Chapter 6
Fire in Floodplain Forests of the Southeastern USA

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Abstract Nowadays forest fires are so rare in the Mississippi Alluvial Valley and other floodplains of the southeastern USA that these floodplains appear fireproof. Fire was once much more common across the Southeastern Coastal Plain, including in these forested floodplains. Even so, fire was not the fundamental ecological disturbance in floodplain forests that it was in adjacent uplands; flooding served that role here. Other disturbances, like hurricanes, tornados, and beavers opened floodplain forests and may have been antecedents to fires. Since the arrival of Europeans, the disturbance regime in perhaps no other ecoregion in the continental USA has

Ecoregions: 73, Mississippi Alluvial Plain; 74, river floodplains of the Mississippi Valley Loess Plains; 65, Southeastern Plains; 63, Middle Atlantic Coastal Plain; 75, Southern Coastal Plain; 34, Western Gulf Coastal Plain; 35, South Central Plains; 33, East Central Texas Plains; 32, Texas Blackland Prairies

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C. H. Greenberg, B. Collins (eds.), *Fire Ecology and Management: Past, Present, and Future of US Forested Ecosystems*, Managing Forest Ecosystems 39, https://doi.org/10.1007/978-3-030-73267-7_6

been so fundamentally altered. Levee- and dam-building have radically changed the hydrology of most of these river floodplains. Logging, agricultural conversion, urbanization, and road-building have further altered ecosystem structure and function. Fire is exceedingly rare in modern, closed-canopy floodplain forests, where fuels remain moist year-round, well-drained sites are converted from canebrakes to crop fields, and fires that once burned across adjacent uplands are either halted by habitat fragmentation or actively suppressed. This chapter will discuss the role of fire in floodplains of the southeastern USA in the context of other ecological and human-caused disturbances historically, presently, and looking to the future.

Keywords Bottomland hardwood forests · Lower Mississippi Alluvial Valley · Pyrophytic vegetation · Mesophication · Swamps · Deforestation

6.1 Introduction and Context for Southeastern Floodplain Forests

This chapter is about fire in the forested river valleys of the Southeastern Coastal Plain (SCP), USA. By far the largest floodplain in the USA is the Mississippi Alluvial Valley; the Lower Mississippi Alluvial Valley (LMAV) drains most of the central USA. Numerous other rivers transect the Atlantic and Gulf Coastal Plains (Fig. 6.1). These floodplains are termed “bottoms” or “bottomlands;” the deciduous forests growing there are called bottomland hardwood forests. Floodplain forests are distinct from forests of adjacent uplands. River floodplains can be more fertile than the surrounding uplands, and although the trees growing there must endure flooding, they are less limited by drought. These factors plus a subtropical climate mean flood-tolerant trees grow rapidly to fill floodplains with their dense vegetation (Fig. 6.2a, b). Because of the generally moist growing conditions in these bottoms (Fig. 6.2c), fire has likely always been less frequent than in uplands. When fires do occur, however, they can play an important role in ecosystem function and community dynamics.

In the southeastern USA during typical years, riverine valleys are prone to flooding for substantial periods of the growing season (Wharton et al. 1982). The drivers of this flooding include both local and regional rainfall events, seasonal snowmelt, and along the Atlantic and Gulf coasts, precipitation and surge from occasional tropical storms. Just as flood tolerance separates bottomland tree species from their upland counterparts, flooding frequency, timing, depth and duration are important filters that sort individual bottomland species by site (Kellison et al. 1998). Given the prevalence of flooding in this habitat, species adaptations for flooding can be more obvious than adaptations for fire (e.g., McKevlin et al. 1998).

These forests evolved in floodplains set within frequently burned landscapes, and lightning strikes are a common occurrence in uplands and bottoms alike (Mäkelä et al. 2011). While fire-adapted pines (*Pinus* spp.) and oaks (*Quercus* spp.) have

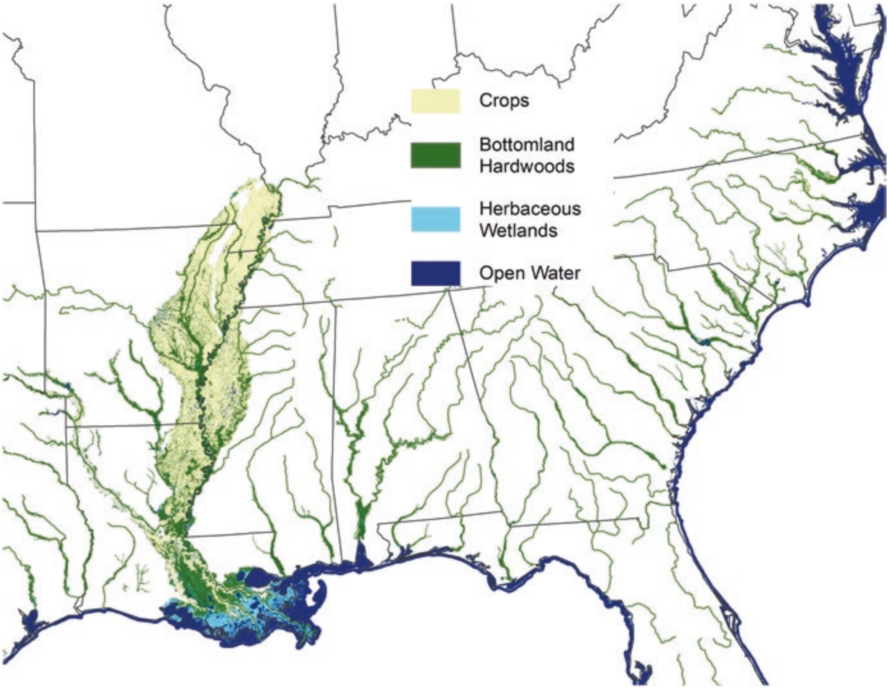

Fig. 6.1 Lower Mississippi Alluvial Valley and other floodplains of the SCP. River valleys dominated by bottomland hardwood forest are in dark green. Areas converted from bottomland hardwoods to cropland are in yellow. (Based on Homer et al. (2020). Image B. Hanberry and P. Gagnon)

historically dominated adjacent flats and uplands (Chap. 3), fires are less common in the moist, verdant forests of the floodplains (Frost 1998). Even so, periodic fires have been documented in floodplain forests (e.g., Lentz 1931a; Kaufert 1933; Hepting 1935; Putnam 1951) and have been ecologically important in certain constituent ecotypes, including some baldcypress (*Taxodium distichum*) bottoms (Ewel 1995) and Atlantic white-cedar (*Chamaecyparis thyoides*) swamps (Laderman 1989). Fires were more frequent in the canebrakes – extensive, monodominant stands of rivercane (*Arundinaria gigantea*), a native bamboo – described by early explorers in alluvial floodplains (Nuttall 1821; Harper 1958; Platt and Brantley 1997; Gagnon 2009). Native Americans, Euro- and Afro-Americans all burned floodplains for agriculture. Humidity and fuel moisture levels are typically high in these dense, riverine forests, so periodic droughts are an important precursor for the spread of any natural fires.

Bottomlands have undergone some of the most ecologically consequential changes of any forested habitats in the USA since the arrival of Europeans. Among the most notable are pervasive alterations to natural hydrology; almost all have been subjected to some combination of levee-building, dredging, river control structures, ditching or other artificial means to drain the wetlands, control river courses and

Fig. 6.2 Floodplain forests of the southeastern USA: (**a**) flood-tolerant trees grow rapidly to fill these floodplains with dense vegetation (photo Paul Gagnon); (**b**) in the southern part of the ecosystem's range, understories can include dwarf palmetto (*Sabal minor*) (photo V. Velez-Thaxton); (**c**) these forests remain moist except during prolonged droughts (photo V. Velez-Thaxton), and; (**d**) baldcypress-tupelo swamps occur in the lowest, wettest forested areas (photo William Conner)

moderate variability in river levels (e.g., Piazza 2014; King and Keim 2019). Most modern floodplains are now heavily fragmented because a majority of forested lands have been converted to cropland, roadways, and housing developments (e.g., Yang et al. 2020). All but a handful of remaining forest stands have experienced multiple cycles of logging that replaced old-growth stand structure with dense, closed canopy second and third growth forests of young trees (Oliver et al. 2005; LMVJV 2007; Battaglia and Conner 2018). Fire is now extremely rare in these floodplain forests, and its occurrence and ecological role are best understood in the context of these myriad changes.

6.2 Ecosystem Processes in Southeastern Floodplain Forests

During prior glacial intrusions and recessions, the Mississippi River drainage carried large loads of meltwater and soil sediment. Movements of the Mississippi River have worked and reworked soil from the western plains, Midwest, and Allegheny and Appalachian Mountains in its floodplain, creating isolated backwater swamps and bayous and building ridges and natural levees (McKnight et al. 1981). Other major alluvial floodplains in the southeastern USA are associated with large rivers of the lower Piedmont and Coastal Plain. All are predominantly forested except after major natural disturbances or anthropogenic activities. On the Atlantic Coastal Plain, soil and vegetation developed through cycles of continental submergence and emergence (Colquhoun 1974). Soils there are generally of Appalachian and coastal origin, and rivers have modified the landscape to a lesser degree than in the Mississippi drainage (Sharitz and Mitsch 1993).

The Mississippi and other major floodplains have diverse topographic features despite low relief. They experience relatively long seasonal flooding tied to regional precipitation far upstream via overbank flow and backwater flooding (Kellison et al. 1998). All include meandering river channels, natural levees adjacent to the rivers, meander scrolls created as the rivers change course (ridge and swale topography), oxbow lakes created as meanders become separated from the main channel, and sloughs of ponded water in meander scrolls and backwater swamps (Leopold et al. 1964; Bedinger 1981; Brinson et al. 1981; Mitsch and Gosselink 1986). Backwater swamps occur in a wide variety of geomorphic situations ranging from broad, flat floodplains to isolated basins (Fig. 6.2d); they tend to be less extensive, and the bottoms are less dissected on the Atlantic Coastal Plain (Braun 1950).

