Chapter 10
Forest Landscape Restoration: Linkages with Stream Fishes of the Southern United States

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10.1 Introduction

With well over 600 native species, the southern United States supports one of the richest temperate freshwater fish faunas on Earth (Fig. 10.1). Unfortunately, an expert review revealed that 27% (188 taxa) of southern fishes are endangered, threatened, or vulnerable (Warren et al. 2000) and that 16–18% of native fishes are imperiled in 45 of 51 major southern river basins. Other groups of aquatic organisms in the region also show high levels of imperilment (e.g., freshwater mussels and gastropods, Neves et al. 1997; Haag 2009; crayfishes, Taylor et al. 1996, 2007; aquatic reptiles, Buhlmann and Gibbons 1997). Based on national extinction rate projections for fishes (Ricciardi and Rasmussen 1999), about 10% of the region's fishes could be extinct by 2050 unless effective conservation actions aimed at maintaining and improving the physical and biological integrity of the region's streams and rivers are implemented.

The combination of historical and current land-use has resulted in a dramatically changed and changing landscape with consequences for fishes and linkages between forests, aquatic systems, and fishes. In that context it is useful to briefly review the basics of interactions between the terrestrial and aquatic systems. The river continuum concept (RCC) (Vannote et al. 1980) provides a useful synthetic framework for conceptualizing the connectivity of undisturbed stream systems, the importance of stream size, and the interplay at the interface of terrestrial and aquatic environments (Fig. 10.2). The physical basis of the RCC is stream size and location along the gradient from the smallest headwater creek to large rivers. As a stream courses along this gradient it grows in size, receives tributaries, and drains an increasingly

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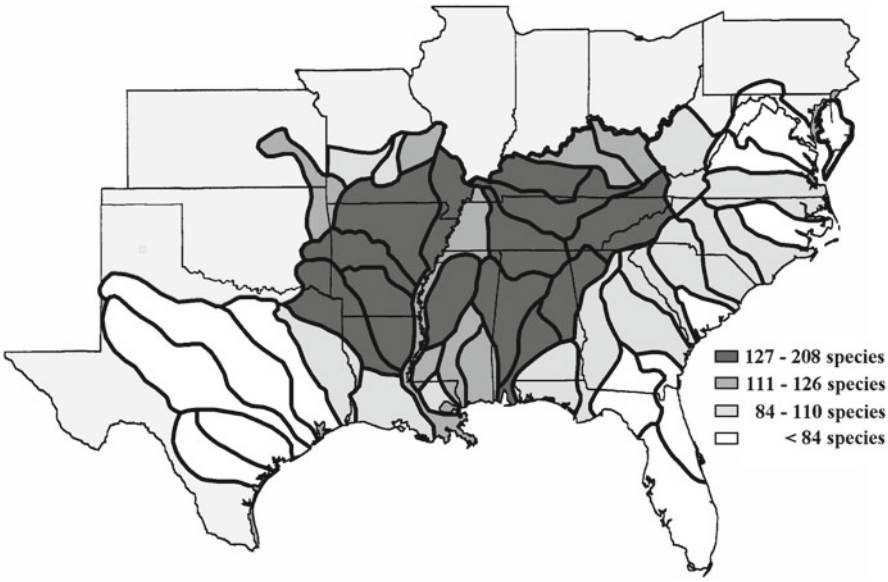

Fig. 10.1 Fish species richness across 51 major drainage units in the southern United States (Compiled from Warren et al. 2000)

large catchment area (Allan 1995). As stream size changes, many associated biological changes are expected to occur with shifts in energy sources for primary production.

As viewed for temperate forested streams (Vannote et al. 1980), small streams are conceived as shaded headwaters where inputs of woody material (CPOM, coarse particulate organic matter, e.g., leaves, stems, trees) from the riparian zone and surrounding landscape (i.e., allochthonous material) provide the resource base for the consumer community (Fig. 10.2). Because of the dense shading, little sunlight reaches the stream channel and in-stream production (autochthonous production) is limited. As the stream broadens into a large creek or small river, the energy inputs change. As shading and woody inputs become less relative to increasing channel width, sunlight can penetrate to the bottom to support significant autochthonous production of periphyton (e.g., algae, diatoms). Macrophytes become more abundant with stream size, most prominently so in lowland rivers of the southern United States. In the largest rivers, turbidity, higher currents, and soft or unstable substrates often preclude growth of macrophytes or periphyton. Here the autochthonous production is mostly from phytoplankton, but most productivity is allochthonous being derived from organic matter received from upstream and lateral tributaries (Minshall et al. 1985).

Processing of CPOM in upstream areas by aquatic macroinvertebrates, especially ones that shred CPOM, provides large amounts of fine particulate organic

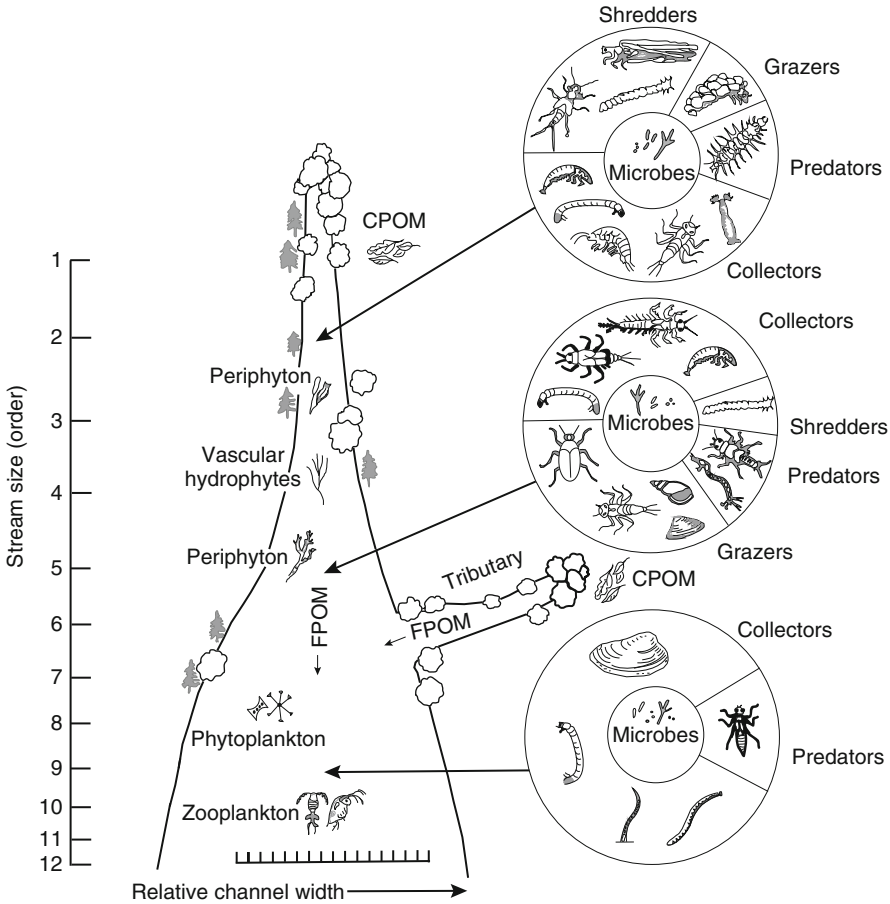

Fig. 10.2 Depiction of the conceptual relationship between stream size (as stream order), energy inputs, and aquatic ecosystem community structure and function under the river continuum concept as conceived by Vannote et al. (1980) (Redrawn from Allan 1995)

matter (FPOM) much of which moves downsteam. As ratios of CPOM to FPOM shift along the stream size gradient so do invertebrate communities (Fig. 10.2). The FPOM cascading to downstream areas serves as part of the energy source along with instream production of periphyton. Hence, in headwaters, shredders, which process CPOM, are expected to be most abundant. In moderate-sized streams, grazers, which consume periphyton, and collectors, which process and consume FPOM, will be abundant, and collectors will dominate in the largest systems. Finally in the largest rivers, the community becomes one dominated by collectors (Vannote et al. 1980; Allan 1995). Hence, under the RCC the role that wood and woody material plays is readily apparent, especially that in the riparian

zone, in defining the energy sources and other biological characteristics of streams and rivers. Here I focus on aspects of wood in streams aside from its foundational role in biological productivity, especially some of its potential effects on fishes.

