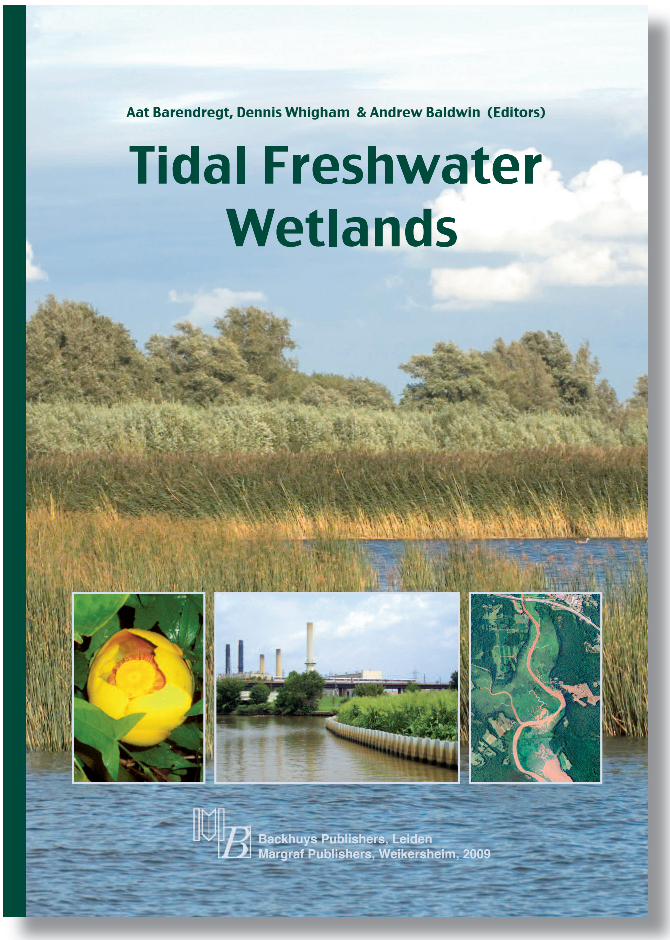
Chapter 14

TIDAL FRESHWATER WETLANDS OF THE MID-ATLANTIC AND SOUTHEASTERN UNITED STATES

James E. Perry, Donna M. Bilkovic, Kirk J. Havens & Carl H. Hershner



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Chapter 14

TIDAL FRESHWATER WETLANDS OF THE MID-ATLANTIC AND SOUTHEASTERN UNITED STATES

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Abstract: Tidal freshwater wetlands (TFW) commonly occur upstream in the tidal estuaries of the mid-Atlantic and southeastern regions on the east coast of the USA. Sediment, supplied to tidal freshwater wetlands via upstream runoff, natural bank erosion, and storm tides, restores marsh elevation and allows TFW to keep up with winter erosion and relative sea level rise. Vegetation zonation is usually indistinguishable, with a few exceptions near the margins of creeks and rivers. Rising sea level is of particular importance to TFW since their survival depends on regular inundation by tidal fresh water. Invasive plant and animal species also have the potential to become a major economic and ecological problem in our TFW. Nutrient cycles in TFW are not well defined, but studies suggest that they are a source of dissolved inorganic carbon (DIC) and export reduced N into the adjacent estuary. Therefore, an increase in salinity, such as through an increase in tidal prism, may alter the rates and dynamics of overall DIC cycling in the mid-Atlantic and southeastern USA tidal estuaries. These TFW are also impacted by activities in adjacent terrestrial environments that are not necessarily managed with any interest in impacts on the wetlands. The consequence of these activities is that habitat and water quality functions of TFW in the mid-Atlantic and southeast region may be significantly compromised. For example, the building of erosion control structures upstream of TFW may alter the sediment load available to counter sea level rise and would, therefore, alter the biotic composition and nutrient processes in TFW. Overall, we have little information on the magnitude or timing of these changes. More research is needed to better understand the changes that may alter the ecology of TFW in the mid-Atlantic and southeast.

Plant nomenclature follows USDA Plants Database (http://plants.usda.gov).

Zoological nomenclature follows Integrated Taxonomic Information System (http://www.itis.gov/)

Keywords: mid-Atlantic wetlands, invasive species, nutrients, sea level rise, southeastern wetlands, wetland biota, zonation

INTRODUCTION

Tidal freshwater wetlands (hereafter referred to as TFW) are important components in the upper reaches of USA estuarine ecosystems. They are found on the upstream edges in estuaries where the lunar tides of the ocean meet out-flowing fresh water moving through rivers and streams from their headwaters (see: Chapter 1). This combination creates a unique environment in which the ebb and flow of the tide dominates the water cycle. The rising and falling waters, however, are fresh, not salty or brackish. This combination of factors makes TFW one of the most species-rich and structurally diverse ecosystems (Odum et al. 1984, Odum 1988).

There are numerous TFW along the east coast of the USA, many of which have been impacted by human activities. In the 18th and 19th century many southeastern TFW were diked and converted to rice fields (Odum et al. 1984, Huang & Morris 2003, Wetzel et al. 2004). Most of these diked wetlands have been abandoned over the past century and left to convert back to productive TFW (Odum et al. 1984, McKellar et al. 2008). All TFW along the Atlantic coast are, and will continue to be, impacted by relative sea level rise, groundwater withdrawal, water diversion projects, and watershed land use changes (Perry & Hershner 1999, Baldwin et al. 2001, Baldwin & Pendleton 2003, Huang & Morris 2003). In this chapter we will explore the biological, chemical, and physical properties of the TFW along the shores of the mid-Atlantic (Delaware, Maryland, and Virginia) and the southeastern states (Georgia, North Carolina, and South Carolina).

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Table 1. Distribution of tidal freshwater wetlands in the mid-Atlantic and southeastern USA. After: Mitsch & Gosselink 2000.