Minor alluvial floodplains are associated with smaller order streams of the upper Coastal Plain, Piedmont, and mountain valleys. They exhibit relatively narrow and often discontinuous floodplains and a pronounced and dynamic riparian zone. Soils of minor bottoms are of local origin with less variation in texture and mineralogy. These sites are generally, but not always, less productive than those of major bottoms (Hodges and Switzer 1979).

6.3 Annual Flood Pulse and River Movement

Hydrologic inflows in southeastern floodplains (SCPF) are dominated by runoff from surrounding uplands and by overflow from flooding rivers (Mitsch and Gosselink 1993). With its vast catchment that includes snowmelt from the Great Plains, annual flooding in the middle and lower Mississippi River has a strong seasonal signature and can occur throughout March, April, and May (Villarini 2016; Therrell and Bialecki 2015). Smaller rivers flood from local and regional rainfall, and high water typically occurs in February and March, with a relatively weak seasonal signature and higher likelihood of influence from land-falling tropical storms later in the year (Villarini 2016). Annual flooding of the Ohio River tends to be intermediate between these, in March and April. Flooding in peninsular Florida is most common in late summer and early fall (August and September) because of summer monsoons, sometimes augmented by tropical storms (Villarini 2016).

Flooding can come from direct runoff from surrounding uplands, adjacent overflow of riverbanks and from groundwater (Brinson 1993). Concave topographic features or depressions in floodplains can impound water to cause extensive flooding. Types of depressions include oxbows, backswamps, and swales between relict levees where drainage is restricted (Brinson 1990). Heavy clay soils common to backswamp deposits have low infiltration rates and hold surface water much longer than the well-drained soils common on natural levees and point bars (Bedinger and Reed 1961; Kresse and Clark 2008). Even though backswamps typically remain flooded for extended periods, water levels can vary seasonally and annually. High water levels coincide with winter-spring rains and melting snow runoff. Low levels occur in the summer from high evapotranspiration and low rainfall (Wharton and Brinson 1979). During extreme droughts, like those of 1924 and 1960, even backwater swamps may lack surface water for extended periods (Mancil 1969).

Current floodplains are geologically young surfaces in which erosion and deposition are both occurring (Hodges 1998). Of the two, deposition is the dominant process in most floodplains. As streams overflow their banks, water velocity slows, and rapid deposition of suspended sediments occurs. The heaviest particles fall out of suspension first and form natural levees or "fronts" that are often the highest elevations in the floodplain. Slower rates of deposition of finer textured material occurs on the flats or slackwater areas. As they meander, streams form new fronts, while old fronts become levee ridges within the floodplain. An abandoned stream channel first becomes a lake but may eventually fill with sediment. By this process, stream meanders produce ridge and swale topography. Ridges are formed as bars, usually sandy, and normally much narrower than levee ridges.

6.4 Ecological Zonation of Trees

The floodplains of major rivers have broad levees, ridges, flats, and sloughs, whereas these natural features are relatively narrow in smaller floodplains. Species distribution within the floodplain is determined primarily by differences in hydrology, which in turn is related to the geomorphic site variations discussed above. Differences in relief of only a few cm can have a marked influence on distribution and growth of species (Hodges 1998; Battaglia and Sharitz 2006).

Most presettlement stands of bottomland hardwood forests were multi-aged (Putnam et al. 1960; Allen 1997). They would have included numerous old individuals and younger trees growing and filling small forest gaps left when single, large trees died (King and Antrobus 2001). These stands would have had mixed forest structure ranging from practically open near ground level in some places, to closed canopy in others, and variable vegetation as a function of local light, flooding, and fire regimes. Intermittently on the landscape, disturbance agents like thunderstorms and beavers would have produced multi-tree gaps. Flood events and river movements would have opened forest cover to varying degrees. There would have also been some extensive, even-aged cohorts of young trees regenerating after landscape-scale disturbances (e.g., tornados, hurricanes, and ice storms) created large gaps in the forest canopy (Battaglia et al. 1999; Gagnon et al. 2007).

Prior to Euro-American settlement, most stands of trees in bottomland hardwood forests contained diverse species sorted in part by the local flooding regime as influenced by microtopography (Harper 1958; Putnam et al. 1960; Allen 1997). Whereas upland forests in the Coastal Plain were 75–85% pine, floodplain forests were diverse in both broadleaf and coniferous species (e.g., Hanberry et al. 2018). Floodplain forests at higher relative elevations had a greater component of oak and pine species, often including loblolly (*Pinus taeda*) or slash pines (*P. elliottii*) in the Coastal Plain and a variety of both upland and lowland red and white oak species in the LMAV (e.g., Delcourt 1976; Hanberry et al. 2012; Bragg and Bragg 2016). Baldcypress and water tupelo (*Nyssa aquatica*) numbers increased with flooding duration and frequency (Lentz 1931b; Delcourt 1976; Grace and Smith 1995; Bragg and Bragg 2016). Common along stream channels were black willow (*Salix nigra*), eastern cottonwood, "hackberry" (sugarberry; *Celtis laevigata*), green ash (*Fraxinus pennsylvanica*), and multiple species of elms (*Ulmus* spp.) and oaks. Rivercane, sweetgum (*Liquidambar styraciflua*), less flood-tolerant oaks, hickories, beech (*Fagus grandifolia*), and magnolia (*Magnolia* spp.) grew on higher elevation sites within the floodplain, including on terraces above both the active floodplain and the baldcypress-tupelo swamps (Delcourt 1976; King 1982; Rolingson 1993; Foti 2001). Magnolia and beech were present particularly in the smaller floodplains (Burns and Honkala 1990).

Within floodplains of minor stream valleys, river birch (*Betula nigra*) was often the pioneer species on bars and new deposits inside and outside the natural levees (Hodges 1998). The greatest variety of species within the floodplain occurred on the stream fronts and included numerous oaks such as cherrybark (*Quercus pagoda*), water (*Q. nigra*), Shumard (*Q. shumardii*), and swamp chestnut (*Q. michauxii*), along with sweetgum, sycamore (*Platanus occidentalis*), several hickories (*Carya* spp.), green ash, and eastern cottonwood (*Populus deltoides*). On very wet sites with near permanent flooding, the major tree species were baldcypress, water tupelo, and/or swamp tupelo (*Nyssa biflora*; Fig. 6.2d).

6.5 Ecological and Historical Role of Beaver

Beavers were an important influence on forest dynamics in floodplains. Through their foraging and pond-building, beavers altered forest structure and composition in ways that may have influenced the pre-Euro-American fire regime. After being nearly extirpated during the early twentieth century, beavers are again present throughout most southeastern floodplains, although their dam-building is most common where they can turn intermittent streams and seepages into permanent standing water (Fig. 6.3a; Arner et al. 1969; Arner and DuBose 1978; Elsey and Kinler 1996; Tumlison et al. 1982). In such locations, beaver ponds can number several per km^2 (Barnes and Dibble 1988). Beavers and their dams are less abundant in the lower coastal plain because dams built in sandy substrates are prone to blowing out during floods (Butler 1991).

Their pond-building inundates trees, selectively killing even large individuals, with flood-tolerant species like baldcypress and tupelo being the beneficiaries (Arner et al. 1969). Beaver pond creation can raise the water table for considerable

Fig. 6.3 A variety of natural and human-caused disturbances occurs in the southeastern USA with the capacity to open small and large gaps in forest canopy: (**a**) beavers like the ones that built this dam have returned to most floodplains after near extirpation by fur trappers during the nineteenth century (photo Sammy King); (**b**) Hurricane Hugo caused widespread damage to forests in coastal South Carolina in September 1989 (photo William Conner); (**c**) long track tornados like the one that caused this damage in Tensas Parish, Louisiana are common in the Lower Mississippi Alluvial Valley (photo Paul Gagnon), where; (**d**) crop fields have replaced approximately 80% of bottomland hardwood forests (photo Paul Gagnon)

distances around ponds (Arner et al. 1969), increasing the area within which trees die. This dead zone can reach well beyond pond perimeters. Alternatively, where beaver foraging is continual, as around established ponds, they can convert forests into shrublands of buttonbush (*Cephalanthus occidentalis*) and alder (*Alnus* spp.; Arner et al. 1969). Over time their ponds fill with sediment, and beavers have to travel farther to forage; eventually they abandon their ponds.

Before Euro-American fur-trappers decimated beaver populations, their influence in these floodplains was possibly much more prevalent, arguably even pervasive. Abandoned ponds and beaver meadows would have been filled with dense, regenerating vegetation. In some locations, sediment filled ponds and beaver meadows may have facilitated the regeneration of such light loving, pyrogenic species as bottomland oaks and rivercane.

6.6 Humans and Fire Through Time in Southeastern Floodplains

Fire's role through geologic time in what is now the southeastern USA has likely tracked fluctuations in climate as reflected in cyclical glaciation events. The earth entered its current interglacial period around 11,000 ybp, by which time temperatures warmed to historical levels and glaciers had receded over most of North America. Rivercane abundance is commonly viewed as an indicator of fire in southeastern floodplains (Wright and Bailey 1982; Frost 2000; Gagnon 2009), and thickets of rivercane first appeared in the pollen record approximately 9500 ybp (Royall et al. 1991; King et al. 2005). By 5000 ybp, climatic patterns were similar to modern ones (Saikku 2005), implying that lightning and thus fires were common on the landscape. The pollen record indicates increased fire frequency and indicates plant communities of the northern Gulf Coast transitioned from oak- to pine-dominated during this time (Delcourt and Delcourt 1987; King et al. 2005).

