

Chapter 2 - Hydrology of Tidal Freshwater Forested Wetlands of the Southeastern United States

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2.1. Introduction

The downstream, coastward boundary of tidal freshwater forests is easy to define. There is usually an abrupt border from forest to fresh, brackish, or salt marsh as tidal effect and salinity increase. Upstream, however, there is a continuum within the forested community as salinity and tidal signature diminish. The boundary conditions can be defined by salinity ranges, species distributions, or hydraulic relations (Cowardin et al. 1979; Light et al. 2002; Hicks et al. 2000). Unfortunately, each of these criteria leads to a different spatial and functional delineation of the tidal freshwater zone. Odum et al. (1984) summarized the existing literature at that time on the ecology of tidal freshwater marshes, but little attention was given to analyzing the hydrology of the upper boundary of these systems, the forested edge.

We propose that tidal freshwater forested wetlands are coastal forested wetlands where the hydrology is affected by astronomical tides, and salinity does not normally exceed the tolerance of nonhalophytic tree species. This definition provides a comprehensive classification of tidal freshwater forests that considers aspects of hydrology, salinity, and biota. Hydrology of these sites is primarily dictated by local tides and river discharge, but it is also influenced by local rainfall, evapotranspiration, surface runoff, and

subsurface drainage. Almost 70 years ago, Beaven and Oosting (1939) qualitatively described the hydrology of a tidal freshwater forest dominated by baldcypress (*Taxodium distichum* [L.] L.C. Rich.) and swamp tupelo (*Nyssa biflora* Walt.); in general, however, investigative research of tidal freshwater systems first focused on the herbaceous components of tidal freshwater marshes (Doumlele 1976, 1981; McCormick 1977; Whigham and Simpson 1977; Odum et al. 1978). Odum et al. (1984) included the forested edge as a part of the marsh, listing a baldcypress-tupelo community type as the most landward portion of a tidal freshwater marsh, forming an ecotonal boundary between the marsh itself and wooded swamp or upland forest at approximately the level of mean high water (average high tide). The hydrologic characteristics of tidal freshwater forested wetlands are directly related to the conditions which prevail at the upper extreme (laterally or upstream) of tidal freshwater marshes.

The hydrology of tidal freshwater forested wetlands has been studied even less than other aspects of this type of ecosystem. Very few of these wetlands have had a water-level recorder installed within the swamp to directly measure surface inundation rates and groundwater levels. More often, hydrology is inferred from a continuously recording gage in a nearby channel. In many cases, wetland hydrology data consist of manual measurements of water depth taken during site visits, resulting in individual water level data points that are weeks or months apart. Channel hydrology may provide a fairly accurate estimate of adjacent wetland hydrology in cases where the terrain is flat and/or the soil is relatively permeable (Zampella et al. 2001; Burt et al. 2002); however, areas away from the channel may be slow to drain and are usually inundated for longer periods than indicated by the stream gage.

Researchers have become increasingly aware of the importance of actually recording water levels in all types of wetlands instead of relying on estimates derived from gages in waterways adjacent to the studied wetland. Tidal freshwater systems are no exception. Chapters 4-13 of this book present specific tidal freshwater forested wetlands and include descriptions of the hydrologic characteristics of each site. Some authors present actual hydrographs from continuous recorders installed within the swamp; however, we use our own previously unpublished data to produce within-forest hydrographs in this chapter.

The hydrology of tidal baldcypress swamps and other riverine tidal forested communities are described in this chapter. We also discuss the hydrology of the coastal margins of groundwater-dominated forested wetlands which may transition directly into brackish or salt marsh. First, we introduce the forcing functions of freshwater input, tides, sea level, and sa-

linity; these factors are described in the context of how they interact at the upper extreme of tidal influence near the level of mean high water. We rely heavily on hydrologic data from the national network of tide and stream gages available from the National Ocean Service, Center for Operational Oceanographic Products and Services (NOAA 2006a) and the U.S. Geological Survey, National Water Information System (USGS 2006). Second, we describe the hydrology of specific tidal freshwater forests as reported in the literature, supplemented by references to chapters in this book. The effects of elevation, microtopography, and wind on tidal inundation patterns are discussed. Following that is a discussion of the relation of hydrology to the biological and biogeochemical functions of tidal forests. Finally, we describe how changing hydrologic conditions might affect the sustainability of tidal freshwater forests.

2.2. Forcing functions

Freshwater input (rainfall, river flow, and ground water) and the physical forcing of the tide act together to control water levels in tidal freshwater wetlands. Sea level is the moving base that controls the elevation at which these two interact. The physical interaction between salt water and fresh water controls salinity, which is a major environmental factor influencing the biology and chemistry of tidal wetlands. The forcing functions that define the characteristics of tidal freshwater forests are the same that regulate all estuarine wetlands, from saline to fresh. In fact, the international classification system of the Ramsar Convention on Wetlands couples tidal freshwater swamp forests with mangrove forests into one functional group, “intertidal forested wetlands,” under the classification “marine/coastal wetlands” (Ramsar Convention Bureau 1990). This discussion, however, will focus on the upper extreme of tidal influence and how the forcing functions interact there to affect tidal freshwater forested wetlands.

2.2.1. Freshwater input

Annual precipitation in coastal areas of the southeastern United States ranges from approximately 600 mm in south Texas to 1,600 mm on the northern rim of the Gulf of Mexico and to near 1,300 mm along the Atlantic coast (Muller and Grymes 1998). In south Texas, high evaporation and low river discharge limit freshwater availability, and there is very limited occurrence of swamp forest near the coast (Shew et al. 1981). From east

Texas eastward to the rest of the Gulf of Mexico and south Atlantic coasts, freshwater runoff is plentiful. High rainfall provides freshwater flow to sustain tidal forested wetlands in Barataria Basin in the Mississippi River deltaic plain of Louisiana (Figure 2.1a) which have been cut off from river flow by levees. Rainfall, along with its effect on ground water, also dominates the hydrology of freshwater forests in the karst limestone topography of Florida and the sandy soils of wetland communities directly behind coastal beaches along the entire coastline of the southeastern United States. In these cases, the tidal signature may only be apparent in groundwater fluctuations.

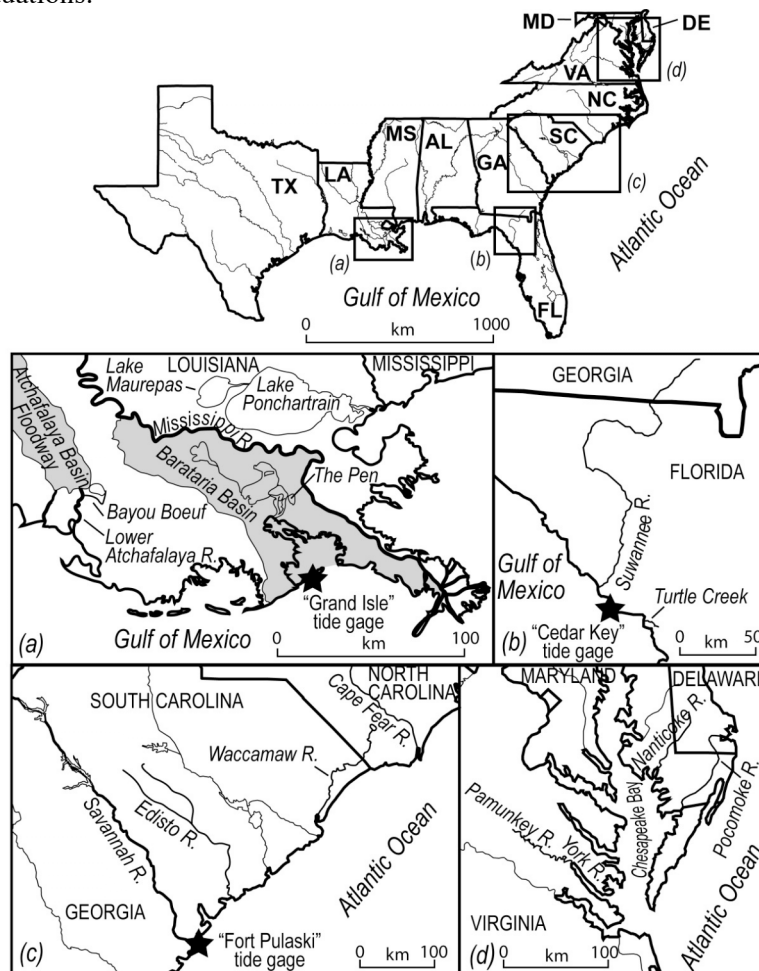


Fig. 2.1. Location of tidal freshwater forested wetland study sites referenced in the text. The Atchafalaya Basin Floodway and Barataria Basin are shaded gray. Stars refer to the location of tide gages.

River flow does not correlate to local rainfall (see Chapter 1). A river's discharge depends on rainfall and evapotranspiration over its entire drainage basin as well as on antecedent groundwater conditions. Poff et al. (1997) identified five critical components of river flow regime that regulate ecological processes in river ecosystems: the magnitude, frequency, duration, timing, and rate of change of hydrologic conditions. The interaction of these five river flow components with coastal tides regulates ecological processes in tidal freshwater wetlands. The Suwannee River in Florida and the Savannah River in South Carolina and Georgia (Figure 2.1b, c) have comparable drainage basin areas and mean annual precipitation, resulting in similar mean annual discharge rates (Table 2.1). In general, within a given climatic regime, rivers with similar drainage basin areas will have similar mean annual discharge rates. Similarity of climate also puts southeastern United States rivers in the same category with respect to seasonal pattern of river discharge; the month of October is the time of year of lowest average river discharge throughout the southeastern United States, although there is high variability from year to year for each river (USGS 2006). Human activities such as dredging, channelization, and damming of rivers all affect the interaction of coastal tides with river flow regime. The spatial distribution of freshwater forests in riverine tidal settings depends on the interaction of river discharge rate with tide range.