State	Area (ha)
Delaware	823
Maryland	10,345
Virginia	16,000
North Carolina	1,200
South Carolina	26,115
Georgia	19,040

Distribution

TFW are found on the upstream reaches of coastal estuaries in many parts of the world (see: Chapter 1). However, the highest concentrations of TFW in the USA are found in the mid-Atlantic and southeastern regions, where numerous well-mixed estuaries occur (Odum et al. 1984). There are over 8 x 10^5 ha (2 x 10^6 ac) of TFW broadly distributed from the Chesapeake Bay region in Virgina and Maryland to Florida and the Gulf of Mexico (Odum et al. 1984, Mitsch & Gosselink 2007). The approximate areas of TFW in the mid-Atlantic and southeastern USA are given in Table 1. Nearly all tributaries of Chesapeake Bay, and coastal South Carolina and Georgia, give rise to expansive TFW. In North Carolina most of the marshes are located behind barrier islands that inhibit lunar tide fluctuation. However, TFW are found in southeastern North Carolina above the estuarine-reach of Cape Fear River.

Physiographic setting

TFW vary in form and size from narrow fringing wetlands of only a few square meters to vast wetlands that cover hundreds of hectares between river and stream meanders. The slopes of the larger wetlands are gradual and drain nearly completely at low tide through many small tidal creeks and underground muskrat runs (Odum et al. 1984, Odum 1988, Simpson et al. 1983a, Perry 1997, Baldwin et al. 2001, Mitsch & Gosselink 2007). Tides in TFW occur twice daily and lag behind tides at the mouth of the estuaries by as much as six hours (NOAA 2007). In the Chesapeake Bay the tide range varies from about 0.3 m (1 ft) in the upper Rappahannock River, just southeast of Fredericksburg, Virginia, to slightly more than 1.2 m (4 ft) on the Mattaponi River at Walkerton, Virginia. The latter represents one of the largest tidal ranges in the Chesapeake Bay watershed (NOAA 2007). Tide range in the southeastern TFW varies from 2.7 m (8 ft) in the Savanah River (Wetzel et al. 2004) to less than 10 cm (a few inches) in Pamlico Sound, North Carolina. While the salinity of the tidal waters that reach these regions' TFW is usually less than 0.5 ppt, this may vary widely in TFW on the upstream reaches of the estuaries waters. Sweet Hall Marsh, a TFW on the Pamunkey River, Virginia, USA, is located on the upstream reaches of the York River estuary; the salinity of the tidal waters that flood Sweet Hall Marsh depend heavily on the precipitation runoff of the upstream watershed and may vary on a daily, weekly, monthly, and yearly level. In 2002, recorded as a severe drought year in eastern Virginia (VDEQ 2007), salinities in the water column adjacent to Sweet Hall Marsh varied from 1 to 12 ppt. In 2003, recorded as a normal rainfall year (NCDC 2004), salinity at Sweet Hall Marsh varied between 0.0 to 1.0 ppt (Davies 2004) (Fig. 1).

BIOTA

Zonation and vegetation

While zonation can be clearly seen in some areas of particular wetlands, it may be difficult to find in others (Whigham & Simpson 1977, Doumlele 1981, Odum et al. 1984) (Fig. 2). TFW in the mid-Atlantic and southeastern regions of the USA are dominated by vascular plants that are adapted to prolonged periods of soil inundation and saturation. More than 60 wetland species of vascular plants have been identified in TFW of the Pamunkey River, Virginia (Doumlele 1981, Perry & Atkinson 1997, Perry & Hershner

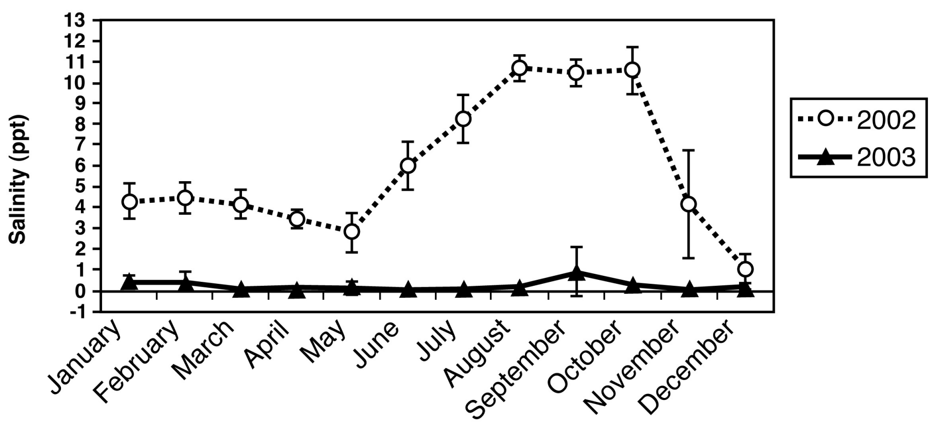

Figure 1. Average monthly water column salinity for Sweet Hall marsh on the Pamunkey River, Virginia, for the years 2002 and 2003. Rainfall for the growing season (April to October) of the year 2002 was designated as severe drought (VDEQ 2007) while the 2003 growing season was designated as normal rainfall (NCDC 2004). Salinity was measured using a YSI 2000 handheld meter. From: Davies (2004).

1999, Davies 2004), 137 species in the TFW of Jug Bay Wetlands Sanctuary, Lothian, Maryland, USA (JBWS 2007a), and 98 species in a study of four TFW along the Patuxent River (Anderson et al. 1968). Many are an important source of food and habitat for waterfowl. TFW also harbor several rare plant species found only along the Atlantic coastal plain including the yellow pond-lily (formerly known as: narrow-leaved spatterdock) (*Nuphar sagittifolia*), found below the mean low water reaches of the tides, and sensitive joint vetch (*Aeschynomene virginica*), found where muskrat activity has created eat-out areas and, therefore, eliminating taller species that would normally overshadow the sensitive joint vetch plants. The latter species is federally listed as Threatened (Ware 1991, Townsend 2007) and is endemic to TFW and slightly brackish wetlands of Maryland, New Jersey, Virginia, and North Carolina (Ware 1991, USFWS 1995, Bailey et al. 2006, Perry & Atkinson 2007).

Odum et al. (1984) defined eight TFW plant communities: 1) spatterdock, 2) arrow arum/pickerelweed, 3) wild rice, 4) cattail, 5) southern wild rice, 6) mixed aquatic, 7) big cordgrass, and 8) bald cypress/blackgum communities. The latter community, comprised mainly of woody species, will not be considered in this chapter.