Humans began inhabiting eastern North America more than 13,500 ybp, and the first record of humans in the LMAV date back to 12,000 ybp (Saikku 2005; King et al. 2005; Coughlan and Nelson 2018). The climate began drying out around 9000 ybp, and by 5000 ybp, climate and ecosystems had stabilized and human settlements had increased along rivers (Carroll et al. 2002). The Woodland Culture existed between 3000 and 1300 ybp and was categorized by pottery, semi-permanent settlements, and horticulture.

The Mississippian Culture followed the Woodland Culture and continued until European contact and was characterized by earthwork mounds, shell-tempered pottery, and maize and bean agriculture in floodplains and along stream networks (Carroll et al. 2002; Coughlan and Nelson 2018). These people relied heavily on floodplains for agriculture because the soils on natural levees and terraces were often fertile, well-drained, and easier to till with wooden implements (Carroll et al. 2002; Coughlan and Nelson 2018). They cleared trees in these areas to make room for their cultivated fields, and fire was an essential tool (Komarek 1974). By 1500, as many as two million Native American people lived in the southeastern USA (Carroll et al. 2002). They burned to establish new fields, remove post-harvest residues for subsequent cultivation, control insects and diseases, drive game animals, and stimulate habitat and new browsing opportunities for white-tailed deer (*Odocoileus virginianus*), their chief game species (Carroll et al. 2002; Saikku 2005; Coughlan and Nelson 2018). Their periodic clearing and burning also benefited rivercane, for which Native Americans had myriad uses ranging from basket-weaving and weaponry to spiritual ceremonies (Platt and Brantley 1997; Fowler and Konopik 2007; Platt et al. 2009; Gagnon et al. 2013).

Native American populations began declining shortly after Juan Ponce de León began exploring the region for Spain in 1513. In very short order, he and other early Spanish explorers introduced myriad diseases from the Old World. Multiple, repeated epidemics killed large percentages of the population (Newson 1983). By 1600, Native American populations had collapsed (Newson 1983; Carroll et al.

2002). Survivors faced societal breakdown, including loss of institutional knowledge and the labor to perform careful land management (Carroll et al. 2002; Stanturf et al. 2002). Even so, evidence of Native American land management remained for decades, including old fields, trails, and cultivated nut and fruit trees; these influenced both reorganizing native societies and early Euro-American settlers (Coughlan and Nelson 2018).

Many early settlers had experience using fire as part of traditional pastoral management in Europe (Stanturf et al. 2002; Coughlan 2013), and they quickly adapted Native American burning practices for their own uses. They sought out agriculturally productive sites within wide floodplains and a history of Native American use (Fowler and Konopik 2007; Coughlan and Nelson 2018). They judged soil fertility in part by the height and density of rivercane stands, knowing that quality stands would also provide excellent forage for their animals (Stewart 2007; Coughlan and Nelson 2018). Livestock herders generally occupied floodplains initially (Hickman 1962; Platt and Brantley 1997; Kinzer 2017). Farmers followed, settling in fertile, cleared lowlands. The frequency and extent of burning tended to increase after settlement; oftentimes settlers burned annually to improve the quality and quantity of livestock forage (Van Lear and Waldrop 1989; Brantley and Platt 2001).

6.7 Factors Influencing Fire Probability in Southeastern Floodplains

Conditions in these bottomlands are not often conducive to sustained combustion; large, natural fires occur only at the confluence of weather extremes at multiple scales. As in any ecosystem, fires in bottomland hardwood forests depend on the co-occurrence of ignition sources with flammable fuels. Many underlying precursors are similar to those in upland systems: inter- and intra-annual drought periodicity; distribution of flammable vegetation and fine fuels on the ground, including timing of leaf fall and their decomposition; presence of lightning or human-caused ignition; and dynamic fire compartment sizes. Other precursors, like seasonal flooding regime, are particular to floodplains. Groundwater levels and surface flooding strongly influence fire probabilities in bottomlands because they largely determine soil and fuel moisture levels.

The annual flood pulse is an important control on fires in these floodplains. In general, areas with shorter hydroperiods likely burned more frequently and with lower severity than those with longer hydroperiods (Mitchell et al. 2014). Even outside the season of highest water, the many creeks, bayous, and sloughs in these floodplains often remained wet enough to function as firebreaks (Kaufert 1933). As waters rose during the annual flood pulse, seasonal streams joined this expanding network of firebreaks, causing fire compartments to shrink further. In large river floodplains in typical years, there would have been minimal fire activity during the flood pulse because fuels were too moist and because this network of watercourses constrained fire spread on the landscape.

Even without Native Americans burning, there was no shortage of fire sources on the Coastal Plain landscape before Europeans arrived. Forests over most of the southeastern USA receive ≥5 cloud-to-ground lightning strikes per km^2 annually, while locations near the Atlantic and Gulf Coasts can receive two or three times that (Mäkelä et al. 2011). At the same time, snowmelt-fed spring flooding in river systems like the Mississippi tend to co-occur with the onset of the summer rainy season (Villarini 2016), which may also be peak natural fire season (*sensu* Platt et al. 2015). This underscores the importance of drought conditions as a precursor for fires in these floodplains.

Drought cycles in the southeastern USA include both multi-year and multi-decadal drivers. The La Niña phase of the El Niño Southern Oscillation (ENSO) occurs on a 2–7 year cycle (average 5 years) and corresponds with warm, dry winters in the southeastern USA (McCabe et al. 2004). The Pacific Decadal Oscillation (PDO) and Atlantic Multi-decadal Oscillation (specifically, a warmer than normal North Atlantic, i.e., positive AMO) are also influential (McCabe et al. 2004; Apurv et al. 2019; Sadeghi et al. 2019). The Pacific North American (PNA) teleconnection pattern (specifically, a reverse PNA) may be particularly influential of droughts in late winter and early spring over the middle Mississippi and Ohio River Valleys (Therrell and Bialecki 2015). Droughts are likely to be longer and more severe when several of these atmospheric drivers co-occur. As climatologists continue to tease apart these atmospheric and oceanic influences on weather over the southeastern USA, our understanding of inter-annual weather patterns (and fire potential) will continue to improve.

Given that fires were both uncommon and dependent upon inter-annual drought cycles in these floodplains and their watersheds, it is difficult to infer their seasonality; however, accounts from foresters early in the twentieth century offer insights. These speak to one additional important precursor for fires of any substantial size in these floodplain forests: fuels of sufficient quantity and flammability. Lentz (1931a, 1931b) and Kaufert (1933) attribute fire spread in bottomland hardwoods to dry leaf litter during the spring season of extended drought years, although Kaufert (1933) acknowledges that fires were different when canebrakes were still common in the floodplains.

6.8 Forest Gap Dynamics and Fire

Canopy disturbances may be important precursors of fire in bottomland hardwood forests. They are common, owing in part to the shallow root systems of species adapted to waterlogged soil conditions (Wharton et al. 1982) and resultant susceptibility to windthrow (Gunter and Eleuterius 1973). The size of canopy openings depends on the nature of the causal disturbance. They range in size from branch damage, to single treefalls (King and Antrobus 2001; Collins and Battaglia 2002) of senescent individuals, to large-scale forest blowdowns from tornadoes (Gagnon et al. 2007; Nelson et al. 2008, 2009) and hurricanes (Putz and Sharitz 1991; Chapman et al. 2008). These disturbances generate fine litter and coarse debris loads, create microtopographic variation that affects soil moisture levels, and increase the light available near the ground (Battaglia et al. 1999).

The fuels generated during these discrete events interact with background litter production, weather, biota, microtopography, soil type, and floodplain hydrology to determine their potential flammability. Results of a recent study on bottomland hardwood leaf traits (Cash and Anderson 2020) indicates that several species of oaks (cherrybark, Shumard, swamp chestnut) and hickories (bitternut [*Carya cordiformis*], mockernut [*C. tomentosa*]) may actually be "pyrophytes" (*sensu* Kreye et al. 2013) that produce litter sufficiently flammable to carry fire. Moreover, litter loading in areas where the dominant species were considered pyrophytes was strongly correlated with the percent of plots that burned in prescribed fires, suggesting a link between forest composition and likelihood of fire spread in the event of ignition. A related study (Kreye et al. 2013) set in uplands found the litter of other species common in floodplains such as loblolly pine and sweetgum (Heitzman et al. 2004; Battaglia and Conner 2018), to have pyrophytic characteristics.

Disturbances generate litter whose characteristics influence the likelihood of fire in the short-term, whereas the post-disturbance environment influences likelihood of fire in the long-term by affecting regeneration patterns and thus, future forest composition and resulting fuels. Canopy openings facilitate establishment of shade-intolerant species like sweetgum (Battaglia and Sharitz 2006) and loblolly (Pederson et al. 1997). In addition, increased light availability in these areas promotes ascension into upper forest strata of advanced regeneration that often includes sapling oaks and hickories (Collins and Battaglia 2008). As many light-demanding floodplain trees tend to be on the lower end of the flood tolerance spectrum (Hall and Harcombe 1998), drier microsites (e.g., tip-up mounds) and topographically higher parts of the floodplain favor their recruitment and survival (Jones et al. 1994). The same is true for rivercane, another shade-intolerant pyrophyte with limited flood tolerance (Gagnon 2009). The combination of larger, more persistent forest openings with drier, elevated safe sites is most likely to promote development of contiguous, fire-prone patches and communities that facilitate and sustain occasional entry of fire into these forests.

6.9 Gap Creating Disturbances in Southeastern Floodplain Forests

Across the range of southeastern floodplains, storms vary considerably in type, frequency, intensity, scale, and footprint. Geographic location of the forest site plays an important role. For example, ice storms are more common in the northerly portions of the range, including the Ohio and central Mississippi Alluvial Valleys and rare along the coasts (Changnon and Karl 2003). By contrast, tropical storms are more frequent, intense and have a greater impact nearest the Atlantic and Gulf coasts (Fig. 6.3b). Although tornados can occur virtually anywhere in southeastern floodplains, there is considerable variation in tornado likelihood by location, with long track tornados (those traveling ≥40 km on the ground) being particularly common in central Mississippi and northeastern Louisiana (Fig. 6.3c; Dixon et al. 2011).