2.2.2. Tide

The timing and magnitude of tides are determined by a complex interaction of astronomy, bathymetry, and meteorology. Coastal water levels undergo regular daily, monthly, and annual fluctuations, all of which vary by region. Most mean tide ranges are larger along the Atlantic coast (1–2 m) than within the Gulf of Mexico (0.3–1.0 m) (Table 2.1, Figure 2.2). Barataria Basin has the lowest tide range of the three sites in Table 2.1, and although isolated from river flow, it has the highest rainfall. The tide range at the mouth of the Savannah River is more than twice that of the Suwannee River. Thus, given their similarity of climate and discharge, tide regime has more effect than does rainfall or river flow on differences in tidal swamp characteristics in these two river systems.

The Atlantic coast of the southeastern United States has semidiurnal tides, whereas the Gulf of Mexico has areas with diurnal tides and areas with mixed tides (Figures 2.2 and 2.3). Lunar cycling causes a repeating 28-day bimodal cycle of tide levels timed to the full and new moons (Figure 2.4). Prevailing winds as well as unpredictable storm winds that cause episodic surge events can affect water levels at any time. Tropical cyclones

Table 2.1. Hydrologic statistics for three areas of the southeastern United States where tidal freshwater forested wetlands occur. NA = not applicable.

System	Coastal tide station	Geographic coordinates of coastal tide station	Mean annual precipitation basinwide [mm] ^a	River drainage basin area [km ²] ^a	Mean annual river discharge [m ³ /s] ^a	Tides		
						Magnitude class	Frequency class	Mean tide range [m] ^{b, c}
Barataria Basin ^e	Grand Isle, Louisiana	29° 15.8' N 89° 57.4' W	~1,500	NA	NA	Lower microtidal	Diurnal	0.32
Suwannee River	Cedar Key, Florida	29° 8.1' N 83° 1.9' W	1,340	24,967	294	Upper microtidal	Mixed	1.16
Savannah River	Fort Pulaski, Georgia	32° 2.0' N 80° 54.1' W	1,140	27,414	319	Lower mesotidal	Semidiurnal	2.29

^a Data from Benke and Cushing (2005).

^b Tide means are calculated for the 19-year period from 1983 through 2001 (data from NOAA 2006a).

^c Mean tide range: mean high water minus mean low water.

^d Mean diurnal range: mean higher high water minus mean lower low water for sites with two high tides and two low tides daily.

^e Barataria Basin is a rain-fed system which is isolated by levees from riverine input but open to tidal influence from the coast.

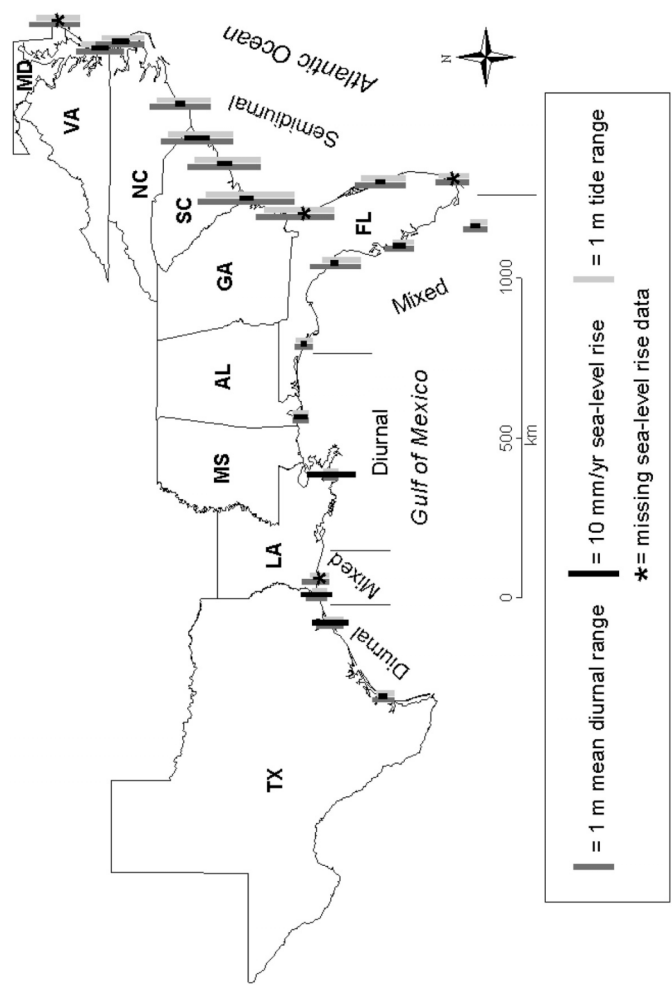


Fig. 2.2. Tide type, tide means, and annual sea-level rise for selected sites in the southeastern United States (data from NOAA 2006a). Annual sea-level rise is calculated from monthly means for stations with 25 years or more of data. Tide means are calculated for the 19-year period from 1983 through 2001. Mean diurnal range = mean higher high water minus mean lower low water (for sites with two high tides and two low tides daily). Mean tide range = mean level of all high tides minus mean level of all low tides. Semidiurnal = two high tides and two low tides daily, with approximately equal amplitudes. Diurnal = one high tide and one low tide daily. Mixed = relatively large inequality in heights of two high tides and/or two low tides daily (Hicks et al. 2000).

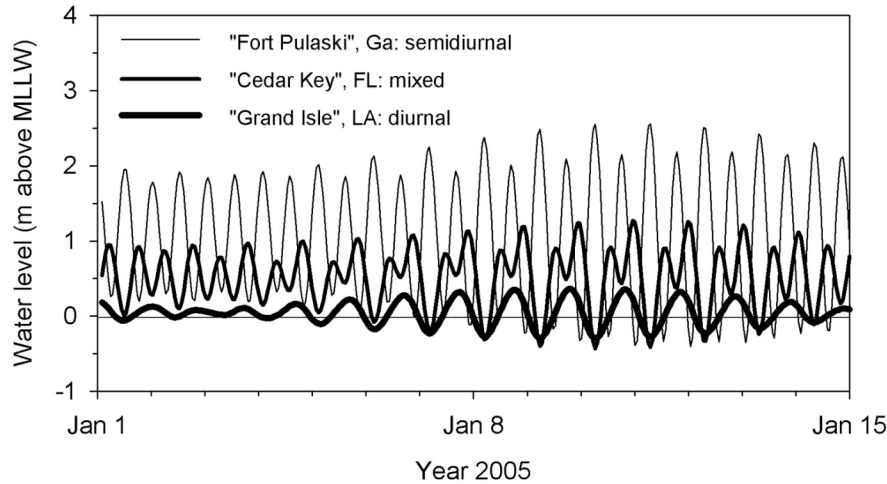


Fig. 2.3. Example of predicted tide levels at three locations that exhibit semidiurnal, mixed, and diurnal tides (data from NOAA 2006a). Predicted tides are calculated from the harmonic oscillations of coastal water levels caused by gravitational pull of the Sun and the Moon, dependent on the geomorphology of the coastline and ocean basins and disregarding local wind and river flow. MLLW = Mean Lower Low Water = mean level of the lower of two low tides daily.

may affect coastal water levels (Figure 2.4) locally or across the entire southeastern United States depending on size and pathway of each storm. In the microtidal environment of Louisiana, wind has a greater affect than do astronomical tides on coastal water levels (Baumann 1987), which is also true for some coastal areas bordering Chesapeake Bay in Maryland (NOAA 2006a, see Chapter 5).

At what point is a riverine freshwater wetland considered tidal? The National Ocean Service defines the point where the mean tide range is less than 6 cm as the head of the tide (Hicks et al. 2000). The depth of a river channel controls how far the tide travels up the channel. The tide continues upstream until the bottom elevation is near that of high tide. Upstream of the head of the tide, water level in the stream is related only to the flow of the stream and is not considered tidal. The head of the tide is not to be confused with the point of tide reversal; the point of tide reversal is the farthest point upstream from the coast at which the tidal current actually flows upstream (Hicks et al. 2000). Below the point of tide reversal, current within the main river channel reverses flow depending on whether the tide is flooding or ebbing. Between the head of the tide and the point of tide reversal, water in the channel continues to flow downstream even during a flood tide that is raising the water level. The concept of a tidal wave