Spatterdock communities are dominated by nearly monospecific stands of spatterdock (*Nuphar lutea*) (Fig. 2a) and are found on the marshes' boundary with open water. Inundation stress is high in this community as it is usually located below the mean low water mark. Pressurized gas flow (Mitsch & Gosselink 2007) and the presence of aerenchymous tissue in the stems and the thick rhizomes (Odum et al 1984) provide the spatterdock with the ability to survive the long inundation periods. The rare narrow-leaved spatterdock, if present, can be found in this community.

Moving landward between the low water and high water line is the arrow-arum/pickerelweed community. It usually exists as a thin fringe of herbaceous vegetation dominated by arrow arum (*Peltandra virginica*) and pickerelweed (*Pontederia cordata*) (Fig. 2). These species may also be found farther inland in the wetland, in areas of lower elevation, along internal creekbanks, and in muskrat eat-out zones. Arrow-arum in particular can be found growing throughout the wetland and can dominate much of the wetland during the early part of the growing season. By mid-season it succumbs to the taller dominant species of the other communities (Perry & Hershner 1999, Davies 2004, Perry & Atkinson 2007). Where this community mixes with other communities, plant species richness is high (Odum et al. 1984, Davies 2004, Perry & Atkinson 2007). A shorter ground cover layer is common in the arrow arum/pickerelweed community and is mainly comprised of eastern grasswort (*Lilaeopsis chinensis*) and awl-leaf arrowhead (*Sagittaria subulata*). Also found in this layer are several rare plants such as Welsh mudwort (*Limosella australis*), Nuttall's mudflower (*Micranthemum micranthemoides*), and the shore quillwort (*Isoetes riparia*) (Townsend 2007).

The wild rice community is dominated by northern wild rice (*Zizania aquatica*), but contains many other sub-dominant species, such as rice cut grass (*Leersia oryzoides*), halberdleaf tearthumb (*Polygonum arifolium)* and arrowleaf tearthumb (*Polygonum sagittatum*), usually in the latter part of the growing season. In many mid-Atlantic and southeastern TFW this community can be expansive (Odum et al. 1984). Where it merges with other communities, we find the largest and most species-rich portion of TFW.

In the mid-Atlantic region, cattail communities tend to be small and are dominated by broadleaf cattail (*Typha latifolia*), narrowleaf cattail (*T. angustifolia*), and/or an aggresive hybrid of the two, *Typha* x *glauca* (Bevington 2007). Farther south, broadleaf and southern cattail (*T. domingensis*) are most common and community size may increase. Recent studies indicate that cattail-dominated areas may be on the increase in TFW that have received nutrient-rich runoff from adjacent farm fields.

Southern wild rice communities are also small in the mid-Atlantic region but increase southward. Named for the perennial southern wild rice (*Zizaniopsis miliacea*), wild rice communities include such associates as the broadleaf and southern cattails, Jamaica swamp sawgrass (*Cladium mariscus* ssp. *jamaicense*), rice cutgrass, and common reed (*Phragmites australis*).

Most TFW fall within a category called the mixed aquatic community (Odum et al. 1984) (Fig. 3). Arrow-arum is the

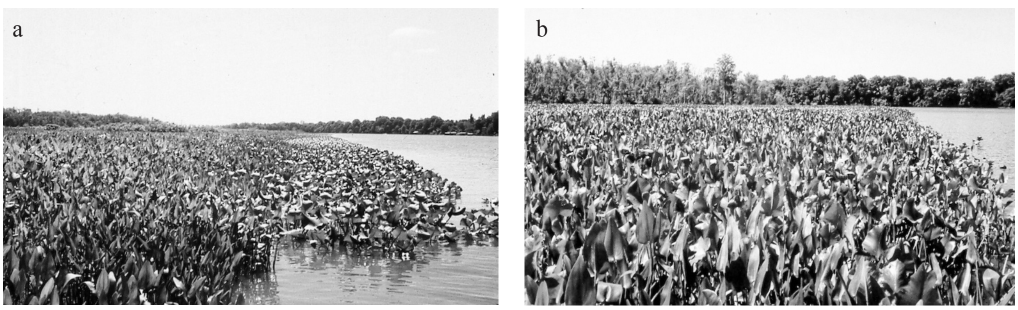

Figure 2. Examples of two communities that show both a strong and no zonation. (a) Arrow-arum/pickerelweed (*Peltandra virginica* / *Pontederia cordata*) (on left) and spatterdock (*Nuphar lutea*) community on the right showing a strong zonation between the two. (b) Both communities well mixed with no zonation. Both photos were taken on the Pamunkey River, Virginia on the same day. Photo (a) is from the waterward edge of Lilly Point marsh and (b) from the northern waterward edge of Sweet Hall marsh. The marshes are approximately 5 km apart, with Sweet Hall marsh closest to the estuary. Photos by J. Perry.

dominant species early in the growing season; however, as the season progresses, many other species quickly take over. Knotweeds (*Polygonum punctatum, P. hydropiperoides*), sweet flag (*Acorus americanus*), tussock sedge (*Carex stricta*), royal fern (*Osmunda regalis*), and marsh fern (*Thelypteris palustris*) play an important role in the herbaceous layer (Doumlele 1981, Odum et al. 1984, Perry & Hershner 1999). The tussock sedge and royal fern form rounded hummocks approximately 0.3 m (1 ft) in diameter and up to 0.75 m (2.5 ft) high and are commonly associated with muskrat eat-outs when found in this community (Fig. 4). The higher elevation of the presence of hummocks allows less inundation-tolerant species, such as Canada germander (*Teucrium canadense*), crimsoneyed rosemallow (*Hibiscus moscheutos*), hemlock waterparsnip (*Sium suave*), poison ivy (*Toxicodendron radicans*), spotted water hemlock (*Cicuta maculata*), and swamp rose (*Rosa palustris*), to survive. Rushes are also an important component of these communities and include chairmaker's bulrush (*Schoenoplectus americanus*), common three-square *(S. pungens),* river bulrush (*S. fluviatilis*), and softstem bulrush (*S. tabernaemontani*). This community probably represents a mixing of many of the other zones.