Tropical storms and hurricanes can affect large areas of floodplain forests. Coastal wetlands receive the brunt of such storms, provide protection for inland areas (Costanza et al. 2008; Sun and Carson 2020), and on a regional scale, experience frequent return intervals (Conner et al. 1989). Depending on storm size, intensity, and track, coastal forests can experience strong winds, ocean surge, wrack deposition, and substantial freshwater flooding. Surges from these storms can inundate coastal areas with waters of variable salinity, depth and duration. For example, Hurricane Katrina's powerful storm surge of more than 3 m affected hundreds of km of coastline (Day et al. 2007). Although surges are ephemeral, their impacts, including pronounced flooding and saline intrusions, can be longer lasting on freshwater wetland communities in particular (Conner et al. 2007; Doyle et al. 2007; Keim et al. 2019).

Further inland, tropical storms can spawn torrential rains and occasional tornados. Although these storms lose strength as they move over land, they can still produce severe and extensive wind damage many km inland, especially in bottomland hardwood forests, where windthrow and snapping of trees are common (Battaglia et al. 1999). Strong winds can open large swaths of canopy, sometimes with a pattern of treefall that reflects the storm's rotation. However, even strong hurricanes leave behind a patchy gradient of damage, with many trees spared. Indeed, surviving trees may readily fill smaller canopy openings through vigorous sprouting. Windthrow of trees exposes mineral soil, leading over time to pit and mound topography (Battaglia and Sharitz 2006). In areas of sustained high winds, coarse woody debris and other litter inputs can be substantial (Rice et al. 1997). Effects of wind disturbance may be less evident in longer hydroperiod swamps (Putz and Sharitz 1991) because of the resilience of the dominant baldcypress.

Tornados can be highly destructive and occur over most of the range of bottomland hardwood forests. Based on data from 1950 to 2007, Dixon et al. (2011) found areas of the South to be the most tornado-prone region in the country in terms of risk of tornado occurrence within a given area. Whereas some of the highest densities of individual tornados in the USA occur over the south-central Great Plains ("Tornado Alley"), fewer individual tornados remain on the ground for longer (long-track tornados) in an area centered in central Mississippi and northeastern Louisiana (sometimes called "Dixie Alley"). Tornados are capable of producing the strongest winds on earth (in excess of 130 m s^{-1}; Wurman et al. 2007). They can open large areas of forest canopy, leaving trees that are twisted, debarked, snapped off, and splintered (Nelson et al. 2008). Their swaths subsequently have high light availability near the ground, considerable coarse and fine debris, and rarely contain spared individuals (e.g., Gagnon et al. 2007). Wide storm tracks function as large gaps or clearcuts where shade-intolerant colonists kickstart succession, and where intense fires can follow in subsequent years (Gagnon 2009).

Ice storms occur when weather systems collide, so they unfold on a broad scale. Although more common at northern latitudes, they occasionally affect southern USA forests below the “glaze belt,” an area from northern Texas into southern New England where storms that produce substantial ice accumulation typically occur once every 3 years (Bennett 1959). Ice can accumulate (glaze) over a period of hours to days. Trees with longer exposure and greater accumulation are at greater risk of damage (Bragg et al. 2003). Larger and older hardwood trees are typically less vulnerable than smaller individuals in the understory. When severe, ice storms generate heavy debris and litter loads, which can increase likelihood of subsequent fires. Breakage from glaze can also make forest stands more vulnerable to other threats (e.g., insect outbreaks, disease). In one study in South Carolina, bottomland hardwood stands had much greater damage and mortality than their cypress-tupelo counterparts (DiRienzo 2019). Damage varied from minor branch splitting and breaking to widespread tree mortality, which resulted from serious damage to crowns and boles, plus uprooting in the most severe cases. There were also patterns of species-specific mortality (range 2–97% among species).

6.10 Fire in Southeastern Floodplain Vegetation

Vegetation in floodplains retains moisture and resists burning longer during droughts than upland vegetation. Before hydrological modifications, this effect was magnified in the lower, wetter sites (Wharton et al. 1982). Historical fire regimes in southeastern floodplains probably varied widely, sometimes over short distances, as a function of local hydrology, microtopography and land use. Just as *flood* regimes in these river bottoms were spatially complex and produced marked vegetational zonation, so too would *fire* regimes have been spatially and temporally complex in ways that both depended upon and reinforced this zonation. Fire frequencies may have ranged from multiple times per decade in most canebrakes (Gagnon et al. 2013), to rare, stand-replacing crown fires centuries apart in nearby, low-lying forests (Wade et al. 2000). In mixed forests of elm, ash, cottonwood, sugarberry, sweetgum, and oaks, mixed and high-severity fires likely occurred in the <35 and 35–200 year interval classes, whereas tupelo and cypress wetlands probably burned in the 35–200 and >200 year interval classes (Frost 1995; Wade et al. 2000).

Every tree species has its own unique suite of traits by which it persists through ecological disturbances like fires. Bark thickness is among the most recognized determinants of tree resistance to fire injury (Hare 1965; Vines 1968; Hengst and Dawson 1993; Jackson et al. 1999). Mature individuals of sweetgum, cottonwood, and several white oaks (section *Leucobalanus*) possess notably thicker bark and the capacity to heal wounds faster than other bottomland species (Hengst and Dawson 1993; Sutherland and Smith 2000). By contrast, even older, established individuals of certain other species possess thin bark and thus appear poorly adapted for fire

(Hengst and Dawson 1993; Sutherland and Smith 2000); these include sycamore, hackberry, water oak, and silver maple (*Acer saccharinum*) among others. Postfire regeneration through lightweight, highly dispersible seeds, root suckers (i.e., clonal growth), stump sprouts and fast growth are other ways these species persist; these are particularly successful after tornados, high-intensity fires, or clear-cutting eliminates forest overstory.

Fuels of at least three different vegetative communities are important for fires in bottomland hardwood forests, with each producing distinct sorts of combustion. The primary fine fuel across most bottomland hardwood forests is leaf litter from trees in autumn. In these floodplains, autumnal leaf litter decomposes rapidly during the subsequent growing season (Kaufert 1933). During extreme drought years, leaf litter remains flammable and made it possible for fires to carry across floodplain landscapes and into patches of denser vegetation, where fires would have rapidly increased in intensity (Lentz 1931a; Kaufert 1933). Fires in leaf litter generally burn with low-intensity but can cause substantial damage to bottomland hardwood trees (Hepting 1935).

Before the twentieth century, the second important fuel type for fires in bottomlands was the monodominant stands of rivercane called canebrakes. Rivercane occurred throughout the range of bottomland hardwood forests and also in uplands on moist, fertile soils. Until the late nineteenth century, large canebrakes were widespread on natural levees and other well drained sites in the floodplains (Harper 1958; Kaufert 1933; Platt and Brantley 1997; Stewart 2007; NatureServe Explorer 2020). The large quantities of fine fuels produced by rivercane were highly flammable during droughts. Fires in canebrakes and in revegetating canopy gaps were probably the most violent in these forests (Kaufert 1933). Rivercane burned explosively as air heated in culm internodes expanded rapidly, causing the culms to burst and spray embers widely (Platt and Brantley 1997; Gagnon and Platt 2008a). Canebrakes burned every few years and were sufficiently flammable to burn even when other types of bottomland vegetation did not (Frost 1995; Gagnon et al. 2013). The surrounding upland landscapes burned frequently (Chap. 3), and canebrakes would have served as conduits for fire into and within bottomland forests (e.g., du Pratz 1975; Platt and Brantley 1997; Mann 2005; Gagnon 2009).

Rivercane has some unique characteristics among floodplain vegetation that make its abundance suggestive of recurring fires. Rivercane is shade-intolerant, disturbance-dependent and fire-adapted (Frost 1995; Gagnon et al. 2013). Left undisturbed, individual rivercane culms live for 5–10 years, and without a subsequent disturbance like fire, entire stands decline in vigor and eventually die after a few years, sometimes suddenly (Gagnon and Platt 2008a; Anderson and Oakes 2011; Gagnon et al. 2013). Current best estimates are that established, persistent canebrakes burned with an approximate interval of every 3–8 years (Gagnon et al. 2013). Any less frequently and rivercane quickly succumbs to the shade cast by rapidly regenerating hardwood saplings on these fertile, well drained sites or to documented demographic collapses likely caused by disease or deteriorating clonal connectivity as rhizome networks age (Hughes 1966; Gagnon et al. 2013). Fires and other gap-opening events eliminate older culms, and the increased light enables rivercane rhizomes to more than replace these old culms with vigorous new growth (Gagnon and Platt 2008a; Gagnon et al. 2013). Wharton et al. (1982) conjecture that Native Americans used fall burning to perpetuate and enlarge canebrakes. Without periodic disturbance, less flammable, fire-sensitive vegetation replaces canebrakes (Platt and Brantley 1997; Gagnon et al. 2013).

The third important fuel type for fires is peat. Fires are rare but important where dead vegetation builds up below waterlines to form peat, especially in blackwater systems along the eastern Coastal Plain and peninsular Florida. They occur primarily during extremely dry years in stands of Atlantic white cedar and cypress (more frequently in pondcypress [*Taxodium ascendens*] than in baldcypress; Garren 1943; Ewel 1995). Peat fires produce prodigious smoke and can burn peat deposits below ground level (Garren 1943). Nowadays without natural fires or prescribed burning, peat accumulates in some wetlands where it did not under the pre-modern fire regime and creates substrate conditions that enable other plant species to invade. During drought periods, peat becomes vulnerable to stand-replacing fires that can kill all advanced regeneration and the soil seedbank so that easily dispersed species establish afterwards (Richardson and Gibbons 1993).