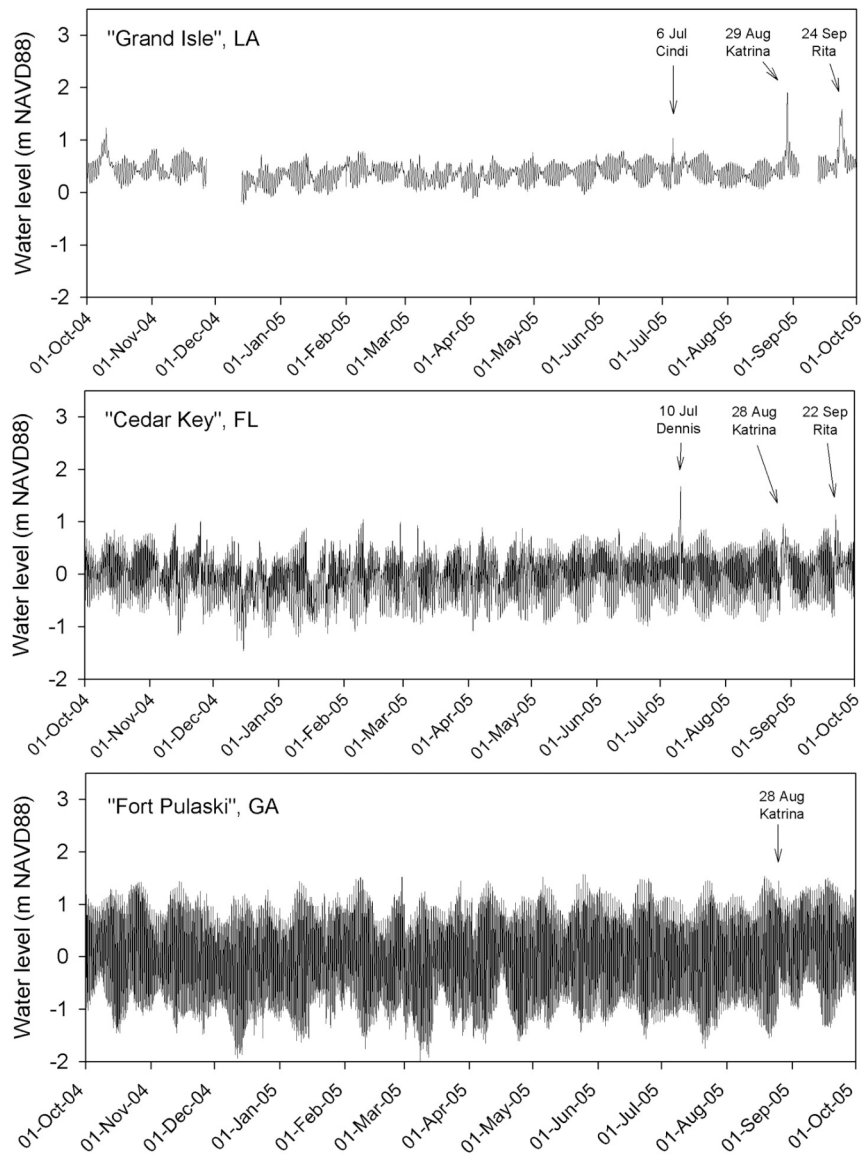


Fig. 2.4. Hourly observed tide levels for Water Year 2005 (01 Oct 2004–30 Sep 2005) (data from NOAA 2006a). The 28-day bimodal lunar cycle is evident from May through August at Grand Isle and Cedar Key. Arrows refer to high water levels caused by hurricanes. NAVD88 = North American Vertical Datum of 1988.

moving upstream against a current is not hard to grasp if one compares it to tossing a stone into a moving current: the resulting ripple radiates in all directions from the point that the stone enters the water, independent of the direction of flow of the current, although the faster the current downstream, the shorter the distance the ripple moves upstream.

The head of the tide and the point of flow reversal are not static points. They move up and down a stream channel in direct relation to river discharge and tide range. The Savannah River at river km 98 is upstream from all tidal influence (Figure 2.5). The tide range at river km 44 varies from ~0.0 to ~0.9 m during the period 2004–2006. There is a clear inverse relationship between river discharge and tide range at these two locations on the Savannah River, even though they are more than 50 km apart. Daily tide range decreases as river discharge increases. At high discharge, the force of water flowing downstream impedes the progression of the tidal wave upstream, which is characteristic of the tidal portion of all rivers (Henderson 1970; USACE 2001).

The head of the tide is farther upstream than tidal swamps occur on large rivers such as the Mississippi River. The hydrograph near the head of

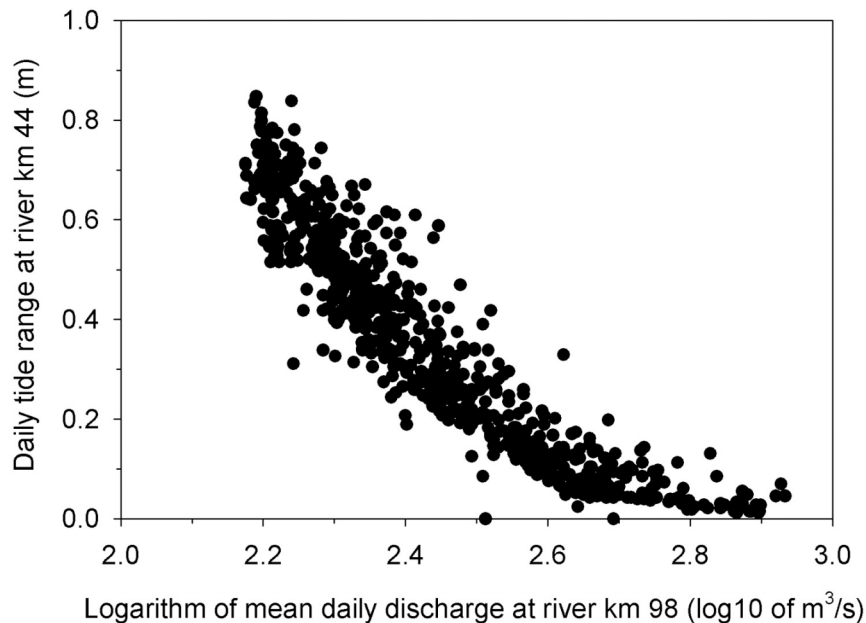


Fig. 2.5. Relationship within the Savannah River between daily tide range at river km 44 (“Above Hardeeville” gage) and logarithm of mean daily discharge at river km 98 (“Near Clio” gage) for the period 01 Oct 2004–30 Sep 2006 (data from USGS 2006).

the tide on large rivers is characterized by a large range of water-level elevations. There is no tidal signature at the highest flows (USGS 2006). The low flow necessary for a tidal signature to become apparent exposes bare river bank below the elevation at which trees occur. Tree seedlings that become established in what could be considered the tide-influenced portion of the river bank usually die during a subsequent rise in the river level.

Tide range diminishes inland from the coast along rivers that narrow and become shallower upstream (Henderson 1970). Dredging of rivers may

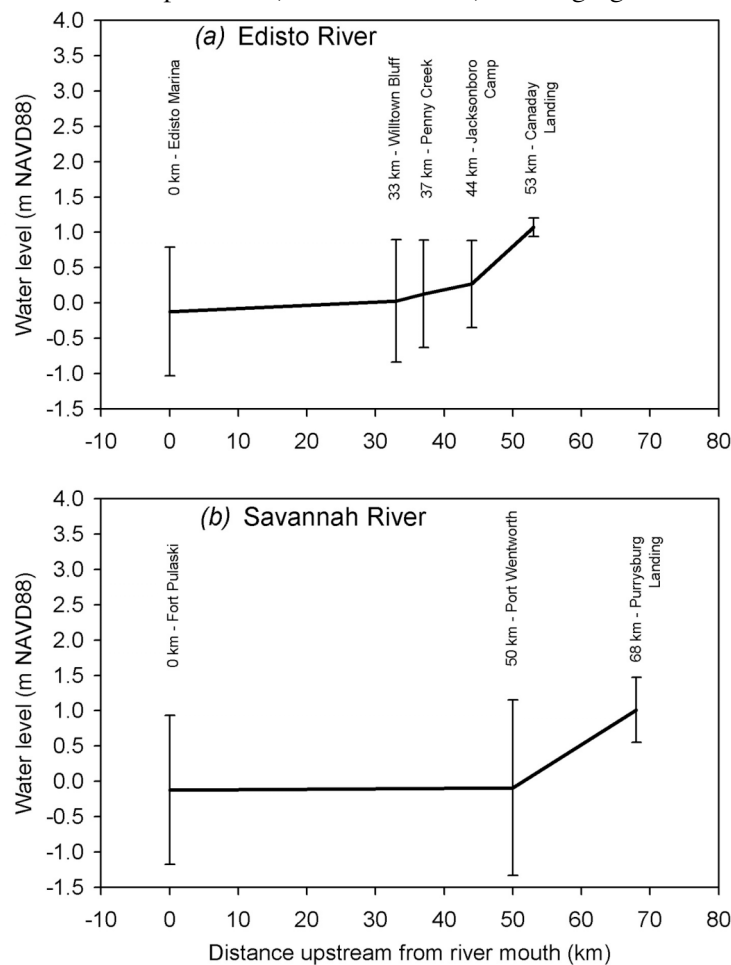


Fig. 2.6. Mean tide level and tide range (represented by vertical bars) referenced to NAVD88 (North American Vertical Datum of 1988) of the coastal reaches of two rivers in South Carolina (data from NOAA 2006a). The top of each vertical bar represents the level of mean high water.

have the opposite effect by magnifying tide range. The tide range of the Edisto River in South Carolina steadily declines with distance upstream and shows a rapid decline over the last 9 km (Figures 2.1c and 2.6a). The level of mean high water is ~80 cm NAVD88 (North American Vertical Datum of 1988) for the first 44 km and rises above 1.0 m NAVD88 at 53 km. In general, the Edisto River follows the tidal behavior of an unmodified stream. Not far down the coast, the Savannah River has a dredged shipping channel, 12.8 m deep from the coast to Savannah, Georgia, and 11 m deep from there to Port Wentworth, Georgia (USACE 2004; USACE 2006). The tide range of the Savannah River increases 37 cm from the coast at the “Fort Pulaski” gage to the end of the shipping channel in Port Wentworth; the tide range then decreases from Port Wentworth to Purrysburg Landing, South Carolina (Figure 2.6b). The level of mean high water is ~1.0 m NAVD88 for 50 km inland and rises to almost 1.5 m NAVD88 at 68 km. This is a classic example of the influence of dredging on tide range.

