Gault (Massachusetts), Ralph Zampella (New Jersey). The manuscript benefited by editorial comments of Allen Griffith.

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