Atlantic white-cedar forests are usually perpetuated by major disturbances like stand-replacing crown fires (Wade et al. 2000). Atlantic white-cedar has thin bark and flammable foliage, making it extremely susceptible to injury and death by fire. Living trees with fire scars are rare because most burned trees die (Akerman 1923; Korstian and Brush 1931; Little 1950). Atlantic white-cedar produces seeds prolifically as early as age three. The seeds, released in the fall, persist in the litter layer. Under normal (wet) conditions, crown fires destroy the aboveground vegetation. Elimination of shrub and brush competition aids subsequent Atlantic white-cedar germination, survival and growth (Laderman 1989). Fires during droughts consume the leaf litter and kill Atlantic white-cedar seeds. Depending on the future fire return interval, an herb bog, shrub bog, or bay forest may follow. Similarly, a second fire that follows soon after a first one can kill young, regenerating white Atlantic white-cedar trees before they can produce seeds.

During droughts or after logging or drainage, fire can have a significant effect on deepwater swamps. Mature cypress trees are seldom killed by fire, although tree vigor may be reduced (Duever et al. 1986). Broadleaf species are often more vulnerable to fire, so burning can maintain cypress dominance (Ewel and Mitsch 1978; Schlesinger 1978). Even-aged cypress stands can develop after fire (Duever and Riopelle 1984), or cypress can be eliminated and willow or tupelo become dominant (Gunderson 1984). One risk of burning in a swamp during drought periods is the possibility of starting a peat fire that can burn uncontrolled for weeks or months, burning away the peat to significant depths (Ewel 1995).

Between 1844 and 1955, fire frequency in the Okefenokee Swamp averaged once every 25–28 years (Hamilton 1984; Izlar 1984). In 1954–55, five fires occurred that together burned 80% of the swamp (Cypert 1961); however, later aerial photos indicated that only 6% of the swamp suffered any noticeable vegetation change (Hamilton 1984). Cypert (1961) also claimed that there was little doubt that the Okefenokee prairies were caused by deep peat burns with the last prairie-forming fire occurring in 1844. Since then, the prairies have been reverting to swamp forest (Cypert 1973). Periodic fires maintain swamp vegetation by killing less tolerant hardwood species and burning away peat accumulations that are necessary for the transition to bay swamp (Hamilton 1984).

6.11 Implications of Logging and Land Conversion for Fire

Euro-American settlers perceived bottomland hardwood forests as a limitless resource, cutting whatever trees they wished to use or sell. The French began logging baldcypress commercially as early as the 1720s, targeting stands near mills located at the mouth of the Mississippi River (Mattoon 1915; Moore 1983). Baldcypress logging accelerated during the latter half of the nineteenth century and peaked during the early twentieth century; in 1913 alone, total harvest exceeded 2.36 M m^3 (1 billion board feet; Mattoon 1915). Loggers during the nineteenth century supplied demand for barrel staves by selectively but extensively targeting white oak species (especially white [*Quercus alba*], but also swamp chestnut, swamp white [*Q. bicolor*], and sometimes overcup [*Q. lyrata*]; Call 1891). The impact on overall forest structure and composition varied depending on white oak frequency in the local overstory. In some areas, effects were minimal (Lentz 1931a), whereas in others, like the Crowley's Ridge area of Arkansas, loggers removed many thousands of mature specimens that composed a substantial portion of the overstory (Call 1891). Abundant logging slash in these newly sunny forest gaps immediately increased site flammability. In the longer term, fire-intolerant species replaced pyrophytic white oaks, less flammable oak litter accumulated on the ground, and flammability of affected sites undoubtedly decreased.

Eventually, many different hardwood species became marketable, and loggers practiced broad scale selective logging and/or clearcutting (Lentz 1931b; Kaufert 1933). Large openings from logging were particularly flammable during dry years, and the fires therein could be intense (Lentz 1931a; Kaufert 1933). Authors at the time attributed these fires to human carelessness or to people burning to improve grazing, but some were undoubtedly lightning-caused. Eventually these stands grew into closed, fire-resistant forests of dense, young trees. Multiple sources during the first half of the twentieth century report recurrent fires in the LMAV (e.g., Lentz 1931b; Kaufert 1933; Putnam et al. 1960). Hepting (1935) indicates that fires occurred at least as far back as 1867 and acknowledged that fires were still a frequent occurrence in 1935. Lentz (1931b) estimated that 80–90% of bottomland hardwood stands burned during 1917–1918 and/or 1924–1925. Kaufert (1933) studied >500 stumps on three clearcut bottomland tracts in Mississippi. He dated fire scars on these stumps back to before the Civil War and found major fire years in 1898–1899, 1911–1912, 1916–1917, 1924–1925 and 1930–1931 (approximately every 5–13 years). He also noted decay in tree boles through basal injuries caused in most cases (90–95%) by slow-burning surface fires that rarely killed mature trees. It is unclear the extent to which these fires were anomalous, reflecting a period of high-intensity, stand-replacing fires during the era of intensive logging and consequent logging debris (Fowler and Konopik 2007).

Subsequent landscape-scale conversion of forest to crop fields (Figs. 6.1 and 6.3d) often occurred concurrently with logging, and it came in waves (King et al. 2005). The last wave occurred during the 1950s–1970s, when high soybean prices put such a premium on arable floodplain land that cleared trees were simply stacked and burned (Stanturf et al. 2001). Silviculture in remaining bottomland hardwood forests has recently included some combination of clearcutting and group selection, typically with the goal of encouraging natural oak regeneration (Meadows and Hodges 1997). Virtually all modern bottomland hardwood forests have experienced multiple rounds of logging (Noss et al. 1995; LMVJV 2007). The result of such logging and concurrent changes to flood regimes in bottomland hardwood areas is dense, closed canopy stands of relatively young trees. In these forests, the understory rarely receives direct sunlight, and light-loving, pyrogenic species like rivercane are largely eliminated (Platt and Brantley 1997; LMVJV 2007). Fire is exceedingly rare in modern, closed-canopy bottomland forests, where fuels remain moist year-round, canebrakes are absent, and fires that once burned across adjacent upland landscapes are either arrested by habitat fragmentation or actively suppressed.

6.12 Implications of Altered Floodplain Hydrology for Fire

Humans began altering the hydrology of southeastern floodplains centuries before such efforts intensified in response to deadly flooding in the early twentieth century. Hydrological alterations are now pervasive throughout the range of bottomland hardwood forests (King and Keim 2019). Dams, levees, channelization and river control structures are the most visible and impactful alterations (Fig. 6.4a). Others include highways that partially block floodplains, land clearing and leveling for agriculture, and increases in impervious cover as floodplains urbanize.

Dams are now present on all major tributaries of the Mississippi River and on most large rivers in the southeastern USA (Alexander et al. 2012). Although every dam's design purpose will determine specifically how it modifies river flows, dams typically moderate flow variability by reducing peak flows and increasing low flows (Schmidt and Wilcock 2008). Shifts in plant communities toward those associated with drier sites commonly result. At the same time, increased low flows can elevate surface and groundwater levels when floodplains would have typically been dry and most likely to burn (Gee et al. 2015; Hupp et al. 2015).

Below dams, wing dikes cause water to cut deeper into the bed of the river. Resulting entrenchment can reduce the frequency of overbank floods because a greater volume of water is needed to overtop the new, higher banks (Schmidt and Wilcock 2008; Hupp et al. 2015). This lower river bed can increase groundwater drainage from the floodplain, drying the soil.

Levees disconnect rivers from their floodplains by blocking or containing overbank flooding. There are over 5630 km of levees in the lower Mississippi River

Fig. 6.4 Hydrological controls and invasive species are altering bottomland hardwood forests: (**a**) the Morganza Spillway in central Louisiana is part of an integrated system to control annual flooding and river movement (photo Sammy King); (**b**) invasive Chinese tallow grows rapidly in canopy gaps (photo Loretta Battaglia); (**c**) wild hogs are increasingly abundant; their rooting can negatively affect regeneration of native, large-seeded oaks and hickories (photo William Conner), and; (**d**) nutria are rodents from South America, now established in this system, where they occasionally cause "eat-outs" (photo William Conner)

basin alone (USACE 2020). Levees located near rivers can help funnel large volumes of water through smaller spaces, causing rivers to entrench. Historically, the Mississippi River came out of its banks and covered large portions of its floodplain. This in turn flooded portions of tributary watersheds that were otherwise dry. This additive effect of flooding was largely lost following levee construction. Now over vast areas of the floodplain and those of tributaries, flooding depends entirely on local watershed conditions. Similar modifications on a smaller scale have occurred in most rivers in the southeastern USA.

Channelization makes for more efficient drainage by straightening streams and steepening gradients upstream to downstream. Upstream portions become drier, while flood frequencies increase downstream (Shankman and Pugh 1992). Downstream reaches are often also channelized, so they drain and dry faster too.

Altered local flood regimes mean microtopography no longer filters species by flood tolerance to the same extent. Modern bottomland hardwood forests comprise smaller trees growing much more densely. Most floodplain sites are of high fertility (i.e., high site index) that historically supported numerous large trees >130 cm diameter at breast height (dbh), including individual cypress and oaks that surpassed 200 cm dbh (Leitner and Jackson 1981; Rolingson 1993; Bragg 2003; Hanberry et al. 2012). Despite that forests contained fewer trees, basal area was greater historically than now because trees were larger (Ouchley et al. 2000; Hanberry et al. 2012). Both flooding and fires likely reduced the number of small diameter trees in the past. Nonetheless, old-growth forests with infrequent disturbances often have lower tree densities than modern forests because they include large diameter trees that use more growing space and out-compete tree seedlings for resources.