Forest landscape restoration is among the most significant conservation actions that could positively affect the region's fishes and other aquatic fauna, particularly if used in concert with other management options (e.g., Wissmar and Bisson 2003). In this context, I view forest landscape restoration broadly to include management actions which increase and maintain forest coverage in watersheds and restore riparian forests, especially late successional ones. Although I do not cover specific management actions in detail, they might involve approaches such as restoring continuous forest to riparian buffer corridors along stream and river systems in agriculture and urban watersheds (Bentrup 2008; Bentrup et al. 2012) which are otherwise largely deforested. Even more broadly, opportunities for forest landscape restoration may involve entire watersheds on public (e.g., national forest, wildlife refuge) or private lands (e.g., industrial forests, smallholder forests, agroforests), or urban areas (community reforestation). These may be driven, not directly by benefit to fishes or other aquatic organisms, but by improving water quality, increasing wildlife habitat along stream systems, decreasing effects of extreme events (i.e., floods, droughts), mitigating impervious surface run-off, or other ecological or aesthetic motivations. Even so, forest restoration can also potentially benefit the ecological health and function of aquatic ecosystems and the fishes they support.

Here, I focus on three objectives. First, I briefly describe the aquatic setting of the region. Second, I review some of the major historical and on-going impacts to aquatic habitats particularly as related directly or indirectly to forests. My third objective is to present and illustrate selected examples of the benefits of forest landscape restoration for fishes in the southern United States. I selected five important and interdependent, but by no means all-inclusive, benefits to fishes that could emerge from restoration of forest landscapes including: (1) instream wood as habitat and cover; (2) instream wood as a substrate for food production; (3) instream wood as a spawning substrate; (4) moderation of water temperature by trees in streamside forests; and (5) increased access to floodplain forests for foraging and reproduction. Finally, I updated and expanded a previously compiled list of fishes (Dolloff and Warren 2003) to include species that are associated with flooded forests, instream wood (e.g., detritus, leaf packs, debris dams, sticks, and logs), or riparian vegetation (e.g., root wads, root fibers, overhanging limbs). The purpose of the list is to document the fishes which are obligately or facultatively dependent on wood and to inform the forestry community of the high diversity of fishes that might be affected positively by forest landscape restoration activities. I recognize the importance of forest landscape restoration to water quality (sediment, pesticide, and nutrient reduction, *sensu* Waters 1995) and quantity and hence to fishes but do not address those benefits here. I believe that the benefits and examples outlined provide heuristic if understated insights into the complex nature of fish, instream wood, riparian, and watershed interactions (Veery et al. 2000; Gregory et al. 2003; Brown et al. 2005b; Hughes et al. 2006).

10.2 Aquatic Setting in the Southern United States

River systems of the southern United States are highly variable in terms of physiography, geomorphology, hydrology, chemistry, and biology. Here I provide a brief, oversimplified description of the streams and rivers in the region but detailed accounts of the region's rivers are available (see Benke and Cushing 2005). The area encompasses 12 entire states and parts of 4 others, at least 10 major physiographic provinces (Benke and Cushing 2005) and 51 major drainage units (encompassing about 78 medium to large river systems; Warren et al. 2000) (Fig. 10.1). The area can be divided into four major hydrologic regions: Southern Atlantic Slope (roughly Virginia to eastern Florida), East Gulf Slope (western Florida to Mississippi River), West Gulf Slope (Mississippi River to southwestern Texas), and southeastern Ohio and Lower Mississippi river basins. The Eastern Continental Divide, formed by the northeast-southwest trending Blue Ridge Mountains, is the major relief feature in the region (maximum 1,700 m asl), sending waters east toward the Atlantic Slope or west and south toward the Ohio and lower Mississippi Rivers and Gulf of Mexico. Rivers lying just east and west of the divide begin as steep-gradient, cool, low productivity, rocky streams traversing rugged, mountainous terrain.

10.2.1 Southern Atlantic Slope

Rivers flowing to the Atlantic Ocean transition from the Blue Ridge Mountains to the rolling hills of the Piedmont (about 150–160 m relief) where streams are warmer and may be rocky, sandy, or silty and then drop off an escarpment (the Fall Line) to the gently rolling to nearly flat Coastal Plain. On the Coastal Plain, streams and rivers generally are warm and often highly productive with low gradients, silty to sandy substrates, and darkly stained water (i.e., high in organic carbon) (Smock et al. 2005). Permanent and perennial oxbows, lakes, and wetlands are often associated with Coastal Plain stream systems. Much of the Blue Ridge Mountain area has >80% forest cover; somewhat less and more variable forest cover is present on the Piedmont and Coastal Plain areas, but over most of the region forest cover is between 21 and 60% (Wear 2002).

10.2.2 Eastern Gulf Slope

Along the Eastern Gulf slope, most streams head as rocky, often gravel dominated, streams of relatively moderate-gradient in uplands of the hilly upper Coastal Plain, the Piedmont, Appalachian Plateaus, and Valley and Ridge physiographic provinces and transition below the Fall Line to productive, slow flowing, sand and silt-dominated

systems of the Eastern Gulf Coastal Plain (<150 m relief); near the Gulf Coast, streams are often darkly stained (Ward et al. 2005). Much of this region, except along the coast is densely forested, including most of Alabama and southeastern Mississippi with forest cover estimated as 61–100% (Wear 2002) over most non-urban or non-agricultural areas.

10.2.3 Western Gulf Slope

Streams of the Western Gulf Slope lie along an east–west moisture gradient such that the east (western Louisiana and eastern Texas) is well-watered and the west extremely arid. Streams of the Western Gulf Slope in western Louisiana and eastern Texas lie entirely on the Coastal Plain (relief <200 m) and generally are dominated by sand and silt throughout their lengths and display other characteristics typical of Coastal Plain streams (Dahm et al. 2005). Streams of the Western Gulf Slope of central and western Texas head on uplands (i.e., Edwards Plateau of southern Great Plains physiographic province) (relief 700–1,200 m) and ultimately enter the Western Gulf Coastal Plain. Dense forest in this region is primarily confined to eastern Texas and west and central Louisiana where forest cover in most counties is 21–40% or even higher (61–80%) in extreme eastern Texas (Wear 2002).

10.2.4 Southeastern Ohio and Lower Mississippi River Basins

The southeastern Ohio and lower Mississippi River basin region has two major upland areas which profoundly affected river drainages and much of the biology of the region. East of the Mississippi River lies the Eastern Highlands (Blue Ridge, Valley and Ridge, Appalachian Plateaus, and Interior Low Plateaus physiographic provinces) (max relief 1,700 m) through which drain several major rivers including the Tennessee River, Cumberland River, and southeastern Ohio river tributaries (Tennessee, Kentucky, and northern Alabama). To the west across the Mississippi Alluvial Valley lies the Interior Highlands (Ouachita and Ozark Plateaus) (maximum relief 826 m) which also drain major rivers such as southern tributaries to the Missouri River and the White, Arkansas, and Red river systems (southern Missouri, Arkansas, eastern Oklahoma, northern Louisiana) (Brown et al. 2005a; Matthews et al. 2005). In the Highlands, streams are of moderate to high gradient and vary from boulder-strewn to gravel-dominated. Rivers transition from the Highlands to lower gradients of the Mississippi Alluvial Valley, which is dominated by sandy, silty Coastal Plain-like systems. In the Valley, floodplains of streams and rivers characteristically have permanent and perennial wetlands, ponds, and oxbows. The densest forest is scattered within the region. A region of high forest cover is along

the Cumberland Plateau of eastern Tennessee and eastern Kentucky with cover ranging mostly from about 41–80%. Other areas of similarly high forest cover include most of central Arkansas and northern Louisiana. Lowest forest cover is in the Mississippi River Alluvial Valley (about 0–20%).