The big cordgrass community (Fig. 5) is dominated by big cordgrass (*Spartina cynosuroides*) and is found in TFW that are located near the head of the estuary. These communities are often impacted by surges of salt water over the marshes during storms, or through an extension of salt water up an estuary due to sea level rise (Perry & Hershner 1999, Davies 2004, Perry & Atkinson 2007) (see: discussion below). Many of Odum et al. (1984) "transitional wetlands" of Delaware probably fit into this catagory (see:

Figure 3. Mixed marsh communities are the most diverse of the tidal freshwater communities. While co-dominated by numerous species, they may change throughout the season. The photo was taken in Sweet Hall marsh on the Pamunkey River, Virginia in mid-September. Mixed marsh co-dominated by crowned beggartick (*Bidens coronata*, foreground), crimsoneyed rosemallow (*Hibiscus moscheutos,* center), and shallow sedge (*Carex lurida*, right forefront). The tall plant throughout the photo is New York ironweed (*Vernonia noveboracensis*). Photo by J. Perry.

Figure 4. Photo of a muskrat eat-out area in Jug Bay, Patuxent River, Maryland. Photo by A. Baldwin.

Table 1). Other species in this community include common reed, knotweeds, smooth cordgrass (*Spartina alterniflora*), swamp dock (*Rumex verticillatus*), and tidal marsh amaranth (*Amaranthus cannabinus*).

In the winter, TFW may appear as mud flats. Unlike the salt marshes dominated by more fibrous and persistent species, TFW species quickly decompose (Simpson et al. 1983a, Odum 1988). The shallow water-ward slopes and lack of a berm allow the plant remains in the TFW to quickly wash from the marsh surface into the adjacent estuary.

Fauna

Many animals use TFW and their adjacent uplands and waterways. Jug Bay Wetlands Sanctuary, Lothian, Maryland, has identified 27 mammal species, representing six families, that use the wetland sanctuary and note another 14 species, representing three families, that potentially occur on the sanctuary (JBWS 2007b). This includes the destructive nutria (*Myocastor coypus*), an invasive species that was introduced into the US Gulf states, and muskrats (*Ondatra zibethicus*); both play an important role in vegetation and marsh substrate dynamics (see: Impacts section below for further discussion). Beaver (*Castor canadensis*), otter (*Lutra canadensis*), eastern raccoon (*Procyon lotor*), mink (*Mustela vison*), and marsh rabbit (*Sylvilagus palustris*) also inhabit TFW (Odum et al. 1984). Other mammals, such as the southern flying squirrel (*Glaucomys volans*), Virginia opossum (*Didelphis virginiana*), red fox (*Vulpes vulpes*), gray fox (*Urocyon cinereoargenteus*), bobcat (*Lynx rufus*) and white-tailed deer (*Odocoileus virginianus*) make frequent forays into TFW (Odum et al. 1984, J. Perry pers. obs.).

The diverse structure of TFW formed by their high numbers of plant species provides a good habitat for birds. Two hundred and eighty species of birds use TFW (Odum et al. 1984). Jug Bay Wetlands Sanctuary has listed 257 bird species, 60 of which use the TFW for feeding, breeding, and refuge; 12 species were found only in TFW in Jug Bay Wetlands Sactuary (JBWS 2007c). Mallards (*Anas platyrhynchos*), American black ducks (*Anas rubripes*), and red-winged blackbirds (*Agelaius phoeniceus*) are common inhabitants, and great blue herons (*Ardea herodias*) go there often to feed. Rare bird species found in the mid-Atlantic TFW include the least bittern (*Ixobrychus exilis*), snowy egret (*Egretta thula*), Louisiana heron (*Egretta tricolor*), northern harrier (*Circus cyaneus*), and swamp sparrow (*Melospiza georgiana*) (Odum et al. 1984, JBWS 2007c). The snowy egret and Louisiana heron are common members of the southeastern TFW areas, as are all the species mentioned above. Populations of the once federally listed as Endangered bald eagle (*Haliaeetus leucocephalus*) and Threatened osprey (*Pandion haliaetus*) have rebounded and are now commonly seen circling over TFW in both the mid-Atlantic and the southeast; both raptors have recently been downgraded to lower levels of federal protection (Evans 1982, USDI 2007).

Amphibians and reptiles are also well represented in the mid-Atlantic and southeastern TFW. One study recorded more than 100 species throughout mid-Atlantic TFW (Odum et al. 1984). While lizards are rare (only three have been recorded from Jug Bay Wetlands Sactuary), snakes and turtles are common. The turtles found in TFW include the common snapping turtle (*Chelydra serpentina*), eastern mud turtle (*Kinosternon subrubrum*), eastern musk turtle (*Sternotherus odoratus*), eastern box turtle (*Terrapene carolina carolina*), red bellied turtle (*Pseudemys rubriventris*), and the red eared slider (*Trachemys scripta elegans*). Alligator snapping turtles (*Macrochelys temminckii*) and soft shelled turtles (*Apalone spinifera*) can be found in the southeastern TFW (Odum et al. 1984, JBWS 2007d). Snakes include common species such as the black rat snake (*Elaphe obsoleta*), eastern kingsnake (*Lampropeltris getula*), northern water snake (*Nerodia sipedon sipidon*), queen snake (*Regina septemvittata*), and the glossy crayfish snake (*Regina rigida rigida*), which is extremely rare in Virginia but common throughout the southeast (Odum et al. 1984, Perry 1997, Mitchell & Reay 1999, JBWS 2007d). The venomous cottonmouth (*Agkistrodon piscivorus piscivorus*) can be found in TFW south of the James River, Virginia (Mitchell & Reay 1999).

Figure 5. Big cordgrass (*Spartina cynosuroides*) community on the south-waterside edge of Sweet Hall marsh where recorded salinities greater than 0.5 are becoming common (also see: Fig. 1). This community represents a transition between a tidal freshwater marsh and oligohaline estuarine marsh. The dominant species include the facultative-halophyte big cordgrass (*S. cynosuroides*) and the invasive form of common reed (*Phragmites australis* var. *australis*). A small population of smooth cordgrass (*S. alterniflora*) was also present in 2004. Photo by J. Perry.