The Savannah River flow regime is also affected by three major reservoirs and several low-head locks and dams (USACE 2006; see chapter 12). The most obvious affect of the dams is to dampen peak flows and raise the level of minimum flows (Smock et al. 2005), allowing the tide to dominate the hydrograph of the coastal reach of the Savannah River for a more prolonged period of time.

2.2.3. Sea level

Coastal water levels have cyclic annual variation in addition to daily and monthly cycling of the tides. All three sites depicted in Figure 2.4 have mean water levels lowest in late winter and highest in early fall. Despite the large difference in tide range between Grand Isle, Louisiana, and the “Fort Pulaski” gage, mean monthly water levels are surprisingly similar (Figure 2.7). This same seasonal trend was reported by Baumann (1987) for the Gulf of Mexico. Seasonal trends in relative mean sea level are attributable to large-scale oceanic thermal expansion and contraction as well as to seasonal atmospheric pressure differentials (Chen et al. 2000; Yan et al. 2004). Sea level is approximately 30–40 cm higher in September and October than in January. The seasonally high sea level in the fall can be significant for flooding of tidal freshwater wetlands, especially in coastal Louisiana, with its broad and relatively flat Mississippi River deltaic plain. As mentioned in the last section, the fall is also the time of lowest average river discharge throughout the southeastern United States, which lowers the supply of fresh water to the coast (USGS 2006). Higher sea level at this

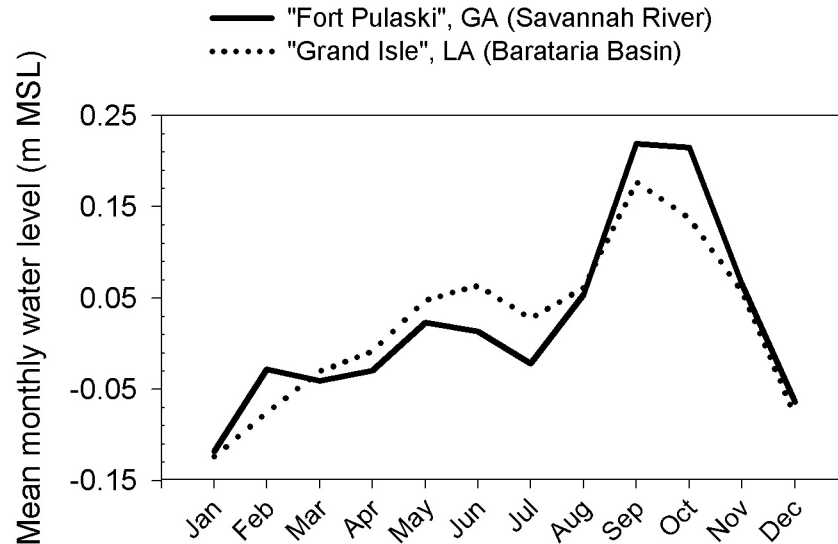


Fig. 2.7. Five-year (1999–2004) mean monthly water level relative to mean sea level (MSL) at two coastal tide gages in the southeastern United States (data from NOAA 2006a).

time of year increases the chance for saltwater intrusion into tidal freshwater wetlands.

Superimposed on the regular cycles of tide variation is long-term global eustatic sea-level rise (see Chapter 1). Eustatic sea-level rise couples with large-scale tectonic movement and/or local subsidence to manifest in apparent sea-level rise that varies widely throughout the Gulf of Mexico and southern Atlantic Ocean (Figure 2.2). The current rate of apparent sea-level rise at Grand Isle is almost 10 mm/yr (NOAA 2006a). A rise in sea level of almost 30 cm in 30 years on top of a 30 cm tide range at Grand Isle is a much greater percentage increase than at the “Fort Pulaski” gage, where apparent sea-level rise is currently less than 3 mm/yr in the presence of a tide range greater than 2 m (NOAA 2006a). Accordingly, tidal swamp forests in Louisiana are being affected by sea-level rise to a much greater degree than are those along the Savannah River (Conner and Day 1988; Conner and Brody 1989).

2.2.4. Salinity

It may seem contradictory to discuss the salinity of freshwater ecosystems; however, it makes perfect sense to state that the measured salinity of

a tidal freshwater system can be 0 ppt. Indeed, freshwater swamps at the extreme upper elevation of the tide are characterized as such, dominated by water with negligible salinity year round. It is at the lower edge of tidal freshwater systems that salinity becomes a controlling, sometimes chronic, factor. By our own definition, tidal freshwater forests are characterized by freshwater species on the edge of saltwater habitat. The U.S. Fish and Wildlife Service wetland classification system (Cowardin et al. 1979) classifies tidal freshwater forested wetlands as either estuarine intertidal or palustrine with a tidal modifier. The difference between the two systems depends on the use of 0.5 ppt as the lower salinity limit of estuarine wetlands and the upper salinity limit of palustrine wetlands when measured during the period of average annual low flow. The wetland classification system (Cowardin et al. 1979) does not have tidal forests in the riverine system, even though many tidal freshwater forests are adjacent to and flooded daily by flowing rivers.

River discharge, topography, and proximity to tidal influence interact to form many different patterns of salinity in estuaries. Near the coast, deep rivers with high freshwater discharge tend to stratify with fresh water on top and a saltwater wedge on bottom. Tidal freshwater swamps nearby could experience little to no saltwater influence even though water at the bottom of the adjacent river has high salinity. Shallow estuaries with low riverine input can be well mixed from top to bottom. Tidal freshwater swamps located near the head of such an estuary may experience salinity values which rise and fall with the tide.

The size of a river channel and magnitude of its discharge affect the salinity in its lower reaches. The Waccamaw River, South Carolina, is a system with a relatively small drainage basin and low discharge (Figure 2.1c) (see Chapter 9). Surface salinity remains very low at high and moderate discharge but spikes sharply at the lowest flows (Figure 2.8a). Freshwater conditions (salinity <0.5 ppt) are common in the Waccamaw River. In contrast, surface salinity in the larger Savannah River remains at 2–5 ppt throughout normal discharge as well as during drought (Figure 2.8b). Only during extremely high flow (e.g. January–July 2003) does salinity drop to almost fresh conditions for an extended time. In the lower Savannah River, freshwater conditions are uncommon, even though base river flow (200–300 m³/s) is almost an order of magnitude higher than in the Waccamaw River. The depth of the dredged Savannah River channel allows a significant saltwater wedge to intrude upstream along the bottom, which mixes with the freshwater above (see Chapter 12).

The absence of river input has an enormous effect on salinity in coastal Louisiana. Tidal swamps occur mostly without direct river influence ex-

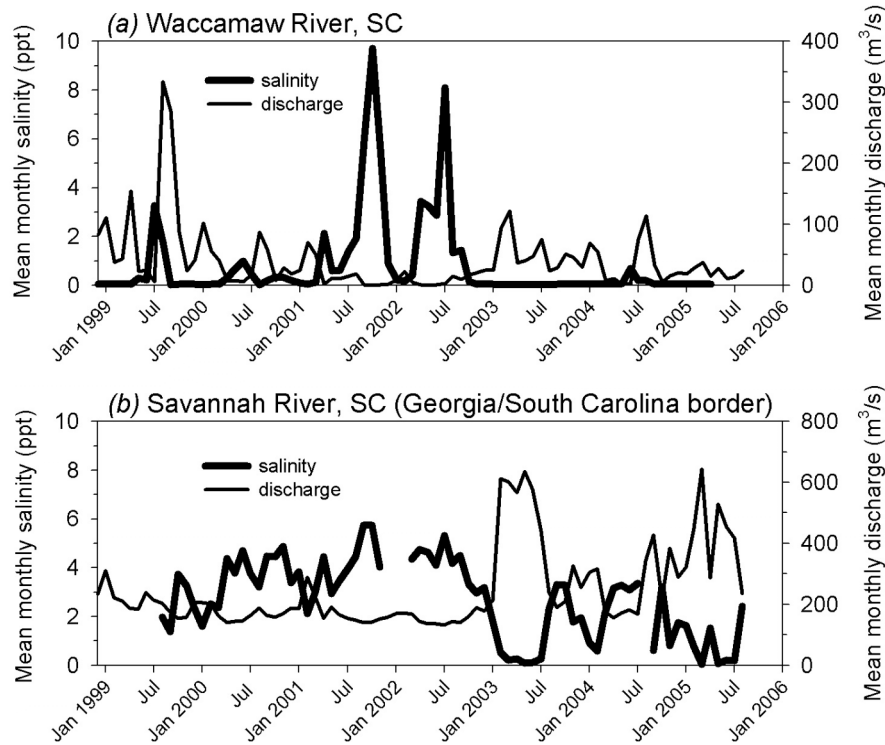


Fig. 2.8. Mean monthly surface salinity and mean monthly discharge for two rivers in South Carolina (data from USGS 2006). (a) Waccamaw River: salinity from “Hagley Landing near Pawleys Island” station (~river km 34); discharge from “Conway Marina” station (~river km 89). (b) Savannah River: salinity from “Port Wentworth” station (~river km 33); discharge from “Hardeeville” station (~river km 61).

cept near the Lower Atchafalaya River, where ship navigation canals allow river water to penetrate areas away from the main channel (Swarzenski 2001). Forested wetlands in the vicinity of Bayou Boeuf at Amelia, Louisiana (Figure 2.1a) are influenced by the Atchafalaya River and were unaffected by a local drought from 1999 to 2000, as indicated by continued fresh conditions during that period (Figure 2.9a); river discharge was sufficient to keep salt water from intruding into the area. In contrast, the swamp forests of Barataria Basin are isolated from river influx by extensive flood-control levees but are open to the Gulf of Mexico. Fresh water enters primarily as runoff from local precipitation. The Pen is an embayment in Barataria Basin approximately 50 km from the Gulf of Mexico (Figure 2.1a). Monthly average salinity in The Pen was high throughout the 1999–2000