10.3 Factors Affecting Forest Linkages to Fishes

Large-scale declines of aquatic biota are signals of a pervasive degradation of southern U.S. waters and of the failure of humans to recognize the interactive nature of land and water ecosystems and management (Angermeier 1995; Burkhead et al. 1997; Warren et al. 1997). Historically, three major overlapping periods of land-use occurred in the southern United States, all of which affected and continue to affect water quality, water quantity, and fish habitat: (1) the era of agricultural and timber exploitation; (2) the era of dam building and channel modification; and (3) the era of population growth, industrialization, and urbanization (Abell et al. 2000; Wear and Greis 2002; Haag 2009). Unfortunately, precise information is generally lacking or fragmentary on the fish fauna for most of these eras (1700-early 1900s) and explicit documentation of impacts is not always possible. However, the direct and indirect causes of land-use associated fish and other aquatic community impacts are well documented (Scott and Helfman 2001; Allan 2004; Hughes et al. 2006; Peacock et al. 2005; Helfman 2007).

10.3.1 Era of Agricultural and Timber Exploitation

Agricultural exploitation with removal of forests of the southern United States started in the seventeenth century but reached a peak in the late nineteenth century, and timber exploitation in mountainous and wetland environments peaked in the early twentieth century. The area of forested land in the south declined by 40% from 1890 to 1919 (Williams 1989). Timber exploitation during this period resulted in the removal of mature riparian vegetation along most stream and river courses. Few riparian areas have had time (or have been permitted) to produce the large, late-successional trees that are not only the source of instream wood but are also critical in forming complex, long-lasting habitat configurations important to aquatic organisms and other critical functions (see subsequent; Dolloff and Webster 2000; Dolloff and Warren 2003). The loss of old or late-successional riparian forests drastically reduced recruitment of large wood into flowing waters and coupled with natural processes of decay and downstream transport, resulted in unnaturally low accumulations of large wood in streams across entire landscapes. Without instream wood, many streams and rivers in the region have undoubtedly become more homogeneous with reduced habitat complexity, stream productivity, fish abundance and

diversity, and accompanying dramatic shifts in fish assemblage composition (Jones et al. 1999; Scott and Helfman 2001; Benke and Wallace 2003; Dolloff and Warren 2003; Warren et al. 2009).

A second impact during the era of agricultural and timber exploitation was a dramatic increase in sediment in streams, rivers, and wetlands as agricultural and logging activities intensified and covered large areas of watersheds. Early explorers and naturalists to the southern United States repeatedly characterized streams in the region as clear and dark as opposed to the brown or red color that now dominates many southern U.S. streams (Burr and Warren 1986; West 2002). For example, soil loss in the North Carolina Piedmont was estimated at 0.25 cm 1,000 year^{-1} prior to European settlement. Current rates from clean cultivated land are 20–762 cm 1,000 year^{-1} (West 2002); earlier historical losses from denuded agricultural lands combined with logged slopes likely were even higher. Similarly, in the upper Coastal Plain of Mississippi, valley bottoms were covered by up to several meters of sediments as watersheds were deforested and hill-top agriculture increased in the early to late 1830s (Shields et al. 1995a and references therein). As a result of soil tillage and loss of forest cover, high loads of sediment filled southern U.S. streams and rivers. Sediment can adversely affect fish food production, ability of fishes to forage, and development of fish eggs and larvae, most dramatically so in upland stream systems (Helfman 2007).

During this era, wetlands also filled with sediment or were logged, drained, and often put into agricultural production, all of which directly affected habitat for many wetland dependent and riverine fishes. About 50% of all wetlands and 65% of forested wetlands in the United States occur in the south. Over the conterminous United States, 47% of all wetlands were lost between 1780 and 1980. Between 1950 and 1970, 16% of southern forested wetlands were lost (Ainslie 2002). In the Lower Mississippi River Valley alone, 80% of 10 million ha of wetlands were lost to agriculture by the 1970s.

10.3.2 Era of Dam Building and Channel Modification

The era of dam building and stream channel modification imposed a second major impact on fishes and aquatic systems of the southern United States. The period from about 1920–1985 marked a frenzy of dam building and stream channelization in the southern United States for the ostensible purposes of flood control (flooding being exacerbated in part by sediment-clogged waterways), hydroelectric power generation, navigation, water storage, and recreation. The frenzy of dam building eliminated most free-flowing large rivers and many small- and medium-size streams in much of the United States including the south (Benke 1990; Dynesius and Nilsson 1994) with a resulting biotic impoverishment of these systems (Burr and Warren 1986; Pringle et al. 2000; Bednarik and Hart 2005; Haag 2009).

Many riverine and stream fishes are dependent on the heterogeneity of free-flowing systems with log-jams, woody snags, brush piles, gravelly shoals, sand bars, and pools, which occurred naturally from headwater streams to even the largest rivers in the region. Many fishes are also dependent on seasonal late winter and spring floods which send streams and rivers over their banks into adjacent forests and wetlands. As reviewed in part here, the river-floodplain interaction gives fishes access to shallow low-velocity spawning sites and supplemental food resources as well as provides nursery areas for larvae and juveniles. Impoundments created by dams completely eliminated all such habitats, and the dams themselves created barriers to migratory fishes, isolated and fragmented stream and riverine fish populations, and eliminated or caused declines in many fish species (e.g., Etnier et al. 1979; Burr and Warren 1986; Robison and Buchanan 1988; Angermeier 1995; Winston et al. 1991; Burkhead et al. 1997). For example, fish diversity in the Clinch River (upper Tennessee River drainage) before impoundment of Norris Reservoir consisted of 17 families and 65 species; post-impoundment, four families were lost and species diversity decreased to about 30 species (Neves and Angermeier 1990).

Stretches of river not impounded directly but located downstream of dams (referred to as tailwaters) often were changed dramatically by dam releases. Because of dam releases, tailwaters often are subjected to highly altered, unnatural flow regimes (precluding natural winter-spring flood cycles), unnaturally cold temperatures (affecting fish growth, reproduction, and food production), low dissolved oxygen concentrations (often eliminating all fishes) or some combination of these impacts (Krenkel et al. 1979; Layzer et al. 1993; Travnicheck et al. 1995; Tippit et al. 1997; Bednarik and Hart 2005). For example, the tailwater releases on the South Fork Holston and Watauga rivers (upper Tennessee River drainage) decreased fish diversity from 43 to 17 and 32 to 13 species, respectively. Similar and often greater decreases in diversity occurred in association with most dams (Neves and Angermeier 1990).

During the dam-building period, river systems supporting the most diverse temperate, riverine fish fauna in the world (e.g., Tennessee, Cumberland, Ohio, Alabama, Coosa, and Tombigbee rivers) were transformed into a series of reservoirs and regulated reaches with little free-flowing main-channel native fish habitat remaining (Etnier and Starnes 1993; Boschung and Mayden 2003). Most of the large tributaries in these systems also were dammed. In the Tennessee River alone, there are 53 major dams (>40 ha): nine on the main channel and the remainder on tributaries (Etnier and Starnes 1993). The amount of natural fish habitat lost is astounding. As one example, 11 major dams on the Clinch, Holston, and French Broad rivers (upper Tennessee River) eliminated 1,100 of 2,800 km of river habitat for resident native fishes (Neves and Angermeier 1990).

In conjunction with dam-building, many small- to medium-size streams and rivers were channelized completely from headwaters to mouth ostensibly to reduce flooding. In the process of stream channelization, riparian areas are cleared of forest and vegetation, and by dredging, the channel is straightened and

Fig. 10.3 Typical channelized stream, the Little Tallahatchie River canal, in the southern United States. The Little Tallahatchie River, Lafayette County, Mississippi, was channelized in about 1960 (photo by M.L. Warren, Jr.)

deepened (Fig. 10.3). Many channelized streams are subjected to periodic maintenance activities such as re-clearing of riparian zones, re-dredging of the channel, or removal of instream wood ("snagging and dragging") (Jackson and Jackson 1988; Shields and Smith 1992; Shields et al. 2000). Even if no maintenance is performed, it may require 65 years after channelization for small lowland rivers and their riparian forests to show some semblance of recovery (e.g., sinuosity, in-channel heterogeneity, large riparian trees) (Hupp 1992). Channelization and associated maintenance activities result in streams with exacerbated, unnaturally flashy storm flows, homogeneous flow conditions especially at base flow, decreased flow permanence, no interaction with the floodplain, increased water temperatures from decreased riparian shading, little to no wood or other organic matter, and little to no recruitment of wood into the stream. Relative to undisturbed streams, the fish assemblages in these streams are less diverse, subject to large temporal variations in composition and abundance, and tend to be dominated by one or few species of small-bodied fishes tolerant of the extreme conditions caused by channelization (Shields et al. 1994, 1995b; Adams et al. 2004; Haag et al. 2007; Warren et al. 2009). The full payment of the extinction debt for aquatic organisms caused by dams and channelization likely is yet to be realized (Haag 2009).