It is difficult to assess the net cumulative effects of flood control measures on fire probabilities in bottomland hardwood forests. On the one hand, sites have largely become drier, which should increase groundcover vegetation, fuel loads, and fire probabilities. On the other hand, less flooding means increased woody vegetation that may further shade the understory and counteract this effect (Menges and Waller 1983; Hanberry et al. 2012). Dammed rivers with increased low flows may cause higher groundwater tables during the driest season (late summer/fall; Gee et al. 2015) preventing sites from drying out when they might otherwise burn.

6.13 Importance of Fire for Floodplain Wildlife

Faunal assemblages in bottomlands are distinct from those in adjacent uplands or aquatic habitats, although numerous individual species are common among these. The key features influencing animal diversity in bottomlands are: food supply (e.g., acorns, invertebrate abundance); width and structure of streamside vegetation; abundance of coarse woody debris, and; availability of den trees, cavities, and snags (Jones et al. 2010). Flooding, fires, and beavers can damage trees and so initiate formation of the cavities upon which many animals rely (e.g., Kaufert 1933).

Many of the 70+ mammal species occurring in these floodplains prefer bottomland hardwood forests (Klimas et al. 1981). These include 14 rodent, 3 shrew, and 11 bat (Heitmeyer et al. 2005) species. Several bat species roost in floodplain trees, and bats forage frequently over rivers and lakes, where flying insects are abundant (Trani 2002).

Floodplains also support many songbirds, waterfowl, wading birds, and secretive marshbirds. The LMAV alone supports 143 bird species, including 17 of conservation concern (Trani 2002). This vast floodplain is part of the Mississippi Flyway, where more than 40% of North America's waterfowl and 60% of all USA bird species migrate or winter (LMVJV 2015). During the breeding season, >70 species of birds breed in bottomland hardwood forests (Pashley and Barrow 1993). Carolina parakeet (*Conuropsis carolinensis*), passenger pigeon (*Ectopistes migratorius*), ivory-billed woodpecker (*Campephilus principalis*), and Bachman's warbler (*Vermivora bachmanii*) used floodplain forests extensively but are now at least functionally extinct.

When fire consumes dry upland forests, floodplains provide refugia from which plant and animal species can subsequently recolonize the uplands (Wigley and Lancia 1998). Some wildlife species use wetlands seasonally or at different stages of their life histories. Amphibians like the gopher frog (*Lithobates capito*) breed in wetlands but live the remainder of their adult lives in uplands. Other species like snapping turtles (*Chelydra serpentina*) live their adult lives predominantly in water but lay eggs in sandy, upland habitats (Wigley and Lancia 1998). More than 175 species of reptiles and amphibians inhabit this ecosystem (Jones and Taylor 2005).

Canebrakes provided cover, nesting, roosting, and foraging for at least 70 species of vertebrates (Platt et al. 2001, 2013). Rivercane is semelparous (i.e., monocarpic) and has mast flowering events that produced an abundance of seeds consumed by numerous vertebrates that likely included Carolina parakeets and passenger pigeons (Platt and Brantley 1997; Gagnon and Platt 2008b). Bachman's warbler may have been a canebrake specialist (Remsen 1986). Canebrakes were among the most nutritious native fodders, and now extirpated herds of elk and bison foraged on them, as did settlers' livestock and the previously threatened Louisiana black bear (*Ursus americanus luteolus*; Hughes 1951; Rostlund 1957; Platt et al. 2001). Rivercane is also host to the larvae of at least six species of butterfly (Platt et al. 2001).

Fires were important for cavity-nesting fauna. Heat from fires burning in leaf litter wounded adjacent trees and thus facilitated the entry of fungi into their interior wood. Numerous factors and wounding agents promote wood decay in living trees (Vasaitis 2013), but foresters conducting censuses and fire scar studies in bottomland hardwood forests during the early twentieth century determined fires as the primary cause of heart rot there (Lentz 1931a; Kaufert 1933). Hepting (1935) detailed how fungal infections spread up through interior wood via fire-scars in living trees and included dramatic photos of hollowed-out trees.

Infections in bottomland hardwood trees that followed wounding by fire were a boon to animals dependent upon decayed wood for foraging or cavity-building. These included such diverse avifauna as woodpeckers (ivory-billed, pileated [*Dryocopus pileatus*], red-headed [*Melanerpes erythrocephalus*], red-bellied [*M. carolinus*], hairy [*Picoides villosus*], downy [*P. pubescens*]; Tanner 1942; Conner et al. 1994), owls (barred [*Strix varia*], eastern screech [*Megascops asio*]), wood ducks (*Aix sponsa*), and various passerines (prothonotary warbler [*Protonotaria citrea*], white-breasted nuthatch [*Sitta carolinensis*], Carolina chickadee [*Poecile carolinensis*], tufted titmouse [*Baeolophus bicolor*] among others). Mammals would have also benefited, including Louisiana black bears, raccoons (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), and eastern gray squirrels (*Sciurus carolinensis*). Insects were also beneficiaries, including various beetles (e.g., families Cerambycidae and Erotylidae), carpenter ants (*Camponotus* spp.) and termites (e.g., *Reticulitermes* spp.) among others. Herpetofauna likely used low cavities and hollow trees as dens, including timber (canebrake) rattlesnakes (*Crotalus horridus*), copperheads (*Agkistrodon contortrix*), tree frogs (*Dryophytes* spp.) and numerous others (Moseley et al. 2003).

6.14 On the Paucity of Fire in Southeastern Floodplains

Recent human activity has altered many key determinants of fire occurrence and timing on the floodplain landscape. Ditching and levee-building has radically altered the web of stream courses that served as firebreaks during all but the driest years. The process goes back 150 years in the LMAV, when tiling and ditching of prairies for crop production began accelerating the drainage of spring meltwater into Midwestern tributaries, causing an earlier, more pronounced spring flood (Sparks et al. 1998). Hydrological modification for navigation and water storage further altered annual streamflow. For example, during most years prior to 1900, the Illinois River (a tributary of the Mississippi) experienced a predictable annual cycle of spring flood followed by low water during the summer and fall; since 1975 river hydrographs are markedly less predictable, and the period of low water in summer and fall is altogether absent during many years (Sparks et al. 1998). Levees disconnect rivers from their networks of tributaries, while humans managing rivers for navigation ensure they never go below specified depths in main channels. Overall, human regulation of streamflows for flood control and water storage has reduced seasonal signatures in flooding across the continental USA (Villarini 2016).

One can view many of these and other human management practices as seeking to moderate the natural extremes in these highly dynamic floodplains. It is an extension, and possibly a more extreme example, of the mesophication occurring in upland forests throughout the USA (*sensu* Nowacki and Abrams 2008). In floodplain areas, this includes controlling both the highest and lowest river flows to moderate varying hydrology across space and time in an effort to make navigation more efficient, agricultural production more reliable, and human habitation safer. Humans reduce flooding by storing water behind dams; containing floodwaters behind levees; and promoting drainage through tiling, ditching, channelizing, dredging, and encouraging entrenchment. At the same time, humans reduce drought effects by increasing low flows during the driest times of the year and by irrigating. Since broad scale fires in these floodplains relied on rare, dry conditions, drought reduction practices have combined with landscape fragmentation to produce a landscape within which fires are less likely now than before Euro-American settlement.

Following myriad changes, forest fires are now so rare that modern bottomland hardwood forests appear fireproof, but it was not always so. Those river bottom locations that would have burned most frequently were those on the highest ground. Such sites supported canebrakes and other fire-tolerant species (e.g., white oaks like white, post, and swamp chestnut oak). Farmers knew well that the biggest, densest stands of rivercane grew on the most fertile sites, and they systematically targeted these for conversion to agriculture during the nineteenth century (Stewart 2007). By contrast, lower sites were converted later or not at all. Vast floodplain areas have been leveled for rice and other agricultural production, a process that has eliminated much natural microtopographic variation. Low sites in agricultural production remain problematic for cropping and are often the focus of forest restoration efforts today. It is most often the flood-prone sites that have either remained forested or are being restored to forest. The result is that previously spatially complex flood and fire regimes are homogenized and minimized. Today's forests have dense, closed canopies and perpetually humid understories that lack sufficient fuels to carry fire. Fires in these floodplain forests were always dependent on severe droughts and occurred at the confluence of multiple interacting disturbances (Gagnon and Platt 2008a; Gagnon 2009). Prescribed fires in these lowest, wettest sites that compose today's bottomland forests are all but impossible. Fires were never common in these floodplains. Following these fundamental changes to ecosystem structure and function, natural fires in modern bottomland hardwood forests are all but eliminated.

6.15 Forest Fragmentation in Southeastern Floodplains

Converting vast tracts of forested land into cropland, roadways, urban development and residential housing has caused severe fragmentation of the southeastern floodplain forest landscape. This pattern is perhaps most pronounced in the Lower Mississippi Alluvial Valley (LMAV), where >80% of the 10 million ha of original forest have been lost (Figs. 6.1 and 6.3d; King and Keeland 1999; Yang et al. 2020). Those scattered remaining tracts located on ridges and other sites suitable for agriculture are typically small and surrounded by expansive croplands, and they lack connectivity to other patches (Burdick et al. 1989). As such, they have reduced capacity to support species diversity (Rudis 1995), and the populations residing there have lower rates of genetic exchange with other populations (Boersen et al. 2003). Seed movement via hydrochory (i.e., water dispersal) is an important secondary dispersal mechanism in floodplains (Kroschel et al. 2016) and is likely restricted in hydrologically impaired watersheds. By reducing connectivity and fire compartment size, forest fragmentation precludes fires from traveling across the landscape.