Fish community composition in TFW commonly includes species from three major categories: 1) resident freshwater species including cyprinids (minnows and shiners), centrarchids (black bass, sunfishes, and crappies), and ictalurids (catfishes); 2) estuarine residents including white perch (*Roccus americanus*), killifish (*Fundulus* spp.), bay anchovy (*Anchoa mitchilli*), tidewater silverside (*Menidia* spp.), hogchoker (*Trinectes* spp.), and naked goby (*Gobiosoma bosc*); and 3) migratory species such as striped bass (*Morone saxatilis*), herring and shad (*Alosa* and *Dorosoma* spp.), American eel (*Anguilla rostrata*), Atlantic menhaden (*Brevoortia tyrannus*), Sciaenids (spot, croaker, silver perch, spotted seatrout, and black drum), summer flounder (*Paralichthys dentatus*), snook (*Centropomus* spp.), and tarpon (*Centropomus pectinatus*) (Odum et al. 1984; Mitsch & Gosselink 2000). The Jug Bay Wetlands Sanctury, Lothian, Maryland, USA, lists 39 fish species representing 17 families (JBWS 2007e). Rozas and Odum (1987b) observed 25 species representing 13 families in Parsons Island Marsh, Chickahominy River, Virginia, USA. D. Bilkovic (pers. obs.) identified 21 fish species that used oligohaline waters downstream of Sweet Hall Marsh on the Pamunkey River, Virginia, USA (Table 2); six of these were freshwater species. She further noted an increase in diadromous and freshwater fish during flood years (Fig. 6).

IMPACTS

Sea level

An increase in sea level and in the rate of sea level rise is of particular importance to TFW. Their internal structure and long-term survival depend on regular inundation by tidal fresh water. Along the middle and southern Atlantic shoreline of the USA, sea level has been slowly rising relative to the land's surface for much of the recent past. NOAA tide gauges indicate that the rate of rise in this region varies between 2 mm/yr at Fernandina Beach, Florida, to over 4 mm/yr at Sewells Point, Virginia, USA (NOAA 2007). Rising sea level has several consequences for estuarine systems. First, fixed points along the shoreline experience increased inundation frequency as the water level rises. Second, the increasing water volume in an estuary, and the absence of any concomitant increase in freshwater inflow, can result in a net landward movement of sea water mixed into the system. This produces a slow increase in salinities at points along the estuarine gradient. Finally, if there is a general increase in

Table 2. Fish of Pamunkey River. Fish species captured in the transitional zone between the tidal freshwater and oligohaline wetlands of the Pamunkey River, Virginia for the years 2003-2004. From: D. Bilkovic (pers. comm.).

Common name	Scientific name	Life history
American eel	*Anguilla rostrata*	Diadromous
American shad	*Alosa sapidissima*	Diadromous
Atlantic croaker	*Micropogonias undulates*	Estuarine
Atlantic menhaden	*Brevoortia tyrannus*	Diadromous
Atlantic silverside	*Menidia menidia*	Estuarine
Banded killifish	*Fundulus diaphanous*	Estuarine
Bay anchovy	*Anchoa mitchilli*	Estuarine
Blue crab	*Callinectes sapidus*	Estuarine
Catfish spp.	*Ictalurus* spp.	Freshwater
Gizzard shad	*Dorosoma cepedianum*	Semi-diadromous
Hogchoker	*Trinectes maculates*	Estuarine
Largemouth bass	*Micropterus salmoides*	Freshwater
Longnose gar	*Lepisosteus osseus*	Freshwater
Mummichog	*Fundulus heteroclitus*	Estuarine
Pumpkinseed	*Lepomis gibbosus*	Freshwater
Satinfin shiner	*Notropis analostanus*	Freshwater
Sheepshead minnow	*Cyprinodon variegates*	Estuarine
Spot	*Leiostomus xanthurus*	Estuarine
Spottail shiner	*Notropis hudsonius*	Freshwater
Striped bass	*Morone saxatilis*	Diadromous
White perch	*Morone americana*	Semi-diadromous

water depths throughout the system, waves can deliver more energy to the marsh shoreline resulting in potential increases in erosion, inundation of marsh vegetation, and increases in sediment deposition processes.

Sea level rise is the result of three general processes: 1) eustatic sea level rise, which is basically a worldwide process resulting from increased water volumes due to melting of polar ice caps and glaciers and thermal expansion of sea water, 2) tectonic rebound, where the mid-Atlantic region sinks as the northeast region of the USA is rebounding from the retreat of the last glacial period, and 3) local apparent sea level change, which is due to vertical movement of the land surface resulting from local processes such as land-subsidence due to groundwater withdrawal. Relative sea level change (i.e., the accumulative change of the three processes mentioned above) can, and does, vary significantly. In Virginia and southern Maryland there is a net downward movement (due in part to the rebound in the northeast), while in South Carolina and Georgia there have been slight increases. On a smaller scale, within the Chesapeake Bay region there are several local areas of relatively high rates of subsidence that appear to be related to large withdrawals of groundwater from deep aquifers (Holdahl & Morrison 1974). The result is local relative sea level change rates of 7 mm/yr or more. Two wetlands that have been studied for many years are located in these mid-Atlantic high subsidence zones. The Blackwater Wildlife Refuge in Maryland is one source of concern since its TFW and oligohaline tidal wetlands have lost vegetative cover over the past several decades and have reverted to shallow open water habitat (Stevenson et al. 1985, Kearney et al. 1988). Kearney et al. (1988), working in the Nanticoke Estuary, MD, documented a loss of 43 ha (13.7% of total wetland surface area) of healthy TFW over a 50 year period, and an increase in stressed TFW from 81 ha to 129 ha (25.1% to 41% of total). They also noted an increase in wetland loss as one traveled downstream to the oligohaline wetland areas. They suggested that the loss in TFW area was due to an increase in tidal prism and interior ponding, and that the increase in oligohaline loss was due to a combination of shoreline erosion (because of increased fetch) and ponding. In Virginia, wetlands on the Pamunkey River have undergone plant community shifts (Perry & Hershner 1999, Davies 2004, see discussion below). In both cases, the changes observed seem directly attributable to the local subsidence and the eustatic rise in sea level.