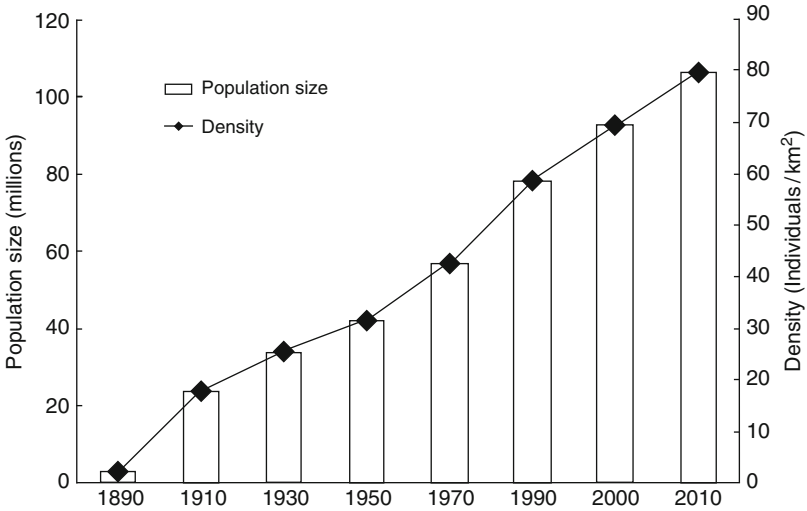

Fig. 10.4 Population growth and density from 1890 to 2010 in the southern United States. Data compiled from censuses for Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia

10.3.3 Era of Population Growth, Industrialization, and Urbanization

The next era, one of population growth, industrialization, and urbanization, although primarily a post-World War II phenomenon, began on a slow, but steadily increasing, pace as soon as Europeans settled the region. In 1890, the population across 13 southern states stood at almost 3 million people (12 persons km^{-2}) (Fig. 10.4). By 2010 the population stood at about 105.4 million people (79.8 persons km^{-2}). Growth was not uniform across the region. Between 1950 and the present most population growth was concentrated in the Appalachian Plateau, Valley and Ridge, the upper Piedmont, and along the Gulf and Atlantic coasts (Wear 2002). Since 1980, the population in the region grew at a higher rate than the rest of the United States (Tarrant et al. 2002; Wear 2002) and by 2010 the region's share of the U.S. population reached 34%. With increased population came increased urbanization. In 1945 urbanized land comprised only about 2.1% (about 2.8 million ha) of the land area in 11 southern states. By 1992, land converted to transportation or urban use roughly tripled to 6.6% of land area and is projected to increase to 16% by 2020 and 23% by 2040 (Wear 2002).

Although total areal coverage of forest in the region (about 56% in 1992, excluding Texas and Oklahoma) has changed little since the beginning of rapid population growth in 1945, the region now is largely characterized as a fragmented, edge-dominated mosaic of second (or third)-growth forests within a matrix of farmland, old fields, and urbanized areas (Wear 2002). Planted pine (*Pinus* spp.) forests, occurring predominantly in the Piedmont and Coastal Plain and covering smaller areas within

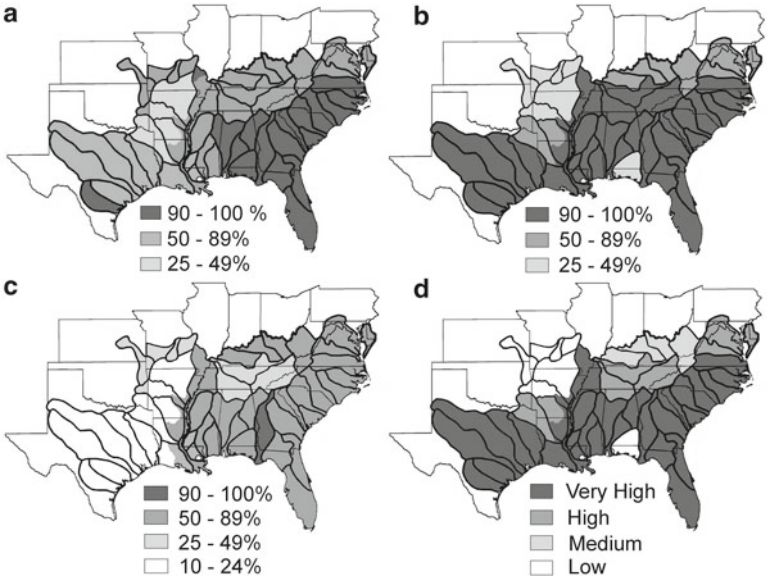

Fig. 10.5 Alteration and degradation of surface waters in the southern United States: (**a**) percentage of catchment (landcover) alteration, (**b**) percentage of surface water alteration, (**c**) percentage of water quality degradation, and (**d**) percentage of aquatic habitat fragmentation across the southern United States (Compiled from Abell et al. 2000)

the Eastern and Interior Highlands, constitute about 20% of the total forest coverage. Area in natural pine, mixed pine-hardwood, upland hardwood, and lowland hardwood forests is projected to decline by about 15% by 2040. Plantation expansion is projected to increase from 8.9 million ha in 1992 to 21.8 million ha in 2040 (Prestmon and Abt 2002).

In aggregate, these three eras of land-use dramatically changed the landscape across the southern United States. As integrators of watershed land-use, aquatic systems in the region were also dramatically affected. Perhaps not surprisingly given the land-use legacy, expert-based appraisal of present conditions of aquatic systems revealed high and widespread levels of catchment alteration, surface water degradation, and aquatic habitat fragmentation (Fig. 10.5). Forest landscape restoration could contribute to the improvement of conditions of aquatic systems in the region both within stream and river channels and in the riparian systems that bound their channels.

10.4 Instream Wood as Habitat and Cover

Cobble and gravel substrates are rare or absent in many lowland streams where instream wood is often the only element contributing to channel roughness and hence to the formation of complex riffle and pool habitats (Smock and Gilinsky

Fig. 10.6 Fishes benefit from (**a**) small woody debris piles (*limbs and leafs*) and (**b**) large log jams which help form heterogeneous stream habitats, afford stable substrate for invertebrate colonization, provide cover and velocity refuges at high flow, and refuge from predators at low flow (Photos by M.L. Warren, Jr.)

1992). Relatively modest quantities of instream wood can shift fish assemblage attributes from colonizing to intermediate or stable stages (Warren et al. 2002), primarily by influencing habitat development and providing cover. The colonizing stage of fish assemblages is typical of shallow, uniform habitats with little instream wood, flashy hydrology, and propensity for drying. Colonizing fish assemblages are dominated by small-bodied species, particularly minnows (e.g., *Notropis* spp., *Cyprinella* spp.) (Schlosser 1987; Shields et al. 1998; Adams et al. 2004). Intermediate assemblages typify streams with some increase in pool volume and begin to be comprised of larger-bodied fishes (e.g., catfishes, spotted bass, longear sunfish). As pool depth and volume increase further, stable assemblages develop with fewer, but larger, top predator fishes. Abundance of small-bodied, invertivorous fishes decreases, particularly minnows, as predation and resulting competition for refugia among prey species increases. At the stable stage, shallow riffle areas between pools provide important habitat (e.g., refuge from predators) for bottom-dwelling invertivorous fishes. Wood-formed riffle-run-pool complexes support a significant proportion of the stream fish diversity in Coastal Plain streams and are likely critical to the persistence of many darters (*Etheostoma* spp., *Percina* spp.), madtom catfishes (*Noturus* spp.), and many other fish species (Monzyk et al. 1997; Chan and Parsons 2000; Warren et al. 2002; Shields et al. 2006). Even relatively small-diameter pieces of wood, in shallow sandy flowing areas, can create heterogeneous zones of variable velocities and depths (Fig. 10.6). Experimental microhabitat units (brush bundles, leaf packs, and faux rootlets) placed in wood-starved upper Coastal Plain streams in Mississippi (Fig. 10.7) were used extensively by crayfishes and a diversity of stream fishes, particularly small-bodied individuals and juveniles of large species. During winter and late spring sample periods, 89% of the microhabitat units were occupied by fishes, crayfishes, or both (Fig. 10.8), and catch rates

Fig. 10.7 Constructed microhabitat bundles (cane, *left*, faux rootlets, *middle*, leaf pack, *right*) experimentally placed in wood-starved streams in northern Mississippi, U.S.A. (rule at *bottom* = 1 m) (Photo by M.L. Warren, Jr.)