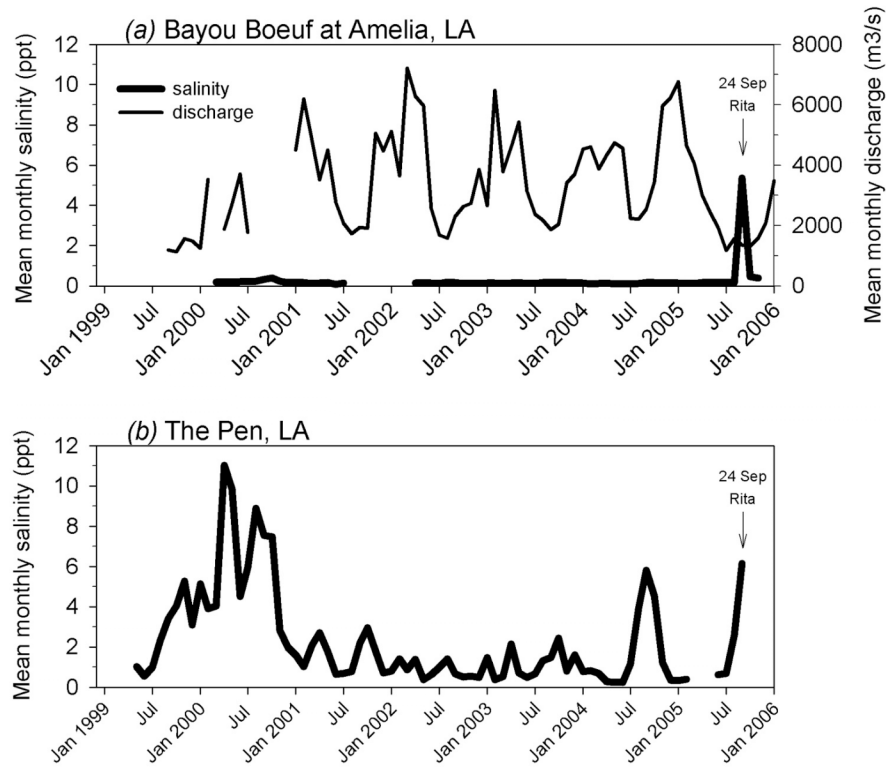


Fig. 2.9. Mean monthly surface salinity at two sites in coastal Louisiana near tidal freshwater forested wetlands. (a) Bayou Boeuf at Amelia is influenced by the Atchafalaya River (data from USGS 2006: salinity from Bayou Boeuf at “Amelia” station, discharge from Lower Atchafalaya River at “Morgan City” station). (b) The Pen, in Barataria Basin, has no river influence (salinity data from LADNR 2006, Naomi Siphon Diversion Project, station BA03C-60). Arrows refer to high mean monthly salinity in September 2006 as a result of the Hurricane Rita storm surge.

drought, reaching over 10 ppt during that period (Figure 2.9b). The passing of Hurricane Rita in the fall of 2005 raised water levels sufficiently in Bayou Boeuf and in The Pen such that monthly average salinity was raised considerably (Figure 2.9a, b).

2.3. Hydrology of tidal freshwater forested wetlands

Beaven and Oosting (1939) provided a descriptive narrative of a tidally influenced baldcypress-swamp tupelo forest on the Pocomoke River, Maryland (Figure 2.1d):

“The portions of the swamp adjacent to the river are regularly flooded and drained by the tide ... A few hundred yards from the river drainage at low tide is less complete and there is some standing water at all times. Even where ditches have been dug, the level contour, fallen logs, cypress knees and accumulation of plant debris prevent much run-off at low tide. The land rises very gradually from the river and as it reaches an elevation above high tide it becomes less swampy with a gradual transition from swamp to up-land forest.”

In a typical riverside tidal baldcypress swamp, there is a season when the forest is flooded and drained daily (or twice daily). At other times of the year the river rises and floods the forest floor for long periods. There may or may not be a tidal signature superimposed on that high water, but the tide during those periods does not affect the flooding duration of the forest; only the depth of flooding is affected. When river discharge is low and/or astronomical or wind forces cause the water levels to lower, the forest floor goes dry for an extended period. During this drought the tide influences the groundwater level, which is never far below the surface.

Hydrographs of many types of tidal freshwater forested wetlands follow the pattern described in the previous paragraph. The elevation of the soil surface in tidal forests ranges above and below mean high water. Thus, hydroperiods of tidal freshwater forests range from rarely flooded to permanently flooded, with concomitant changes in forest tree species. Hydroperiod may be defined as any time unit of inundation per time unit of study period, such as hours flooded per day or days flooded per year, and can be expressed as a percentage. Careful attention must be paid to defining the timing and duration of flooding that constitute the calculation of hydroperiod. A wetland which is inundated 50% of the time on an annual basis could describe a riverine backswamp that is continuously flooded for 6 months and continuously dry for 6 months. Another wetland with a 50% annual inundation rate is a tidal wetland that is flooded for 12 hours and drained for 12 hours each day. By definition, there must be a tidal signature evident in the hydrograph of a tidal wetland, either above or below the surface, during some period in a normal annual cycle. Following are de-

scriptions of the interaction of the tide with elevation, microtopography, and wind to create the range of hydrologic conditions present in tidal freshwater forests.

2.3.1. Elevation: the significance of mean high water

Swamp floor elevations in tidal baldcypress swamps are typically equivalent to the level of mean high water in the adjacent water body (Table 2.2, Figure 2.10a), which is true regardless of the tide range or distance from the coast. Codominant tree species in these swamps are usually swamp tupelo and/or water tupelo (*Nyssa aquatica* L.). As the elevation of the swamp floor becomes higher relative to the level of mean high water, baldcypress becomes less dominant and bottomland hardwood species become more dominant (Figure 2.10b). The Pamunkey River site in Virginia (Figure 2.1d) is a higher elevation tidal bottomland hardwood forest dominated by ash (*Fraxinus* spp.), swamp tupelo, and red maple (*Acer rubrum* L.) (Rheinhardt and Hershner 1992; see Chapter 7). This same type of tidal forest was described by Peterson and Baldwin (2004) on the Nanticoke River in Maryland (Figure 2.1d) (see chapter 6). The Pocomoke River study area (Figure 2.1d) consists of two sites which vary in elevation and have baldcypress grading into mixed bottomland hardwoods at both sites (see Chapter 5).

Mean tide ranges at three study sites were higher than at the coast (Savannah River at 5 km, Savannah River, and Pamunkey River) (Table 2.2). The rest of the sites had attenuated tide ranges. Magnification or attenuation as the tidal wave travels upstream is a function of river morphology, tide type and range, and distance upstream.

Other tidal freshwater forests that occur above mean high water are the coastward edges of hydric hammocks (Figure 2.10c) (Vince et al. 1989; Williams et al. 1999a; see Chapter 10 for a definition of hydric hammock), maritime forests (forests bordering coastal beaches) (Bellis 1995), and Atlantic white cedar (*Chamaecyparis thyoides* (L.) B.S.P.) communities (Laderman 1989; see Chapter 4). Hydric hammocks and maritime forests are primarily rain-fed as the source of fresh water and may be considered tidal when they are located close enough to the coast that a tidal signature is evident in a groundwater hydrograph (Bellis 1995; Williams et al. 1999b). Even though they occur above mean high water, proximity to the coast makes hydric hammocks and maritime forests vulnerable to inundation from storm surges. These wetlands may also be subject to overtopping by flood waters when located in proximity to a river (Light et al. 2002). Cowardin et al. (1979) classify hydric hammocks in general as nontidal

Table 2.2. Elevation and tide range of selected tidal freshwater forested wetland study sites in the southeastern United States. Numbers in parentheses are estimates^a.

Study site	Forest type ^b	Distance to coast [km]	Study site forest floor elevation [m] ^{c,d}	Study site mean high water elevation [m] ^{e,e}	Study site mean tide range [m] ^{e,f}	Coast mean tide range [m] ^{e,f}	References ^g
Louisiana: Barataria Basin The Pen	baldcypress swamp	(50)	(0.3) NAVD88	(0.3–0.4) NAVD88	(0.1–0.2)	0.3	This chapter
Florida: Suwannee River	baldcypress swamp	5	0.4–0.5 NGVD29	0.6 NGVD29	0.9	0.8	Light et al. 2002
Florida: Suwannee River	baldcypress swamp	43	1.0 NGVD29	1.0 NGVD29	0.3	0.8	Light et al. 2002
Georgia: Savannah River	baldcypress swamp	(35)	(1.4) NGVD29	(1.4) NGVD29	(2.3–2.5)	2.1	This chapter
North Carolina: Cape Fear River (Indian Creek site)	baldcypress swamp	(60)	0.5–0.7 NAVD88	(0.6) NAVD88	1.2	1.3	C. T. Hackney (pers. communication); Chapter 8
Maryland: Pocomoke River	baldcypress/mixed hardwoods	(155–175) ^h	(0.4–1.4) MTL	(0.2) MTL	(0.4)	0.8	D.E. Kroes (pers. communication); Chapter 5
Virginia: Pamunkey River (“Elsing” site)	mixed hardwoods	(100) ^h	(0.9–1.0) MTL	(0.4–0.6) MTL	(0.8–1.2)	0.8	Rheinhardt and Hershner 1992
Florida: Turtle Creek	cabbage palm hammock	(2–4)	0.4–1.3 NAVD88	(0.4) NAVD88	(0.9)	0.9	Williams et al. 1999a

^a Estimated distances were measured on a map. Estimated elevations and tide ranges are from the nearest one or two gages available at NOAA (2006a).
^b Baldcypress swamp: baldcypress is dominant or co-dominant. Mixed hardwoods: baldcypress is unimportant or absent. Cabbage palm hammock: cabbage palm is dominant or co-dominant.