Tidal wetlands in general can respond to rising sea level by accreting plant litter and inorganic sediments to grow vertically, and by migrating inland to occupy former upland areas (Brinson et al. 1995, Friedrichs & Perry 2001, Blum & Christian 2004). Studies have shown that sedimentation rates in TFW are highly variable spatially and seasonally (see: Chapter 4, Pasternack & Brush 2001, Neubauer et al. 2002, Morse et al. 2004). Pasternack and Brush (2001) found that annual accretion in a TFW of the upper Chesapeake Bay varied from -74.15 to 145.2 $g/cm^2/yr$ with an average rate of 1.0 $g/cm^2/yr$. Neubauer and Anderson (2003) determined that the annual sediment deposited as organic matter in Sweet Hall Marsh allowed the marsh to keep up with current relative sea level rise.

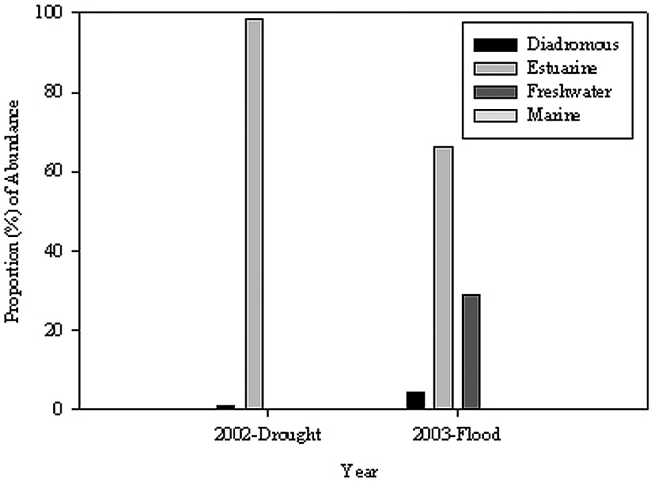

Figure 6. Annual proportion (%) of fish community composition classified as diadromous (migratory), estuarine, freshwater, or marine species based on life history for Lee and Hill marshes, York River, Virginia. Shifts in community structure attributable to extreme annual conditions (drought to flood) are reflected in increases in freshwater, and migratory species during the flood year. From: D. Bilkovic pers. comm.

There is evidence, however, that the ability of TFW to keep up with increases in the rate of sea level rise is limited. Wetlands in Maryland and Virginia are changing in ways that suggest that one of the driving factors is an increase in inundation frequency and salinity. Plant communities that have been studied for decades are showing composition shifts to dominance by species more tolerant of inundation (Perry & Hershner 1999, Davies 2004, Perry & Atkinson 2007) and shifts in salinity gradient (Higinbotham et al. 2004, Wetzel et al. 2004).

Seasonal variability, flood, and drought impacts often alter salinity in tidal wetlands and potentially impact animal and plant communities (Simpson et al. 1983a, Odum 1988, Perry & Hershner 1999, Davies 2004, Bailey et al. 2006). Long-term disturbances that impact salinity, such as long-term drought, flood, or an increase in sea level, have the potential to shift the salinity regime significantly and cause losses in TFW habitat. In concert with salinity and vegetation changes, biotic communities could be affected (Odum et al. 1984, Perry & Atkinson 2007). Tidal wetlands are often characterized by high primary and secondary production and provide critical nursery habitat for many fresh water and estuarine fishery species (Simpson et al. 1983a, Odum et al. 1984). Thus, loss or shifts in the TFW habitat have the potential to greatly reduce fish nursery habitat and prey for the faunal communities.

Long term studies on wetlands in Virginia's Pamunkey River system suggest a gradual contraction of tidal freshwater plant communities upriver as less salt-tolerant plants disappear from down-river wetlands (Perry & Hershner 1999, Davies 2004). While the current evidence in these systems is not dramatic, the observations are consistent with the system level responses expected as seawater moves further into the estuary (Mitsch & Gosselink 2000). However, while rising sea level and land subsidence may lead to a shift toward more salt-tolerant biota, recent climatic stochastic occurrences appear to have offset this trend, at least temporarily (Davies 2004, D. Bilkovic pers. obs.). For instance, under average precipitation conditions the most common fauna found in the water column adjacent to two oligohaline wetlands within the York River watershed were estuarine species with an occasional migratory, freshwater, or marine species (D. Bilkovic pers. obs.). However, during intense flood years, increases in the proportion of freshwater fish species (D. Bilkovic pers. obs.) in relation to estuarine species were evident (Fig. 7). Davies (2004) found that there was a shift in the dominant perennial plants from salt-tolerant species in low-flow years with higher water column salinity, to less salt-tolerant species during wetter years. Her finding implies that perennial freshwater plant species may be able to enter a senescence period during low-flow years. How long the perennial stock may remain viable (i.e., how many low-flow years they would survive), or the level of increase in salinity it may tolerate, is still unknown. Higinbotham et al. (2004) found yearly shifts in the leading edges of salt tolerant *Spartina-Distichlis* plant community and the less tolerant needlerush communities (*Juncus roemerianus*). They hypothesized that the movement was related to yearly changes in soil and water salinity. Ecosystem impacts of chronic long-term forcings overlaid with erratic but potent events are unknown.

The seed banks of TFW are dominated by annual species (Leck 1989). Seeds of certain species, unlike those in other wetland seed banks, appear to have a complete turnover each year (Cronk & Fennessy 2001). Seed bank recruitment is influenced by environmental and biological parameters; among these, sediment accretion (Bonis et al. 1995, Jurik et al. 1994, Giroux & Bédard 1995), and soil salinity (Shumway & Bertness 1992) were negatively correlated with seedling emergence. Leck (1996) recognized other parameters and describes three classes of germination requirements in annual macrophytes: 1) dry germinating (oxygen requiring) plants such as beaked rushes (*Rhynchospora* spp.) and sedges (*Carex* spp.); 2) wet germinating (hypoxic) individuals represented by taxa such as scented water-lily (*Nymphaea odorata*) and yellow bladderwort (*Utricularia inflata*); and 3) generalists (germinating regardless of soil moisture or oxygen content) such as the spikerush (*Eleocharis* spp.) (see: DeBerry & Perry 2000a,b for a brief review of wetland seed banks literature). Needless to say, changes in sedimentation rates, water and soil salinity, soil temperature, and/or inundation time could alter the seed bank composition, seed germination rates, and seed bank recruitment. For many soil seed banks, a physical disturbance mechanism must be present in order to bring buried seeds to the surface where germination may occur (Fenner 1985). Possible increases in sedimentation due to sea level rise could lead to deep burial (Leck & Simpson 1987, Jurik et al. 1994): as sea level rises, more sediment would be expected to be deposited on the wetland surface due to higher water levels and more frequent inundation time and, therefore, the increase in sediment would bury seeds deeper.