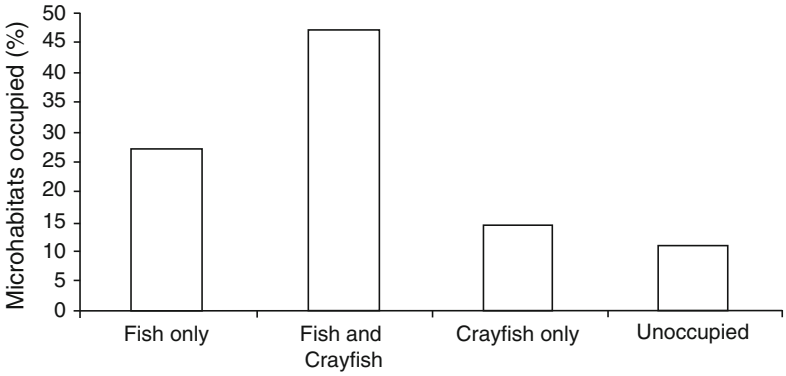

Fig. 10.8 Average percentage occupancy by fish and crayfish of constructed woody microhabitat units experimentally placed in wood-starved Coastal Plain streams in north Mississippi, USA (Redrawn from Warren et al. 2009)

of fishes after 14 and 44-day exposures ranged from 1.7 to 12.2 individual fish per unit. The microhabitats were used by 32 species of fishes, constituting greater than two-thirds of the known fish fauna within the study streams (Warren et al. 2009).

Instream wood and debris piles provide cover and flow refugia for southern US fishes. For many fish species, association with large wood is facultative, particularly in streams where rocky substrates or other elements provide alternative cover within

well-developed riffles, runs, and pools (Table 10.1). Nevertheless, species such as the shadow bass (*Ambloplites cavifrons*) and smallmouth bass (*Micropterus dolomieu*) show extensive use of and spatial partitioning among woody habitats even in upland, rocky streams with strong riffle-pool development on the Ozarkian Plateau (Fig. 10.9). Fish in streams of the Coastal Plain where streambed materials tend to be fine-grained and highly mobile (Felley 1992; Smock and Gilinsky 1992) benefit from pool and riffle formation caused by instream wood (Montgomery et al. 2003; Mutz 2003) but also often use and are highly dependent on wood for cover (Table 10.1). For fishes in these and other streams, wood provides overhead cover and shade, visual and physical isolation, and velocity refuges (Fausch 1993). Overhead cover provides protection from aerial predators (e.g., wading birds, kingfishers) as well as contributing to the camouflaging benefit of shade (Helfman 1981; Power 1984). Visual and physical isolation from other fishes decreases predator-prey interactions and agonistic interactions between conspecifics (individuals of the same species) (Dolloff and Reeves 1990; Crook and Robertson 1999). Occupying positions behind logs, root wads, or other woody cover in flowing water also minimizes energy expenditures, which can be particularly important at extreme cold or warm water temperatures (Fausch 1984; Ross et al. 1992; Warren et al. 2009). For example, two nocturnally active fishes, the brown madtom (*Noturus phaeus*) and the pirate perch (*Aphredoderus sayanus*), are associated strongly during daylight hours with complex woody habitats in small coastal plain streams where all three functions (overhead cover, visual-physical isolation, and velocity refuge) likely play a role (Monzyk et al. 1997; Chan and Parsons 2000). Structural complexity of the woody microhabitat refuges (measured as a function of number and length of woody components) was a significant predictor of the occurrence of the pirate perch (Monzyk et al. 1997). The bayou darter, *Etheostoma rubrum*, a threatened species, responds to the cold, high-velocity flows of winter by seeking refuge behind logs and other instream wood, which likely have a significant impact on overwintering survival and ultimately the population size of the species (Ross et al. 1992). Similarly, sampling in January (water temperature 2–5 °C) of small woody microhabitat units (about 0.3 m^2 per unit) experimentally placed in shifting sand-bottomed streams yielded up to 70 individual minnows (Cyprinidae) per unit offering further evidence that winter refuges are critical for many fishes (Warren et al. 2009).

Although fishes clearly use instream wood when available as habitat, the restoration strategy of placing wood in streams alone may provide short-term benefits but not be of long-lasting benefit. This is particularly relevant in systems rendered unstable by past and present watershed land-use and resultant erosion, incision, and instability of the sand-bed stream channel. For example, large woody structures were added to and bank vegetation established along such a stream in north Mississippi to assess changes in aquatic assemblages and their habitat (Shields et al. 1998, 2008). Prior to restoration, the stream supported a colonizing fish assemblage. Post-restoration base-flow water depths increased (i.e., indicative of pool formation), aquatic invertebrate assemblages became more diverse, and the number of fish species increased. Notably, the fish assemblage acquired more, larger predators as it shifted from a colonizing to an intermediate fish assemblage. Even so, the structures

Table 10.1 Types of associations of native freshwater fish species in the southern United States with in-stream wood (e.g., detritus, leaf packs, debris dams, sticks, and logs) as cover (general, spawning, nesting, or feeding); inundated floodplain forests (seasonal or intermittently flooded), or riparian vegetation (e.g., roots, overhanging limbs, shade)

Family and scientific name	Common name	Association	Source
Petromyzontidae	Lampreys		
Ichthyomyzon bdellium	Ohio lamprey	Cover (larvae)	Boschung and Mayden (2003)
Ichthyomyzon castaneus	Chestnut lamprey	Spawning cover	Becker (1983)
Ichthyomyzon gagei	Southern brook lamprey	Cover (larvae)	Boschung and Mayden (2003)
Lampetra aepyptera	Least brook lamprey	Cover (larvae), shade	Walsh and Burr (1981), Smiley et al. (2005)
Lampetra appendix	American brook lamprey	Spawning cover	Boschung and Mayden (2003)
Lepisosteidae	Gars		
Atractosteus spatula	Alligator gar	Cover (juveniles), egg attachment (probable)	Suttkus (1963), Boschung and Mayden (2003)
Lepisosteus oculatus	Spotted gar	Cover, inundated forest (adults, juveniles, and larvae), egg attachment	Snedden et al. (1999), Killgore and Baker (1996), Rutherford et al. (2001), Boschung and Mayden (2003), Warren unpublished
Lepisosteus osseus	Longnose gar	Inundated forest (adults, juveniles, and larvae)	Killgore and Baker (1996), Warren unpublished
Lepisosteus platostomus	Shortnose gar	Inundated forest (adults and juveniles)	Warren unpublished
Amiidae	Bowfins		
Amia calva	Bowfin	Cover, inundated forest (adults and juveniles), nesting material, nesting cover	Scott and Crossman (1973), Ross and Baker (1983)
Clupeidae	Herrings		
Dorosoma cepedianum	Gizzard shad	Inundated forest (larvae)	Killgore and Baker (1996)
Cyprinidae	Carps and minnows		
Campostoma spp.	Stonerollers	Feeding (algivores)	Matthews (1998)
Chrosomus cumberlandensis	Blackside dace	Cover, shade	Starnes and Starnes (1978)
Chrosomus erythrogaster	Southern redbelly dace	Cover, shade	Ross (2001)