^c NGVD29 National Geodetic Vertical Datum of 1929, NAVD88 North American Vertical Datum of 1988. MTL Mean tide level (a datum which sets zero at halfway between mean high water and mean low water). NGVD29 and NAVD88 are fixed geodetic references, while MTL is calculated from tide gage measurements and is unique to each gage (Hicks et al. 2000).

^d Swamp-floor elevation may include ranges from hollows to hummocks for one to many sites.

^e Tide means are calculated for the 19-year period from 1983 through 2001.

^f Mean tide range = mean high water minus mean low water.

^g References are sources of information for forest type, site location, elevation, and some tide data; all other tide information is from NOAA (2006a). “This chapter” refers to data that are presented in this chapter for the first time.

^h The coast refers to the mouth of Chesapeake Bay (Chesapeake Bay Bridge-Tunnel tide station) for Virginia and Maryland sites.

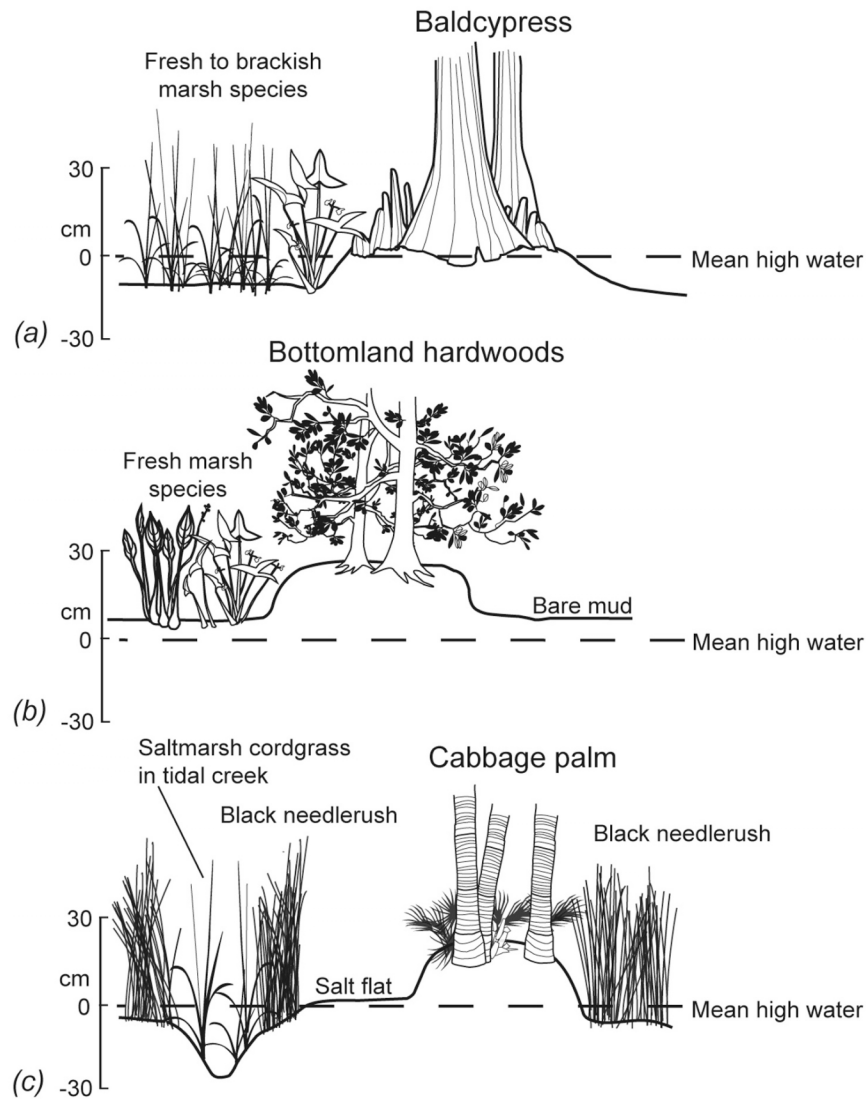


Fig. 2.10. Typical profiles of tidal freshwater forested wetlands showing hummock and hollow topography (high and low elevations, respectively) and position with respect to mean high water. (a) Baldcypress swamp (drawn from descriptions by Light et al. 2002 and personal observation; see Chapters 9 and 11). (b) Bottomland hardwood swamp (after Rheinhardt and Hershner 1992; see Chapters 5, 6, and 7). (c) Cabbage palm hydric hammock (drawn from descriptions by Vince et al. 1989; Williams et al. 1999a; Doyle et al. 2003; see Chapter 10).

palustrine forested wetlands with seasonally flooded water regimes, but sometimes the coastward edges carry the modifier “seasonal-tidal.” Characteristic of hydric hammocks and maritime forests are hydrographs dominated by nonflowing water, or “still-water wetlands” (Wharton et al. 1977) and relatively salt-tolerant yet nonhalophytic trees such as cabbage palm (*Sabal palmetto* (Walt.) Lodd. ex J.A. & J.H. Schultes), live oak (*Quercus virginiana* P. Mill.), and southern redcedar (*Juniperus virginiana* var. *silicicola* (Small) J. Silba). Tidally influenced hydric hammocks are often found directly upslope of salt marsh, in particular irregularly flooded salt marsh dominated by black needlerush (*Juncus roemerianus* Scheele) grading into tidal creeks dominated by saltmarsh cordgrass (*Spartina alterniflora* Loisel.) (Stout 1984; Vince et al. 1989; Williams et al. 1999a). Salt flats that are barren or covered by saltmarsh succulent plant species sometimes occur at the base of cabbage palm island hammocks right at the level of mean high water, presumably because of the lack of tidal flushing and high evaporation rates which combine to create hyper-saline conditions (Figure 2.10c) (Stout 1984; Doyle et al. 2003). Atlantic white cedar, on the other hand is salt intolerant and is usually found upslope of freshwater marshes or swamps, often at the toe of slopes where ground water is plentiful (Beaven and Oosting 1939; Laderman 1989; see Chapter 4). Laderman (1989) reported that Atlantic white cedar almost always occurs above the level of high tide; however, a hydrograph of an Atlantic white cedar community appears in Chapter 4 which exhibits a tidal signature.

Permanently to semipermanently flooded forests of the Mississippi River deltaic plain in Louisiana typically occur below the level of mean high water. While many areas of coastal forest in Louisiana have an irregular microtidal signature, they are so low in elevation that they are very vulnerable to saltwater intrusion, particularly during surge events. The obvious threat of periodic hurricanes is compounded by minor events such as sustained wind from the south, which pushes water up the estuaries and can occur at any time of the year. Most of Louisiana’s swamp forests are classified by Cowardin et al. (1979) as nontidal, semipermanently flooded palustrine forests, but with only slight differences in hydrology they are considered semipermanent-tidal or permanent-tidal. Day JW Jr et al. (2006) describe a tidal freshwater forested wetland near Bayou Boeuf (Figure 2.1a) that is continuously flooded 20–40 cm deep throughout an entire year of study with less than a few centimeters of daily tidal fluctuation. There are permanently flooded baldcypress forests in the Atchafalaya Basin Floodway (Figure 2.1a) that have distinct 10–15 cm daily tidal fluctuations during low flow of the Atchafalaya River (Day RH, unpublished data). Since the substrate in these swamps is never exposed except in an

extreme drought, perhaps they would better be classified as subtidal. Higher elevation swamps within the Atchafalaya Basin Floodway are only flooded during higher discharge of the Atchafalaya River when no tidal signature is apparent.

2.3.2. Microtopography: hummocks, hollows, and hydroperiod

As in all wetland ecosystems, microtopography plays a role in controlling hydroperiod in tidal swamps and associated species assemblages according to their flood tolerances. Rheinhardt (1991, 1992) placed water-level recorders within five tidally influenced bottomland hardwood forests along the Pamunkey River, a tributary of the York River which flows into lower Chesapeake Bay (Figure 2.1d) (see also Rheinhardt and Hershner 1992 and Chapter 7). The Pamunkey River study site listed in Table 2.2 (“Elsing”) has an elevation of 0.85–1.00 m above mean tide level (1.35–1.50 m above mean low water) in an area where the tide range varies from 0.8 to 1.2 m. All but one of the sites were characterized by hummocks and hollows (topographic highs and lows, respectively), common microtopographical characteristics of tidal freshwater swamps. The hummocks support the woody vegetation of the forest and were approximately 15 cm in elevation above the hollows, which were almost always saturated (Figure 2.10b). The hollows are bare mud or contain herbaceous vegetation similar to that found in tidal freshwater marshes. Water level was recorded continuously during three growing seasons, and the tops of the hummocks were almost never inundated. Only the most downriver site experienced flooding above the hummock surface during the growing season, and that was less than 0.1% of the time. During the growing season, the surface of the hollows was inundated 5%–20% of the time, reaching up to 15 cm of water depth, saturating but not overtopping hummock surfaces. The soil of the hollows 0–15 cm below the surface was flooded 20%–100% of the time. The surface of the hollows was often inundated twice daily during spring tide conditions.