Increases in the ratio of forest edge to interior that accompanies fragmentation threaten both area-sensitive species and interior specialist wildlife species. Area-sensitive species require large areas of habitat in which to forage and maintain territories; these species have suffered dramatic declines (e.g., Florida panther and Louisiana black bear), or have been driven to extinction (e.g., ivory-billed woodpecker and Carolina parakeet) with habitat losses (Burdick et al. 1989). The forest edge environment includes abrupt microclimate changes that can negatively affect species sensitive to environmental extremes. Expansion of edges puts forest interior birds at risk of nest predation and parasitism (e.g., by brown-headed cowbirds [*Molothrus ater*]; Hoover et al. 1995). It also increases the prevalence of invasive plant species well- suited to the high light availability characteristic of forest edge environments.

Location within the ecological landscape can exacerbate or ameliorate the effects of fragmentation. Landscape features that link remnants, such as a matrix of managed forests (Wigley and Roberts 1997) or corridors of forest cover, can facilitate the movement of organisms and promote overall biodiversity (Damschen et al.

2008). Ecotones with managed forests may be more beneficial than inhospitable cropland edges and interfaces with urban environments. Fragmented landscapes containing corridors or retaining some forest cover are more conducive to movement of wildlife like swamp rabbits (*Sylvilagus aquaticus*; Berkman et al. 2018) and Louisiana black bears (Boersen et al. 2003). Propagule dispersal of floodplain plants is dependent on distance from forest containing reproductive individuals. Although light-seeded species like green ash can disperse farther than heavy-seeded oaks and hickories (disregarding long-distance movement by animal vectors), seed rain of the former still exhibits dispersal limitation and an exponential decline in propagule numbers with distance from forest edge (Battaglia et al. 2008).

6.16 Invasive Species in Southeastern Floodplain Forests

Invasive species are common in floodplain forests of the southeastern USA. Once established, they flourish in this highly productive ecosystem. To invasive and native species alike, the flood pulse can act as a stress, but also as a means of dispersal and as a subsidy of moisture, nutrients, and sediments (Junk et al. 1989). Floodplain forests at the drier end of the hydrologic gradient in the southeastern USA generally have high productivity comparable to upland systems (Megonigal et al. 1997) and relatively high woody species richness (Sharitz and Mitsch 1993). The pervasive fragmentation of these floodplains (King and Keeland 1999) has exposed these forests to numerous exotic species, many of which are now well established and have the potential to affect fire dynamics. In deepwater swamp communities, many aquatic and semi-aquatic exotics (e.g., common water hyacinth [*Eichhornia crassipes*], giant salvinia [*Salvinia molesta*]) have established. We highlight four common plant invaders with the potential to influence the floodplain fire regime. These include Chinese tallow (*Triadica sebifera*), Chinese privet (*Ligustrum sinense*), climbing fern (both *Lygodium japonicum* and *L. microphyllum*), and common reed (*Phragmites australis*). All of these species can flourish in canopy gaps and other disturbed areas. Once established, all are exceptionally difficult to control.

Chinese tallow is a prolific seed producer that exploits canopy gaps through bird dispersal and hydrochory in floodplains (Fig. 6.4b; Denslow and Battaglia 2002). Its population can dramatically increase following large-scale disturbances like hurricanes Andrew and Katrina (Conner et al. 2014; Henkel et al. 2016). It can sprout vigorously in response to prescribed burning if fires do not kill the trees outright (Grace 1999).

Highly shade-tolerant Chinese privet invades forest understories in floodplains and uplands alike in the southeastern USA, where it displaces native species and interferes with forest regeneration. Under drought conditions in floodplains, Chinese privet may behave similarly to how it grows in upland forests subjected to fire suppression. There, it forms dense thickets that can lead to longer fire return intervals and increased risk of severe crown fires (Wang et al. 2016). Prescribed fire is a suggested management tool for controlling Chinese privet, albeit with caveats about its likely effectiveness (Wang and Grant 2012). For example, a recent study reported little success using prescribed fire to control Chinese privet (Cash 2019). For fire to effectively reduce Chinese privet populations, it might be necessary to burn multiple times at short intervals in combination with herbicide or other control methods (Wang and Grant 2012).

Japanese climbing fern (*Lygodium japonicum*) is another aggressive invader with the capacity to alter fire behavior. It can kill native species through its twining growth that smothers and girdles vegetation. It is now present throughout much of the southeastern USA (USDA and USNRCS 2020) and is considered a noxious weed in many states. Interactions with fire in floodplain forests is poorly understood for this species, but its congener Old World climbing fern (*L. microphyllum*), which has a similar growth form, is well known for its high flammability and climbing fine-fuel “ladders” that enable fires to burn into forest canopies (Volin et al. 2004).

Common reed, or Phragmites (*Phragmites australis*), is a very large clonal grass that forms monodominant stands in freshwater and brackish marshes throughout North America (Marks et al. 1994; Chambers et al. 1999). In the southeastern USA, these marshes often border floodplain forests, and marsh compositional changes toward Phragmites monodominance could alter the fire regime (Fusco et al. 2019). Although Phragmites has been a component of the North American flora for millennia (Orson 1999), genotypes originating in Eurasia now commonly outcompete native vegetation, potentially supplanting more diverse wetland vegetation (Saltonstall 2002). Phragmites thrives in disturbed wetlands, especially where humans have caused elevated nutrient levels, and once established, Phragmites stands can persist indefinitely (Hazelton et al. 2015, 2018). Stands of Phragmites are tall, dense, and flammable during droughts, and where they abut floodplain forests, they are capable of spreading fire into forest midstories. Despite the species’ invasiveness, Phragmites is valued in coastal Louisiana, where it is known locally as roseau cane, because of its ability to counteract subsidence through sediment accretion; there the native genotype especially experiences die-backs caused by the invasive roseau cane scale (*Nipponaclerda biwakoensis*; Knight et al. 2020).

Various invasive animal species cause problems in bottomland hardwood forests. Feral hogs (*Sus scrofa*) do enormous damage to the regeneration layer in floodplain forests, and their populations are increasing in many places (Fig. 6.4c; Kroschel et al. 2016). Their rooting for tubers, acorns, and rivercane rhizomes leaves the forest floor churned with displaced soil and has the potential to alter future fire regimes by shifting composition away from pyrophytic rivercane and oaks and toward Chinese tallow (Siemann et al. 2009; Shoemaker 2018). Nutria (*Myocastor coypus*) are generally confined to open water and adjacent lands, where they consume large amounts of herbaceous vegetation, including regenerating forest seedlings (Fig. 6.4d; Henkel et al. 2017). Their large scale “eat-outs” can cause erosion and conversion to open water and may alter fuel characteristics. The ongoing invasion of the emerald ash borer (*Agrilus planipennis*) is killing ash trees throughout the eastern USA, including green ash, a common floodplain species. Resulting litter, woody debris and canopy gaps (Ruzicka et al. 2010) may facilitate fires in the near-term; longer term implications for fire dynamics are unknown.

6.17 Restoration of Bottomland Hardwood Forests

By the early 1980s, when interest in afforestation of abandoned croplands arose in earnest, direct planting of trees was necessary (Allen 1997). By then, pervasive forest fragmentation had greatly reduced connectivity among patches, and dispersal limitation was a serious constraint for many species. This was especially true of heavy-seeded oaks and hickories, including several species considered pyrophytes (Kreye et al. 2013; Cash and Anderson 2020). These same species are highly desirable for wildlife habitat and forage (King and Keeland 1999). Initial restorations used direct seeding; later efforts used bare-root seedlings. Neither approach was very successful. There were issues with the timing of planting and with competing herbaceous species (Shaw et al. 2003). Mismatches between species and the local floodplain environment was a common problem made trickier by the fact that floodplain hydrology was often highly altered (King and Keim 2019).

Setbacks and challenges demanded adaptive management, which eventually found ways to improve planting success (Stanturf et al. 2004). Managers determined that larger diameter, artificially regenerated seedlings with robust root systems grew faster and survived better than smaller seedlings (Stanturf et al. 1998). More recently, large, containerized seedlings grown in nurseries using the patented Root Production Method™ (RPM; i.e., root-pruning) have increased in popularity because they perform well. They are also more expensive, however, so their use is often supplemental to other, less reliable strategies (Haynes and Egan 2004).

In contrast to active planting, passive restoration relies entirely on volunteer vegetation and is inexpensive (Battaglia et al. 1995). An estimated ~89% of forested area in the LMAV comprises naturally regenerated stands (Oswalt 2013). Local site conditions filter natural regeneration, so resulting vegetation is site-adapted, even where hydrology is altered. Drawbacks include slower stand development (Battaglia et al. 2002), delayed canopy closure, and community composition that may miss restoration targets. Without a nearby seed source, establishment of heavy-seeded, pyrophytic species may be delayed indefinitely (Battaglia et al. 2008). Noxious weeds and other unwanted species may establish, with the potential to retard or interfere with desired successional trajectories.

Desired stand characteristics of forests for wildlife habitat differ from those aimed at optimizing timber production. If timber production is the chief priority, silviculturalists should avoid burning because of fire's potential to damage bottomland trees (Hepting 1935). What follows briefly summarizes relevant sections of LMVJV (2007). Forest management objectives that include wildlife habitat should encourage floristic diversity in the overstory, midstory, and understory and should include trees that produce both hard and soft mast among others. Trees of varying sizes are also important for particular species, so structural diversity that includes some large trees is also desirable. Stressed and standing dead trees, including cavity trees, and coarse woody debris are important to wildlife for foraging and denning. Cutting that reduces canopy closure to 60–70% will enable understory flora to persist without rendering stands uninhabitable to forest birds. A limited proportion of small openings will encourage rivercane growth and regeneration of shade-intolerant tree species, including many pyrophytes.