Chrosomus tennesseensis	Tennessee dace	Cover, shade	Starnes and Jenkins (1988), Jenkins and Burkhead (1994)
Chrosomus saylori	Laurel dace	Cover, shade	Skelton (2001)
Clinostomus elongatus	Redside dace	Cover, shade	Burr and Warren (1986)
Cyprinella analostoma	Satinfin shiner	Egg attachment	Gale and Buynak (1978)
Cyprinella callistia	Alabama shiner	Cover	Ross (2001)
Cyprinella callitaenia	Bluestripe shiner	Probable egg attachment	Wallace and Ramsey (1981)
Cyprinella camura	Bluntface shiner	Cover, inundated forest (adults and juveniles)	Warren et al. (2009)
Cyprinella galactura	Whitetail shiner	Egg attachment	Pflieger (1997)
Cyprinella leedsi	Bannerfin shiner	Cover	Marcy et al. (2005)
Cyprinella lutrensis	Red shiner	Feeding (invertivore), egg attachment	Quist and Guy (2001), Pflieger (1997), Ross (2001)
Cyprinella spiloptera	Spotfin shiner	Egg attachment	Pflieger (1965)
Cyprinella venusta	Blacktail shiner	Cover, egg attachment, inundated forest (adults and juveniles)	Baker et al. (1991), Pflieger (1997), Warren et al. (2009), Warren unpublished data
Cyprinella whipplei	Steelcolor shiner	Egg attachment	Pflieger (1965)
Exoglossum laurae	Tonguetied minnow	Nesting cover	Trautman (1981), Jenkins and Burkhead (1994)
Exoglossum maxillingua	Cutlips minnow	Nesting cover	Jenkins and Burkhead (1994)
Hybognathus hayi	Cypress minnow	Cover, inundated forest (probable)	Baker et al. (1991), Warren and Burr (1989)
Hybognathus nuchalis	Mississippi silvery minnow	Inundated forest (probable)	Baker et al. (1991)
Hybopsis hypsinotus	Highback chub	Cover	Jenkins and Burkhead (1994)
Hybopsis storeriana	Sliver chub	Inundated forest (probable)	Baker et al. (1991)
Lythrurus fumeus	Ribbon shiner	Cover, inundated forest (probable)	Baker et al. (1991), Warren et al. (2009)
Lythrurus roseipinnis	Cherryfin shiner	Inundated forest, feeding (invertivore)	Ross and Baker (1983), O'Connell (2003)
Lythrurus umbratilis	Redfin shiner	Cover	Warren et al. (2009)
Nocomis biguttatus	Hornyhead chub	Cover	Angermeier and Karr (1984)
Nocomis leptocephalus	Bluehead chub	Cover, nesting cover	Jenkins and Burkhead (1994), Marcy et al. (2005)

(continued)

Table 10.1 (continued)

Family and scientific name	Common name	Association	Source
Notemigonus crysoleucas	Golden shiner	Inundated forest (adults and juveniles)	Ross and Baker (1983)
Notropis atherinoides	Emerald shiner	Cover, inundated forest (probable)	Baker et al. (1991), Lehtinen et al. (1997)
Notropis blennius	River shiner	Inundated forest (probable)	Baker et al. (1991)
Notropis maculatus	Taillight shiner	Spawning cover, inundated forest (adult)	Burr and Page (1975), Baker et al. (1991), Warren unpublished
Notropis cummingsae	Dusky shiner	Cover	Marcy et al. (2005)
Notropis rafinesquei	Yazoo shiner	Cover	Warren et al. (2009)
Notropis shumardi	Silverband shiner	Inundated forest (probable)	Baker et al. (1991)
Notropis texanus	Weed shiner	Inundated forest (adults)	Ross and Baker (1983)
Notropis volucellus	Mimic shiner	Inundated forest (probable)	Baker et al. (1991)
Opsopoeodus emiliae	Pugnose minnow	Inundated forest (adults and larvae), egg attachment (probable)	Ross and Baker (1983), Johnston and Page (1990), Killgore and Baker (1996)
Pimephales notatus	Bluntnose minnow	Nesting cover, egg attachment	Hubbs and Cooper (1936), Scott and Crossman (1973)
Pimephales promelas	Fathead minnow	Cover, nesting cover, egg attachment, food	Wynne-Edwards (1932), Scott and Crossman (1973), Herwig and Zimmer (2007), Warren et al. (2009)
Pimephales vigilax	Bullhead minnow	Cover, nesting cover, egg attachment, inundated forest (juveniles and larvae)	Parker (1964), Killgore and Baker (1996), Warren et al. (2009)
Pteronotropis euryzonus	Broadstripe shiner	Cover	Mettee et al. (1996), Boschung and Mayden (2003)
Pteronotropis hypselopterus	Sailfin shiner	Cover	Suttkus and Mettee (2001)
Pteronotropis welaka	Bluenose shiner	Inundated forest (adults)	Ross and Baker (1983)
Pteronotropis merlini	Orangetail shiner	Cover	Suttkus and Mettee (2001)
Pteronotropis stonei	Lowland shiner	Cover	Marcy et al. (2005)
Semotilus atromaculatus	Creek chub	Cover, feeding (juveniles)	Pflieger (1997), Quist and Guy (2001), Marcy et al. (2005), Belica and Rahel (2008)

Catostomidae	Suckers		
Carpiodes carpio	River carpsucker	Cover, inundated forest (probable)	Willis and Jones (1986), Baker et al. (1991)
Cycleptus meridionalis	Southeastern blue sucker	Cover	Ross (2001)
Erimyzon oblongus	Creek chubsucker	Cover	Mettee et al. (1996)
Erimyzon tenuis	Sharpfin chubsucker	Cover, inundated forest (adults)	Ross and Baker (1983), Mettee et al. (1996)
Erimyzon sucetta	Lake chubsucker	Inundated forest (larvae)	Killgore and Baker (1996)
Ictiobus bubalus	Smallmouth buffalo	Cover, spawning cover, egg attachment, inundated forest (juveniles)	Baker et al. (1991), Rutherford et al. (2001), Boschung and Mayden 2003, Warren unpublished
Ictiobus cyprinellus	Bigmouth buffalo	Cover, inundated forest (juveniles)	Baker et al. (1991), Lehtinen et al. (1997), Warren unpublished
Ictiobus niger	Black buffalo	Inundated forest (adults and juveniles), spawning cover, egg attachment	Yeager (1936)
Minytrema melanops	Spotted sucker	Cover, feeding, inundated forest (larvae)	Killgore and Baker (1996), Lehtinen et al. (1997)
Moxostoma poecilurum	Blacktail redhorse	Diurnal cover (juveniles), inundated forest (adults)	Ross (2001), Warren et al. (2009)
Moxostoma robustum	Robust redhorse	Cover	Marcy et al. (2005)
Ictaluridae	North American catfishes		
Ameiurus catus	White catfish	Nesting cover	Marcy et al. (2005)
Ameiurus melas	Black bullhead	Nesting cover, inundated forest (juveniles)	Baker et al. (1991), Breder and Rosen (1966)
Ameiurus natalis	Yellow bullhead	Cover, nesting cover, inundated forest (juveniles and larvae)	Etnier and Starnes (1993), Killgore and Baker (1996), Warren et al. (2009)
Ameiurus nebulosus	Brown bullhead	Nesting cover	Blumer (1985)
Ameiurus serracanthus	Spotted bullhead	Cover	Mettee et al. (1996)
Ictalurus furcatus	Blue catfish	Nesting cover, inundated forest (probable)	Baker et al. (1991), Marcy et al. (2005)
Ictalurus punctatus	Channel catfish	Cover, nesting cover, inundated forest (adults and larvae)	Killgore and Baker (1996), Ross (2001), Boschung and Mayden (2003), Warren et al. (2009)

(continued)

Table 10.1 (continued)

Family and scientific name	Common name	Association	Source
Noturus flavater	Checkered madtom	Cover	Pflieger (1997)
Noturus flavipinnis	Yellowfin madtom	Cover	Dinkins and Shute (1996)
Noturus funebris	Black madtom	Cover, inundated forest (adults), nesting cover	Mettee et al. (1996), Ross (2001), Boschung and Mayden (2003)
Noturus furiosus	Carolina madtom	Cover	Midway (2009)
Noturus gyrinus	Tadpole madtom	Cover, inundated forest (adults and larvae), nesting cover	Ross and Baker (1983), Burr and Warren (1986), Killgore and Baker (1996), Burr and Stoeckel (1999)
Noturus gilberti	Orangefin madtom	Nesting cover	Burr and Stoeckel (1999)
Noturus hildebrandi	Least madtom	Cover, nesting cover	Mayden and Walsh (1984), Etnier and Starnes (1993), Warren et al. (2009)
Noturus gladiator	Piebald madtom	Cover, nesting cover (probable)	Ross (2001)
Noturus insignis	Margined madtom	Cover	Marcy et al. (2005)
Noturus leptacanthus	Speckled madtom	Cover, inundated forest, nesting cover (probable)	Ross and Baker (1983), Mettee et al. (1996)
Noturus miurus	Brindled madtom	Cover, nesting cover	Burr and Warren (1986), Mettee et al. (1996), Burr and Stoeckel (1999)
Noturus munitus	Frecklebelly madtom	Cover	Etnier and Starnes (1993)
Noturus nocturnus	Frecked madtom	Cover, inundated forest (adults)	Ross and Baker (1983), Burr and Warren (1986), Mettee et al. (1996), Warren et al. (2009)
Noturus phaeus	Brown madtom	Cover, nesting cover (probable)	Monzyk et al. (1997), Warren et al. (2009)
Noturus stigmosus	Northern madtom	Cover	Etnier and Starnes (1993)
Pylodictus olivaris	Flathead catfish	Cover, nesting cover, inundated forest (probable)	Baker et al. (1991), Jackson (1999)
Esocidae	Pikes		
Esox masquinongy	Muskellunge	Cover	Axon and Kornman (1986)
Exox niger	Chain pickerel	Cover, inundated forest (adults), egg attachment	Ross and Baker (1983), Scott and Crossman (1973), Jenkins and Burkhead (1994), Boschung and Mayden (2003)