Muskrats have played an important role in wetland surface elevation and the distribution of plant species in mid-Atlantic and southeastern USA TFW (Odum et al. 1984) (see: Fig. 4). Their number and extent have varied, in part due to changes in harvest pressure as humans reduced natural predators in the system and developed and lost a desire for muskrat pelts (USFWS 2006b). As a consequence, muskrats are a spatially variable factor in TFW. However, they have the potential to exert significant influences on community structure where they are locally abundant (Odum et al. 1984). Den building, access tunnel development, and plant harvesting behaviors of muskrats can result in small areas of intense disruption of marsh substrate. Over the normal cycle of construction, occupation, and abandonment of a den, an area several meters in diameter can be thoroughly tunneled. While the ultimate collapse of the tunnels can result in locally significant elevation changes (Perry 1994, 1997, C. Hershner pers. obs.), the change in topography allows several small plant guilds, such as those dominated by royal fern and/or tussock sedge, to survive (Perry & Hershner 1999). In cases of very dense occupations, a population of muskrats may alter a greater part of a wetland's surface removing emergent vegetation, creating shallow open water areas, and enhancing development of drainage networks. Since allochthonous and autochthonous seed sources are important for re-establishment of the muskrat eat-out areas (Baldwin & Pendleton 2003), a large change in muskrat populations and/or a change in sea level rise rates may alter seed inputs and erosion of the wetland soil, thereby altering wetland diversity and habitat.

Invasive species

Invasive plant and animal species have the potential to become a major economic and ecological problem in TFW throughout the region (see: Pimentel et al. 2000) (Table 3). Introduced species such as the European genotype of the common reed (*Phragmites australis* ssp. *australis*) have been shown to be aggressive in replacing many of the plant species that comprise the high species richness of TFW on the Atlantic coast. Saltonstall (2003) has shown that there are 14 different genotypes of the common reed. The native genotype (*Phragmites australis* ssp. *americanus*) has coexisted in the wetlands of the USA for many years without showing aggressive tendencies. The European genotype, on the other hand, was introduced to the USA by the early colonists and has rapidly spread throughout the east coast and Mississippi Valley region (Saltonstall 2002). Davies (2004), however, found a large increase in the native variety of common reed in a Virginia TFW and she hypothesized that the native species was spreading to form monotypic stands. The areas of the wetland that she denoted as currently occupied only by the native common reed originally had high species richness (sensu Perry & Hershner 1999). Field observations of the same area in 2006 found that the native variety had formed large, monotypic stands in several areas, drastically lowering the species richness and diversity (J. Perry & R. Chambers pers. obs.). This presents the question of the possible hybridization of the European and native tall reed varieties. If hybridization were to occur (or if it already has), it may allow the seemingly benign native species to become problematic.

The Asian mudwort (*Murdannia keisak*) is now common in several coastal non-tidal and TFW from Delaware to Louisiana (Dunn & Sharitz 1990, Perry & Hershner 1999, Davies 2004, DeBerry & Perry 2004, Bailey et al. 2006). The mudwort, a low, prostrate, dense monocotyledon, covers marsh soil surface areas that are usually left bare or sparsely colonized by such rare species as Virginia quillwort (*Isoetes virginica*) and/or the viviparous spikewort (*Eleocharis vivipara*) (J. Perry pers. obs.). Both Virginia quillwort and viviparous spikewort are listed as S1 (critically imperilled) species in Virginia (Townsend 2007). Crain et al. (2004) found that transplant seedlings in an oligohaline wetland grew better on the bare ground area between a matrix of vegetation. Therefore, the loss of bare ground in TFW could lead to a decline in available habitat for both rare species and late season annuals, the latter being an important component of the TFW vegetation community (Odum et al. 1984, Leck & Simpson 1987, 1994). Purple loosestrife (*Lythrum salicaria*), an alien invasive species that has become problematic in the Great Lakes region and north-eastern North America, has recently been documented in natural and created TFW on the James River, Virginia (Perry 2005).

Zebra mussel (*Dreissena polymorpha* Pallis), now in the northernmost part of the Chesapeake Bay watershed, competes with native pearly freshwater mussels (*Epioblasma* spp.) (Stein & Flack 1996). Little is known concerning the impact they may have on species diversity or, as a potentially high abundance filter feeding species, on sediments that are an important part of TFW accretion.

The nutria is a species of aquatic rodent introduced from South America into the western and southern portion of the USA in the early 20th Century (Evans 1970, 1983) and into the mid-Atlantic region of the US in the mid 20th Century (ISCWW 2002). They are larger and more voracious than the native muskrat (USFWS 2006b) and are effective disruptors of wetland substrates (ISCWW 2002). Nutria activity is one of the principal causes, along with local sea level rise, for the dramatic breakup and loss of emergent wetland at the Blackwater National Wildlife Refuge (BWNWR) in Maryland. The USFWS (2006b) estimated that nutria were responsible for 500-1,000 acres of wetlands lost per year on the BWNWR, and several times that amount in the adjacent Blackwater and Fishing Bay wetlands.

Nutrient processing

Nutrient exchanges between TFW and the adjacent water column are important elements of the energy flow process of the downstream estuary. They are, however, not well defined (Simpson et al. 1983a, Neubauer et al. 2005a). TFW release reduced nitrogen compounds (Odum et al 1984,

Table 3. Priority invasive plant and animal species of the mid-Atlantic region of the US as determined by each state (Washington, DC, Maryland (MD), Pennsylvania (PA), Virginia (VA), and Delaware (DE)), the U.S. Fish and Wildlife Service (USFWS), and the U.S. Geological Service (USGS). Priority Invasive Species are species that have been documented or are believed to have the greatest ecological or economic impact on the water quality or environmental health of the Bay or tributary and have the greatest political significance, i.e., management of the species impacted by vocal and/or conflicting constituency groups. Modified from the list compiled by Maryland Sea Grant (2002) to show only those species that may impact TFW. Table key: P - Ranked in the top 5 by the jurisdiction or federal agency; J - Identified as a priority by the jurisdiction or state agency but was not in the top 5; F - Identified as a potential threat.