Fire is a tool that land managers sometimes consider for floodplain restoration. Fire has the potential to help control weedy shrubs, encourage growth of rivercane, and improve habitat for wildlife (LMVJV 2007; Gagnon et al. 2013). Burning during the growing season may be necessary if a goal is to eliminate resprouting shrubs and young trees (Lewis and Harshbarger 1976). Burning under prescription in modern floodplains is not easily done because potential time windows are narrow, most fine fuels from autumn pack and decompose the following growing season, and standing vegetation resists burning during typical, humid conditions (Gagnon 2009; Cash and Anderson 2020). Success is more likely where pyrophytes are already a substantial component of the overstory because their litter carries fire better than that of other bottomland species (Kreye et al. 2013; Cash and Anderson 2020). Setting prescribed fires when floodplains might have burned naturally during prolonged droughts is risky and possibly out of the question. One potential workaround is slash-and-burn: cutting the vegetation to be burned during seasonal dry periods (e.g., late spring, late summer or early fall), letting it dry for several days or a couple of weeks, and then burning before the remaining vegetation can resprout and the fine fuels pack or begin to decompose (Fig. 6.5a, b; Gagnon and Platt 2008a, 2013). This strategy is labor intensive and may be impractical for large areas. Otherwise it may be necessary to first establish and manage rivercane or pyrophytic trees to produce a fuel bed sufficiently flammable to carry fire, potentially decades later (Kreye et al. 2013, 2018).

6.18 Sea Level Rise and Fire in Coastal Floodplain Forests

Floodplain forests nearest the Atlantic and Gulf Coasts are subject to the chronic effects of sea level rise that fires could magnify. Periodic but ephemeral tropical storm surges extend farther inland as a result. These intrusions combine the dual stresses of flooding and increased salinity (Doyle et al. 2007). Storm surges penetrate freshwater wetlands composed of species that are intolerant of such events (Krauss et al. 2009). Negative effects may be less where accretion exceeds sea level rise and where there is sufficient freshwater flushing from precipitation, natural surface and groundwater flows, and river diversions (Das et al. 2012). The rate of *relative* sea level rise varies widely across the southern USA coastline (Sweet et al. 2017) and is a critical determinant of whether these systems can ecologically keep pace.

Strong coastal forces influence the Mississippi River Delta at the southernmost edge of the LMAV. The area includes much bottomland hardwood forest comprising trees limited by the same hydrologic constraints and drivers as elsewhere. Coastal influences include rapid relative sea level rise (estimated 12 ± 8 mm year^{-1} at the land surface; Jankowski et al. 2017) and chronic, increasing exposure to flooding and hurricane winds and storm surges (Visser et al. 2012). In areas such as

Fig. 6.5 Prescribed burning in humid floodplains can be tricky; sea level rise threatens coastal forests: (**a**) burning under prescription is typically difficult and may require slash-and-burn techniques (photo Paul Gagnon); (**b**) to ensure thorough burning, slashed fine fuels must dry but not pack or decompose (photo Paul Gagnon); (**c**) salt water incursion can kill trees like this "ghost forest" on the coast of South Carolina (photo William Conner), and; (**d**) where coastal forests are adjacent to marsh, rising sea levels and subsidence can cause rapid landward movement of the forest-marsh ecotone (photo Loretta Battaglia)

the Barataria and Verret Basins of Louisiana, subsidence drives relative sea level rise that exceeds organic and inorganic accretion (Conner and Day 1988). In these places, trees are unable to regenerate successfully, so forests eventually die, leaving behind standing snags and woody debris called "ghost forests" (Fig. 6.5c; Kirwan and Gedan 2019). Forests can convert directly to open water (Conner and Day 1988); alternatively, where forests share an ecotone with marsh, they can quickly transition into oligohaline or freshwater marsh communities (sometimes floating; Battaglia et al. 2007) that are better adapted to elevated salinity levels and/or higher flood frequency (Fig. 6.5d; Shirley and Battaglia 2008; Shaffer et al. 2009). Landward-retreating forest-marsh ecotones with abundant fine fuels and coarse woody debris can accelerate conversion to open marsh by acting as entryways for fires into bottomland forests, particularly during periods of drought.

Rates of relative sea level rise are lower elsewhere along the Gulf and Atlantic Coastal Plains (Sweet et al. 2017). The swamps and floodplain forests flanking these coastal streams and bayous are much narrower and are often sandwiched between upland forests on the landward side and marshes on the seaward side (Battaglia et al. 2012). Both can bring fires into wetland forests. Marsh expansion into tidal freshwater swamps occurs in these narrow floodplains driven by sea level rise and tropical storms, but is constrained by coastal topography and may be delayed where freshwater outflows dilute saltwater incursion (Raabe and Stumpf 2016).

In killing trees, disturbances like tropical storms and fires create potential colonization opportunities for herbaceous marsh species, thereby facilitating forest conversion to marsh. *Combined* effects of fires and tropical storms may push ecotones past stable ecological thresholds, precipitating such conversion. A study in coastal Alabama analyzing both the paleotempestological (prehistoric storm) record and buried charcoal and pollen layers found that fires frequently followed hurricanes (Liu et al. 2008). Multiple, interacting disturbances, including drought, will likely play a pivotal role in controlling the pace of forest retreat and marsh expansion.

6.19 The Future of Bottomland Hardwood Forests

Predicted increases in climate variability, including more intense flooding and drought cycles, may return some degree of hydrological and fire processes in the future. This will depend greatly on human management decisions. Fire, flooding, storms, drought, and insect/disease outbreaks may reduce forest density and restore some ecosystem function. On the other hand, ongoing urbanization with associated increases in impervious cover will be increasingly important in many floodplains, where flood events will grow ever "flashier." Other bottomland hardwood forests will be drained and converted to pine plantations.

Temperatures in the Southeast are projected to increase by 2.5–4.5 °C by the end of this century (Chap. 12; Carter et al. 2014). Although the region has been described as a "warming hole" because overall warming has not yet been observed there (Mascioli et al. 2017), mean summer temperatures during the most recent decade have been the hottest on record because of very large increases in nighttime temperatures (Carter et al. 2018). Assuming greenhouse gas concentrations continue on their current trajectory, overall temperatures in the LMAV are projected to increase by 3.8 °C by the end of this century, including more warming in the northern parts of the floodplain and less in the south (Yang et al. 2019).

Major precipitation-driven flooding is projected to increase in the region this century (Chap. 12), and river floodplains will be affected. The abundance of heavy rainfall events has increased recently, and these are projected to perhaps double by the end of the century (Carter et al. 2018). At the same time, the region has experienced periods of drought, and these may also become more frequent and/or severe (Carter et al. 2018). Increased intra-annual variability in rainfall may produce both flooding and droughts during the same year or even season, including rapid onset of droughts ("flash droughts") as occurred in 2019 (NOAA 2019). Northeastern parts of the forest's range are projected to grow wetter overall, while the southwest becomes drier and experiences reduced water availability exacerbated by increasing population and more intensive land use (Carter et al. 2014). For example in the LMAV, precipitation may decrease by 10 cm $year^{-1}$ (6.5%) by the end of the century, with less reduction in the floodplain's northern areas (Yang et al. 2019). At the same time, sea level rise will flood coasts and accelerate saltwater intrusion.

Climate projections indicate increasingly favorable conditions for wildfires (e.g., Keetch–Byram Drought Index) in the region's floodplains. Expectations are that warming temperatures, more frequent droughts, and reduced relative humidity will expand the fire season and raise summer and autumn fire potential from moderate to high in the southern USA (Liu et al. 2013; Weatherly and Rosenbaum 2017; Carter et al. 2018). Hanberry (2020) found that, depending on which general circulation model she used, by mid-century the number of extreme fire weather days will increase from approximately 2 days now to either 6 or to more than 20. Expected seasonal changes in climate in the LMAV could mean additional increases in summer temperatures and additional decreases in precipitation (Yang et al. 2019). Ongoing climate change with amplified hurricane activity, strong winds, storm surges, flooding, and outbreaks of insects and diseases will increase fuel loading through downed trees, further increasing wildfire risk (Logan et al. 2003).

As the century proceeds, ongoing human development may interact with changing weather to reduce opportunities for prescribed burning and further raise wildfire risk. Increasingly severe and variable weather is projected to reduce windows for prescribed fires. The expanding wildland-urban interface will simultaneously increase both the number of ignitions by humans and societal pressure for active fire suppression (Bar-Massada et al. 2014). Resulting increases in accumulated plant fuels and hotter, more variable weather will increase wildfire risk, although in the floodplains, rapid decomposition rates could moderate this effect. Across the USA, human-caused ignitions have tripled the length of the fire season compared with the lightning season, and humans account for 84% of all wildfires and 44% of total area burned (Balch et al. 2017; also see Chap. 1).

River level patterns are expected to change in the southern USA. In the near future (2011–2050), Naz et al. (2016) foresee increasing spring and summer runoff, reduced winter runoff, and increases in both maximum and minimum runoff. Conflicts caused by increasing water demand from urban populations is already causing legal cases over water rights like the tri-state water dispute over the Apalachicola-Chattahoochee-Flint and the Alabama-Coosa-Tallapoosa. The combination of more frequent drought years and seasons, increasing water consumption, and low winter flows will likely affect rivers lacking flow standards and adjacent floodplain forests.

Given the increasing scarcity of water and the resulting potential for conflict, it is possible that floodplain forests will be increasingly recognized for the ecosystem services they provide. Forested watersheds moderate effects of extreme climate events like drought and heavy rainfall and act as breaks for fires. Although flooding will likely increase where natural vegetation cover is sparse and rivers are channelized, as in the LMAV, remaining floodplain forests may help regulate flooding events. Southeastern floodplains are also likely to resist burning in most conditions, either due to sparse fuels in crop fields, or because floodplain forests are most often not flammable (i.e., sparse herbaceous vegetation, high humidity, moist fuels, and numerous water courses as fire breaks).

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