Esox americanus	Grass pickerel	Cover, inundated forest (adults and juveniles), egg attachment	Ross and Baker (1983), Angermeier and Karr (1984), Finger and Stewart (1987), Ross (2001)
Umbridae	Mudminnows		
Umbra limi	Central mudminnow	Cover	Etnier and Starnes (1993)
Umbra pygmaea	Eastern mudminnow	Cover, nesting cover, egg attachment (probable)	Jenkins and Burkhead (1994), Marcy et al. (2005)
Salmonidae	Trouts and salmons		
Salvelinus fontinalis	Brook trout	Shade	Cherry et al. (1977), Meisner (1990), Clark et al. (2001), Flebbe et al. (2006)
Percopsidae	Trout-perches		
Percopsis omiscomaycus	trout-perch	Cover	Jenkins and Burkhead (1994)
Aphredoderidae	Pirate perches		
Aphredoderus sayanus	Pirate perch	Cover, inundated forest (adults, juveniles, and larvae), feeding, nesting cover, nest construction, egg attachment	Ross and Baker (1983), Benke et al. (1985), Finger and Stewart (1987), Killgore and Baker (1996), Monzyk et al. (1997), Fletcher et al. (2004)
Amblyopsidae	Cavefishes		
Chologaster cornuta	Swampfish	Cover, shade	Marcy et al. (2005)
Atherinopsidae	New World silversides		
Labidesthes sicculus	Brook silverside	Inundated forest (adults)	Ross and Baker (1983)
Menidia beryllina	Inland silverside	Inundated forest (probable)	Baker et al. (1991)
Aplocheilidae	Rivulines		
Rivulus marmoratus	Mangrove killifish	Cover	Taylor and Snelson (1992)
Fundulidae	Topminnows		
Fundulus chrysotus	Golden topminnow	Inundated forest (adults and juveniles), egg attachment	Baker et al. (1991), Ross (2001)
Fundulus dispar	Northern starhead topminnow	Inundated forest (adults)	Finger and Stewart (1987)
Fundulus euryzonus	Broadstripe topminnow	Cover	Ross (2001)
Fundulus notatus	Blackstripe topminnow	Cover, inundated forest (probable)	Baker et al. (1991), Warren et al. (2009)

(continued)

Table 10.1 (continued)

Family and scientific name	Common name	Association	Source
Fundulus notti	Southern starhead topminnow	Inundated forest (adults)	Ross and Baker (1983)
Fundulus olivaceus	Blackspotted topminnow	Cover, inundated forest (adults and larvae)	Ross and Baker (1983), Killgore and Baker (1996), Warren et al. (2009)
Lucania goodei	Bluefin killifish	Cover	Mettee et al. (1996)
Poecillidae	Livebearers		
Gambusia affinis	Western mosquitofish	Cover, inundated forest (adults and juveniles)	Ross and Baker (1983), Finger and Stewart (1987), Warren et al. (2009)
Lucania goodei	Bluefin killifish	Cover	Mettee et al. (1996)
Cottidae	Sculpins		
Cottus bairdi	Mottled sculpin	Nesting cover, egg attachment	Rohde and Arndt (1982)
Elassomatidae	Pygmy sunfishes		
Elassoma zonatum	Banded pygmy sunfish	Inundated forest (adults, juveniles, and larvae)	Ross and Baker (1983), Finger and Stewart (1987), Killgore and Baker (1996)
Moronidae	Temperate basses		
Morone chrysops	White bass	Inundated forest (juveniles)	Warren unpublished
Centrarchidae	Sunfishes		
Acantharchus pomotis	Mud sunfish	Cover	Warren (2009)
Ambloplites ariommus	Shadow bass	Cover	Probst et al. (1984), Mettee et al. (1996), Warren (2009)
Ambloplites constellatus	Ozark bass	Cover	Pflieger (1997), Warren (2009)
Ambloplites rupestris	Rock bass	Cover	Angermeier and Karr (1984), Lehtinen et al. (1997), Warren (2009)
Centrarchus macropterus	Flier	Cover, inundated forest (adults, juveniles, and larvae)	Finger and Stewart (1987), Killgore and Baker (1996), Mettee et al. (1996), Warren (2009)
Enneacanthus gloriosus	Bluespotted sunfish	Cover	Mettee et al. (1996), Warren (2009)
Lepomis auritus	Redbreast sunfish	Cover, nesting cover, feeding (invertivore)	Benke et al. (1985), Warren (2009)

Lepomis cyanellus	Green sunfish	Cover, nesting cover, inundated forest	Ross and Baker (1983), Warren (2009), Warren et al. (2009)
Lepomis gulosus	Warmouth	Cover, inundated floodplain (adults and juveniles), feeding (invertivore), nesting cover	Ross and Baker (1983), Benke et al. (1985), Warren (2009), Warren et al. (2009)
Lepomis humilis	Orangespotted sunfish	Cover, inundated forest (probable)	Baker et al. (1991), Warren (2009), Warren et al. (2009)
Lepomis macrochirus	Bluegill	Cover, inundated floodplain (adults and juveniles), feeding (invertivore)	Ross and Baker (1983), Angermeier and Karr (1984), Benke et al. (1985), Lehtinen et al. (1997), Warren (2009), Warren et al. (2009)
Lepomis marginatus	Dollar sunfish	Inundated forest (adults)	Ross and Baker (1983), Warren (2009)
Lepomis megalotis	Longear sunfish	Cover	Angermeier and Karr (1984), Warren (2009), Warren et al. (2009)
Lepomis miniatus	Redspotted sunfish	Cover, inundated forest (adults)	Ross and Baker (1983), Rutherford et al. (2001), Warren (2009)
Lepomis microlophus	Redear sunfish	Inundated forest (adults)	Ross and Baker (1983), Warren (2009)
Lepomis punctatus	Spotted sunfish	Cover, feeding (invertivore)	Benke et al. (1985), Warren (2009)
Lepomis symmetricus	Bantam sunfish	Cover, inundated forest (adults and juveniles), nesting cover	Finger and Stewart (1987), Warren (2009)
Micropterus dolomieu	Smallmouth bass	Cover, nesting cover	Warren (2009)
Micropterus floridanus	Florida bass	Cover, nesting cover	Warren (2009)
Micropterus notius	Suwannee bass	Cover	Warren (2009)
Micropterus punctulatus	Spotted bass	Cover, nesting cover	Warren (2009)
Micropterus salmoides	Largemouth bass	Cover, inundated forest, feeding, nesting cover	Ross and Baker (1983), Benke et al. (1985), Hunt et al. (2002), Warren (2009),
Micropterus treculi	Guadalupe bass	Cover	Warren (2009)
Pomoxis annularis	White crappie	Cover, inundated forest (larvae)	Killgore and Baker (1996), Hoover and Killgore (1998), Warren (2009)
Pomoxis nigromaculatus	Black crappie	Cover, inundated forest (larvae)	Killgore and Baker (1996), Hoover and Killgore (1998), Warren (2009)
Percidae	Perches		

(continued)

Table 10.1 (continued)