Hummock and hollow topography has also been described in tidal forested wetlands of Maryland’s Eastern Shore (Harrison et al. 2004; Peterson and Baldwin 2004; see Chapters 5 and 6), on the Cape Fear River, in North Carolina (Figure 2.1c) (see Chapter 8), and as hummocks and sloughs (up to 1.2 m difference in elevation) along the Apalachicola River in Florida (Leitman et al. 1984). Duberstein (2004) described hummocks and hollows in tidal freshwater forests of the Savannah River floodplain; he hypothesized that hydroperiods of Savannah River tidal forests were longer than those measured by Rheinhardt (1992) on the Pamunkey River based on

higher organic matter content of the hummocks of the Savannah River sites (see Chapter 12). Water level in a tidal forest of the Savannah River (Figure 2.11) shows a pattern similar to a hydrograph published by Rheinhardt (1992) (reproduced in Chapter 7) and also to hydrographs in Chapters 6, 8, and 9. The higher high tides inundate the hummocks for the first 7 days on the graph, while the lower high tides only flood the hollows. Following that is a period during which no tide inundates the surface of the hummocks or hollows. During this period, the tides impede subsurface drainage, and the soil of the hollows is kept saturated to within 20 cm of the surface.

Light et al. (2002) reported that hummocks are present at the bases of trees at nearly all forested wetland transects studied on the Suwannee River, but are more common in lower tidal areas, where they are large and well defined (see Chapter 11). Light et al. (2002) did not have water-level recorders within forested sites, but they calculated inundation rates based on surveyed elevations of forested sites and river stage. The mud floors (hollows) in tidal swamps remained nearly 100% saturated because the elevation of the mud floors was close to the elevation of median daily high tide stage. Some hummock tops had better drained soils that were not continuously saturated.

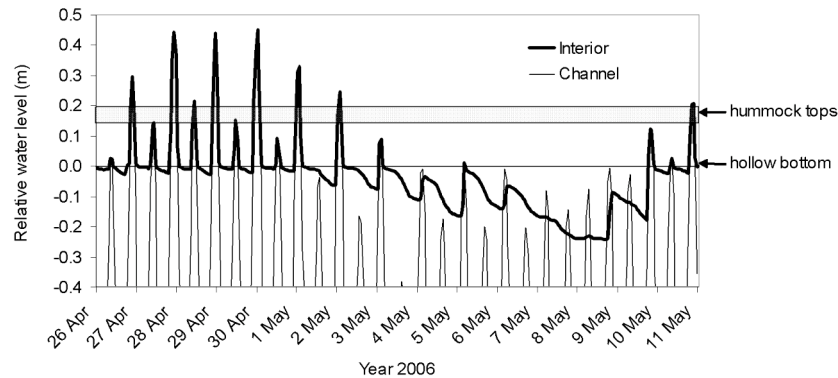


Fig. 2.11. Hourly water levels from stage recorders installed within the interior of a tidal forested wetland and in an adjacent tidal channel at ~river km 35 on the Savannah River, Georgia (referenced as “this chapter” in Table 2.2). The interior gage is installed within a hollow bottom; the soil surface of the bottom is 0.0 m on the relative water level scale of the graph. The tops of the surrounding hummocks are 15–20 cm above the level of the hollow bottom.

Even hammocks have hummocks. According to Light et al. (2002), referring to transects in the lower Suwannee River floodplain (and using the term “mud floor” instead of “hollow”), “... some lower tidal forests have a distinct hummock-mud floor topography that supports hammock species on the hummocks and swamp species on the mud floor.” Hydric hammocks in saltier environments downstream (or coastward) of the tree line may take the form of islands (hummocks) surrounded by salt marsh (hollows) (Figure 2.10c). Light et al. (2002) referred to these as maritime hammocks. Williams et al. (1999a) published hydrographs (partially re-plotted in Chapter 10) of groundwater fluctuations underneath coastal hydric hammocks near Turtle Creek, Florida, which exhibit tidal influence (Figure 2.1b). Ground water level was usually 0.5–1.0 m below the surface of the hammocks, rose occasionally to within 5–10 cm below the surface of one of the hammocks, but never inundated the tops of the hammocks for an entire year of continuous recordings.

The existence of hummocks and hollows is related to the elevation of tidal freshwater forests relative to mean high water. The very upper end of the tide cycle supplies just enough water to inundate the hollows to an extent that they do not support the vegetation that exists on the top of the hummocks. The hollows function as the upper extreme of tidal creeks, providing the benefits of regular flooding and draining without the erosive force of stronger tidal forces downstream. The hummock tops provide a well-watered/well-drained environment with more aeration than forested wetlands with continuously saturated soils. Rheinhardt and Hershner (1992) hypothesized that hummocks are formed and maintained by the accumulation of fallen trees, where tree species may germinate and grow, forming root balls which persist after the fallen trees have decomposed. Leitman et al. (1984) mentions a lack of hummocky terrain at sites along the Apalachicola River that are slightly higher in elevation than tidally influenced forests or that are cut off from tidal influence by natural and artificial levees. Perhaps at the upper extreme of tidal influence, the slow movement of water back and forth with the tide may help loosen the soil matrix in soils not bound by the root balls of trees, providing a gentle erosional force to facilitate the development of hollows. However they are formed, higher inundation rates prevent germination of tree species in the hollows.

2.3.3. Wind and water level

The wind may play as much a role as does river flow in controlling water levels in many coastal areas of the southeastern United States. Inunda-

tion of tidal freshwater wetlands on the lower Pocomoke River (a tributary to Chesapeake Bay) (Figure 2.1d) is controlled more by wind direction and velocity than by river storm flow events (see Chapter 5). The mouth of Chesapeake Bay has a mean tide range of 0.78 m (Table 2.2), which is attenuated over a distance of ~150 km to ~0.4 m in the lower Pocomoke River. Also, the lower Pocomoke River has a much wider channel cross section than does the river farther upstream; therefore rainstorm flow peaks are attenuated. Finally, the orientation of Chesapeake Bay is generally north-south, and the Pocomoke River is located on the eastern side of the bay; therefore prevalent winds from the west and south have the greatest effect on water levels in the tidal swamps of the lower Pocomoke River.

Wind plays an even greater role in upper Barataria Basin, where tidal swamps are isolated by levees from any major riverine influence. A water-level recorder was installed within a tidal baldcypress forest near The Pen, an embayment of the Barataria Bay system (Figure 2.1a). The entrance from the Gulf of Mexico is to the south. The hydrograph shows a tidal signature but is dominated by wind-driven water levels (Figure 2.12a, b). The average daily wind speed and direction coincide with dominant peaks and valleys of the hydrograph (Figure 2.12a, b). Winds from the south (arrows pointing up on the graph) (Figure 2.12b) push the water levels higher, and winds from the north push water out of the system, lowering water level. This is a shallow, well-mixed system, so salinity rises and falls from <1 ppt to >10 ppt as the water mass moves back and forth with the tide and changes in wind direction (Figure 2.12c). The nearest gage from which predicted tides are available is at Grand Isle, on the Louisiana coast about 50 km to the south (Figure 2.12d). The observed Grand Isle data show the same pattern as The Pen gage, and the difference between observed and predicted water level correlates well with the wind vectors from the Louis Armstrong New Orleans International Airport, even though New Orleans is 85 km to the north of Grand Isle and 35 km north of the study site. The general trend of the predicted mean tide level (without wind influence) is higher in October and slowly falls to a low in December. The timing of average daily winds was such that in October the south wind pushed the highest tides even higher and in December the north wind pushed the lowest tides even lower. The Pen was inundated for most of October and November by water with salinity 2–10 ppt. Salinity in The Pen dropped to near 0 ppt in December, but water level within the swamp also dropped. The swamp floor was dry in December, so there was no freshwater flushing effect, and groundwater salinity remained high within the swamp (personal observation).