Current invasive species		**DC**	**MD**	**PA**	**VA**	**DE**	**USFWS**	**USGS**
Asian swamp eel	*Ophisternon bengalense*				F			
Asiatic clam	*Corbicula fluminea*	P		P	P	P		
Blue fish heart parasite	*Henneguya* sp.		J		P			
Canada goose (resident)	*Branta canadensis*	J			J			
Eurasian river ruffe	*Gymnocephalus cernuus*			F				
European starling	*Sturnus vulgaris*			J				
Flathead catfish	*Pylodictis olivaris*				J			
Giant salvinia	*Salvinia* spp.				F			
Grass carp	*Ctenopharyngodon idella*		F		F			P
Green crab	*Carcinus maenas*		P				P	
House mouse	*Mus musculus*			J				
House sparrow	*Passer domesticus*			J				
Hydrilla	*Hydrilla verticillata*	P		F	P	P		
Japanese honeysuckle	*Lonicera japonica*			J				
Japanese knotweed	*Polygonum cuspidatum*			J				
Japanese stiltgrass	*Microstegium viminium*							P
Mile-a-minute weed	*Polygonum perfoliatum*			J				
Morrow's honeysuckle	*Lonicera morrowsii*			J				
Multiflora rose	*Rosa multiflora*			J				
Mute swan	*Cygnus olor*		P	J	F		P	
Norway rat	*Rattus norvegicus*			J				
Nutria	*Myocastor coypus*		P		J	P	P	P
Oriental bittersweet	*Celastrus scandens*			J				
Common reed	*Phragmites australis*	P	P	J	P	J	P	P
Purple loosestrife	*Lythrum salicaria*	P	J	P	P	P	P	
Quagga mussel	*Dreissena bugensis*			F				
Round goby	*Neogobius melanostomus*			F				
Suminoe oyster	*Crassostrea ariakensis*		F					
Water chestnut	*Trapa natans*		P			F		
West Nile virus & Tiger mosquito	*Flavivirus & Aedes albopictus*	F			F			
Zebra mussel	*Dreissena polymorpha*		F	P	F	F		

Bowden 1986, Bowden et al. 1991) and both inorganic and organic carbon into the adjacent water column. The addition of dissolved organic matter and nutrients through the addition of wastewater may enhance denitrification (Neubauer et al. 2005a) and affect plant biomass (Whigham & Simpson 1977). Neubauer et al. (2005a) found that the seasonal flux of dissolved-inorganic carbon (DIC) was similar in a TFW and its adjacent water column. They suggest that the similarity implies that the DIC leaving the TFW is the source of DIC in the adjacent estuary. They also noted that an increase in salinity, such as through an increase in tidal prism, could alter the rates of alkalinity-generated processes such as sulfate reduction (Neubauer et al. 2005a). It follows that an increase in nutrients and salinity will more than likely alter the rates and dynamics of nutrients and overall DIC cycling in southeastern USA tidal estuaries.

REGULATORY PRACTICES

Throughout the region, TFW are protected as part of both federal and state management of wetlands. In general, these regulatory authorities attempt to achieve no net loss of wetland resources by requiring avoidance of impacts wherever possible, and compensation for any unavoidable losses as necessary. In practice, there are two general shortcomings of the state and federal regulatory efforts. First, regulatory jurisdiction is limited to areas meeting a technical definition of wetlands. This almost always means that activities in adjacent terrestrial environments are not managed with any regard for their impacts on the functions and values provided by wetlands. The consequence is that habitat and water quality functions of wetlands can be significantly compromised since these functions are rarely independent of the surrounding landscape. Second, regulatory programs are limited as to their allowable compensation methods for permitted impacts. Increasingly, permitted direct physical impacts on tidal wetlands are small. In fact, they are often so small that regulatory programs either allow them without compensation, or they permit compensation that does not effectively replace the lost resource in the same system. This is a matter of practicality in the operation of management programs, but the result is a slow loss of natural wetlands.

The physical requirements for creating TFW result in very few opportunities to even attempt their construction. The need for tidal energy combined with large volumes of fresh surface water means there are only a very limited number of potentially suitable areas in the coastal landscape. As a practical matter, it is much easier to establish a non-tidal freshwater wetland or a tidal salt marsh; therefore, expending resources on a less assured outcome is typically not even considered. As a result, the combined pressures of climate change and human occupation of the landscape mean that TFW are likely to become an ever smaller component of coastal systems along the mid-Atlantic and southeast coast.

CONCLUSIONS AND RECOMMENDATIONS

Clearly, the protection of TFW in the mid-Atlantic and southeastern USA is an important issue in many different ways. Development, agricultural practices, and dams may reduce the amount of sediment influx into tidal wetlands by trapping material and preventing over-bank flow of sediments during flood conditions. Coastal development is also decreasing the available area for landward movement of tidal wetlands; therefore, sea level rise and onshore development acting together will compel the loss of tidal marshes. Invasive species may change both the composition of the biotic community as well as the physical environment.

Wetland conservation and management have evolved rapidly over the last several decades. Landowners and land managers can implement a wide variety of best management practices to ensure the activities on their lands do not adversely impact these vital wetland communities. These include nutrient reduction targets to help reduce agriculture and development runoff, use of remote sensing and GIS data to better show distribution and stress on TFW, and employment of TFW restoration and creation techniques. However, there is much yet to be learned concerning the complexities of restoration and creation of TFW (Baldwin 2004, also see: Chapter 19).

Current ecological studies indicate that changes, possibly because of rising sea level, will occur in the composition of macro-biota of TFW. However, we have little information on the magnitude or timing of these changes. Finally, Neubauer and Anderson (2003), Neubauer et al. (2005a) and others have pointed out that we have incomplete data on N and C cycling to drive management models, making it difficult to comprehend the complexity of nutrient cycling in TFW. More research is needed to better understand the future ecology of TFW in the mid-Atlantic and southeastern region of the USA.

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