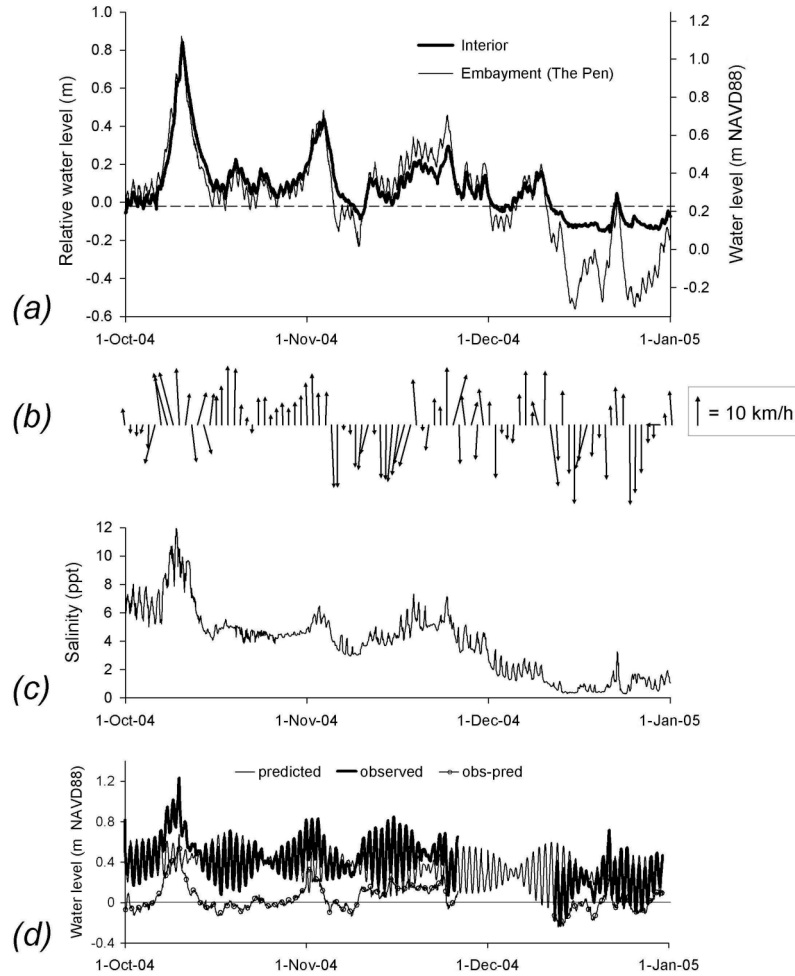


Fig. 2.12. (a) Hourly water levels from a stage recorder within the interior of a tidal freshwater forested wetland and from a tide gage in a nearby embayment (The Pen) (Naomi Siphon Diversion Project, station BA03C-60) (LADNR 2006) in Barataria Basin, Louisiana for a 3-month period (referenced as “this chapter” in Table 2.2). The interior gage is installed within a hollow bottom; the soil surface of the bottom is 0.0 m on the relative water level scale of the graph. (b) Daily wind vectors at the Louis Armstrong New Orleans International Airport (NOAA 2006b). These are resultant speed and direction, defined as the vector sum divided by the number of observations. Arrows pointing up are winds from the south. (c) Hourly salinity records from The Pen (LADNR 2006). (d) Hourly water levels of predicted and observed tides and their difference (observed minus predicted) at Grand Isle, Louisiana (data from USGS 2006). NAVD88 North American Vertical Datum of 1988.

2.4. Hydrology, biology, and biogeochemistry

There is generally a decline in plant species diversity from freshwater to saltwater wetlands (forested or herbaceous), and in both there is a change in species composition with annual inundation rate. Beneath the canopy of tidal freshwater forested wetlands is a community of herbaceous plants which may change with the season and from year to year depending on degree of flooding and salinity of the floodwater; the tree species, however, have to tolerate the changing conditions to survive to maturity. Chronic exposure to inundation by water with salinity of approximately 2 ppt leads to conversion of tidal forested wetland to oligohaline or brackish marsh on the Cape Fear River (see Chapter 8). Light et al. (2002) reported that soil porewater salinity was highest below the root zone in regularly inundated tidal freshwater forests along the Suwannee River, while Williams et al. (1999a) recorded salinities up to ~23 ppt in the groundwater of rarely flooded coastal hydric hammocks. In salt marsh ecosystems, increased productivity has been noted for the creek tidal zone related to daily aeration of the subsurface by tidal action (King et al. 1982; Portnoy and Valiela 1997; Mendelssohn and McKee 1988). Daily flooding and draining can also theoretically increase productivity in tidal freshwater forests. It has been shown experimentally that seedlings of baldcypress and black willow (*Salix nigra* Marsh.) have increased growth rates with hydroperiods that simulate tidal frequency (Conner 1995; Day RH et al. 2006); however, this could only occur in an ideal situation where there is enough freshwater flow that no salt water is introduced with the tidal action. Brown and Lugo (1982) compared freshwater and saltwater forested wetlands in the greater Caribbean Sea basin and the southeastern United States but did not include tidal freshwater forests. They found that the number of tree species, complexity index, and aboveground biomass were higher in freshwater than in saltwater forested wetlands.

Physical and biological aspects of tidal freshwater and salt marshes were compared by Odum (1988), and even though trees were considered part of the marsh landscape, most of the data described herbaceous vegetation ecosystems. One of the greatest differences was in the composition of the anaerobic microbial communities. Generally, fermentors and methanogens dominate in tidal freshwater, and sulfur reducers dominate in the salt marsh. Daily cycling between anaerobic and aerobic conditions in the wetland soil environment, even if limited to near the swamp surface, can influence accumulation of porewater sulfides, cycling of trace metals, decomposition of organic matter, and trace gas emissions (Odum 1988; also see Chapter 8). Prolonged aeration during dry periods may result in pyrite

oxidation, lowered pH, and release of metals, possibly in concentrations that are toxic to the vegetation (Portnoy and Giblin 1997). Verhoeven et al. (2001) compared tidal versus nontidal and forested versus herbaceous freshwater riverine wetlands in the United States and Europe. Soil organic matter, total nitrogen, total phosphorus, and bulk density were higher in tidal freshwater wetland soils than in nontidal wetland soils. One explanation given was the possibility that nutrient-rich riverine sediments were regularly deposited in the tidal freshwater wetlands, presumably as river flow is slowed by the upstream advance of the tide. This explanation is most plausible in the upper reaches of tide effect where the possibility of tidal scour and export is minimal. The sediment and nutrient trapping function of forested wetlands is important along alluvial reaches, and may peak in the upper reach of the tide, only to diminish downstream where tidal influence is greater (see Chapter 5). Verhoeven et al. (2001) also found that forested wetlands had higher soil organic matter and total nitrogen but lower bulk density and total phosphorus than did freshwater herbaceous wetlands, possibly because of the low rates of decay of woody plant tissues compared to the high rates of decomposition of herbaceous species. Again, this assumes *in situ* deposition of autochthonous material in the absence of appreciable tidal scour. More detail on the effects of hydrology on soil biogeochemistry is presented in Chapter 3.

2.5. Forest sustainability

Hydraulic forces move riverine freshwater and tidal salinity effects many kilometers upstream and downstream on daily, monthly, annual and multiyear cycles. The life spans of trees are decades to centuries, during which time the environmental conditions of hydroperiod and salinity regime are prone to change. How can a forest exist in such a variable environment? The trees in the forest have to deal with two thresholds, flood tolerance and salt tolerance. Tolerances vary among tree species, within a species (e.g., salt-tolerant genotypes), and throughout the life cycle of individuals (seed, seedling, sapling, adult) (Hook 1984; Allen et al. 1996; Krauss et al. 1998; see Chapter 14). Both flood and salt tolerance may vary between seedling establishment, sapling survival, and adult growth and productivity within an individual tree (Conner and Askew 1992; Conner 1994; Krauss et al. 1999). Within a given time period in a tidal freshwater swamp, a certain environmental condition allows a tree seed to germinate. The tree either dies or survives depending on the sustained conditions which may or may not change in the individual's lifetime. Global climate

patterns affect the magnitude and seasonality of the fresh water input to the coast, the most critical component to the sustenance of tidal freshwater wetlands (see chapter 1). Certainly in the southeastern United States the conditions under which some baldcypress forests were established were much fresher and less waterlogged than now. Over time, with relative sea-level rise and saltwater intrusion, many baldcypress trees have died, yet salt-tolerant individuals have survived where conditions are no longer favorable for regeneration to occur (Conner and Day 1988; Conner and Brody 1989; see Chapters 8 and 13). The coastal edges of cabbage palm hammocks are suffering a similar fate (Williams et al. 1999a, b). The upper extreme of riverine tidal freshwater forested wetlands are healthy and thriving (see Chapters 6 and 7); however, ghost forests (forests of mostly dead standing trees surrounded by emergent marsh or open water) are a common sight on the coastward edges, as attested to by the photos in Chapters 8, 9, 10, and 14.

2.6. Summary

Tidal freshwater forested wetlands occur anywhere that tides influence the hydrology of freshwater forests. If a tidal forest is healthy, it is usually located at or above the level of mean high water. Hydrology of tidal freshwater forests is primarily dictated by local tides and river discharge. Tide ranges vary by coastal reach across the southeastern United States from microtidal to mesotidal. Actual tide heights are driven by both astronomical and meteorological influences as well as by river channel and estuarine basin geomorphology. The predictable astronomical tides vary daily and seasonally and are well known for most coastal rivers and outlets. Meteorological forces of prevailing winds, frontal passages, and tropical storms can greatly amplify tidal highs and lows and often dominate over astronomical influences in microtidal settings. The upper end of tidal fluctuation in channels with relatively uniform bottom slope occurs at the point where the bottom elevation is approximately at high tide. Salinity and flooding are boundary controls on the downstream extent of tidal freshwater forests. Salinity, as well as duration and timing of flooding, controls tree species diversity, primary productivity, and soil biochemistry. Daily flooding and draining may increase forest productivity when salinity influence is minimized. What are the optimum conditions? More research is needed to understand the specific response of the productivity of tidal freshwater forested wetlands to the many patterns of inundation caused by the interaction of freshwater input and tides.

Hummocks and hollows typify the microtopography of tidal freshwater forested wetlands. The hollows function as the headwaters of tidal creeks within tidal freshwater swamps. Hollows are characteristically saturated 100% of the time and are dominated by herbaceous vegetation. The tops of the hummocks are flooded much less often and support the tree species. The hummocks provide a well-drained environment with more aeration than in forested wetlands with continuously saturated soils.

Conditions are continuously changing in many tidal freshwater forests. Eustatic sea level is rising. The land in many areas of the Southeastern United States is sinking by geologic process. Humans have changed many rivers by building dams, dredging harbors, or both. Tidal freshwater forested wetlands are both complex and threatened. The seemingly incompatible terms “freshwater” and “tidal” relegate these forested wetlands to a relatively narrow position in the landscape at the upstream edge of the estuarine mixing zone. There must be some degree of stability over a time period which includes the life span of trees, but the inexorable rise in coastal water levels at present is causing the coastal fringe of these systems to become increasingly characterized by dead or dying trees.

2.7. Acknowledgments

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