Family and scientific name	Common name	Association	Source
Etheostoma asprigene	Mud darter	Cover, inundated forest (larvae), egg attachment	Page et al. (1982), Burr and Warren (1986), Killgore and Baker (1996), Pflieger (1997), Ross 2001
Etheostoma artesiae	Redfin darter	Cover	Mettee et al. (1996), Warren et al. (2009)
Etheostoma boschungi	Slackwater darter	Cover, inundated forest (adults and larvae)	Etnier and Starnes (1993, 1984), Boschung and Mayden (2003)
Etheostoma chlorosoma	Bluntnose darter	Cover, inundated forest (larvae), egg attachment	Page et al. (1982), Etnier and Starnes (1993), Killgore and Baker (1996)
Etheostoma chienense	Relict darter	Cover, nesting cover, egg attachment	Piller and Burr (1999)
Etheostoma collis	Carolina darter	Cover	Jenkins and Burkhead (1994)
Etheostoma colorosum	Coastal darter	Cover	Mettee et al. (1996)
Etheostoma coosae	Coosa darter	Egg attachment	Mettee et al. (1996)
Etheostoma corona	Crown darter	Nesting cover, egg attachment	Mettee et al. (1996), Boschung and Mayden (2003)
Etheostoma cragini	Arkansas darter	Cover	Pflieger (1997)
Etheostoma davisoni	Choctawhatchee darter	Cover	Mettee et al. (1996)
Etheostoma fricksium	Savannah darter	Cover	Marcy et al. (2005)
Etheostoma gracile	Slough darter	Cover, inundated forest (adults and larvae), egg attachment	Braasch and Smith (1967), Finger and Stewart (1987), Killgore and Baker (1996), Warren et al. (2009)
Etheostoma histrio	Harlequin darter	Cover	Warren (1982), Pflieger (1997), Warren et al. (2009)
Etheostoma inscriptum	Turquoise darter	Cover	Marcy et al. (2005)
Etheostoma lachneri	Tombigbee darter	Cover	Mettee et al. (1996)
Etheostoma lynceum	Brighteye darter	Cover	Warren et al. (2009)
Etheostoma neopterum	Lollipop darter	Cover, nesting cover, egg attachment (probable)	Etnier and Starnes (1993), Boschung and Mayden (2003)
Etheostoma nigrum	Johnny darter	Nesting cover, egg attachment	Jenkins and Burkhead (1994)

Etheostoma olmstedi	Tessellated darter	Cover, nesting cover, egg attachment (probable)	Jenkins and Burkhead (1994)
Etheostoma oophylax	Guardian darter	Cover, nesting cover, egg attachment (probable)	Etnier and Starnes (1993)
Etheostoma parvipinne	Goldstripe darter	Cover, shade, egg attachment	Johnston (1994), Smiley et al. (2005)
Etheostoma perlongum	Waccamaw darter	Egg attachment	Lindquist et al. (1981)
Etheostoma proeliare	Cypress darter	Cover, egg attachment, inundated forest (larvae)	Burr and Page (1978), Killgore and Baker (1996), Pflieger (1997), Warren et al. (2009)
Etheostoma punctulatum	Stippled darter	Cover	Pflieger (1997)
Etheostoma pyrrhogaster	Firebelly darter	Egg attachment (probable)	Carney and Burr (1989), Etnier and Starnes (1993)
Etheostoma ramseyi	Alabama darter	Cover	Mettee et al. (1996)
Etheostoma raneyi	Yazoo darter	Egg attachment	Johnston and Haag 1996, Sterling and Warren unpublished
Etheostoma serrifer	Sawcheek darter	Cover	Marcy et al. (2005)
Etheostoma stigmaeum	Speckled darter	Inundated forest (larvae)	Killgore and Baker (1996)
Etheostoma swaini	Gulf darter	Cover	Etnier and Starnes (1993)
Etheostoma tallapoosa	Tallapoosa darter	Spawning cover, egg attachment (probable)	Mettee et al. (1996)
Etheostoma trisella	Trispot darter	Cover	Etnier and Starnes (1993)
Etheostoma vitreum	Glassy darter	Egg attachment	Winn and Picciolo (1960)
Etheostoma swaini	Gulf darter	Cover, inundated forest	Ross and Baker (1983), Ross (2001)
Etheostoma zonale	Banded darter	Cover	Pflieger (1997)
Etheostoma zonistium	Bandfin darter	Cover, egg attachment (probable)	Boschung and Mayden (2003)
Nothonotus rubrum	Bayou darter	Cover	Ross (2001)
Percina caprodes	Logperch	Inundated forest (larvae)	Killgore and Baker (1996)
Percina cymatotaenia	Bluestripe darter	Cover	Pflieger (1997)
Percina lenticula	Freckled darter	Cover	Ross (2001)
Percina macrocephala	Longhead darter	Cover	Etnier and Starnes (1993)
Percina maculata	Blackside darter	Cover	Etnier and Starnes (1993), Pflieger (1997), Ross (2001)

(continued)

Table 10.1 (continued)

Family and scientific name	Common name	Association	Source
Percina nigrofasciata	Blackbanded darter	Cover, inundated forest (adults)	Ross and Baker (1983), Etnier and Starnes (1994), Ross (2001)
Percina sciera	Dusky darter	Cover	Page and Smith (1970), Etnier and Starnes (1993), Pflieger (1997), Ross (2001), Warren et al. (2009)
Percina shumardi	River darter	Inundated forest (larvae)	Killgore and Baker (1996)
Percina stictogaster	Frecklebelly darter	Cover	Burr and Page (1993), Etnier and Starnes (1993)
Sciaenidae	Drums and croakers		
Aplodinotus grunniens	Freshwater drum	Cover, inundated forest (larvae)	Willis and Jones (1986), Hoover and Killgore (1998)

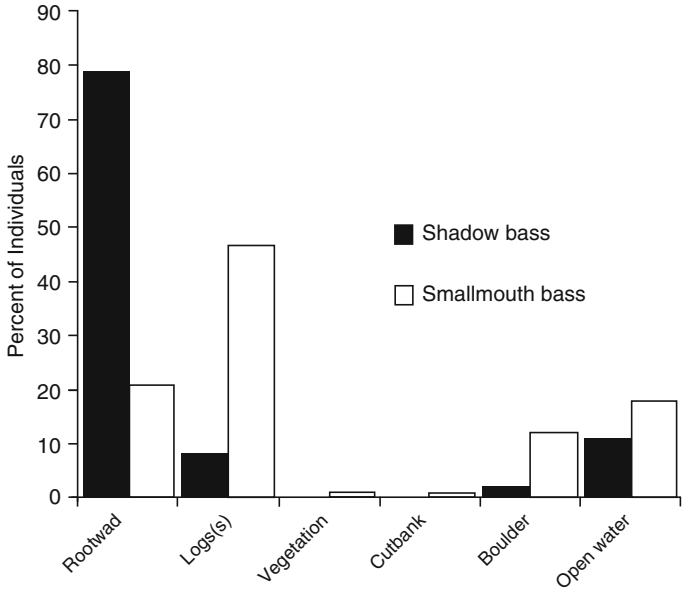

Fig. 10.9 Habitat partitioning of logs, root wads, and four other cover types by two co-occurring top-predator fishes in a rocky, upland river in Missouri (Compiled from Probst et al. 1984)

were short-lived (about 4 year) and failed because the underlying geomorphic and watershed problems causing instability of the channel were not addressed. Restoration efforts in other streams showed similar results (Shields et al. 2007).

10.5 Instream Wood and Food Production

Wood deposited in streams from the riparian zone plays an important role in aquatic invertebrate production and hence, availability of food to other invertebrates, fishes, and other vertebrates (Angermeier and Karr 1984; Smock and Gilinsky 1992; Benke and Wallace 2003). Production in streams is categorized as primary production (biomass or energy from photosynthesis, e.g., algae) and secondary production (biomass or energy from organic carbon sources, e.g., microcrustaceans, aquatic insects). Nearly all fishes in southern U.S. waters depend entirely on invertebrates (secondary producers) for food during one or more life stages (i.e., larval, juvenile, adult) albeit a few are strict herbivores, scraping algae from hard substrates. For example, all the important warmwater sportfishes, such as largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*), feed heavily on microcrustaceans (e.g., water fleas) as young fish, then switch to larger aquatic insects (e.g., midge pupae and larvae, dragonfly larvae, aquatic beetles) as juveniles. Even as adults, largemouth bass and many other top-predator fishes feed extensively

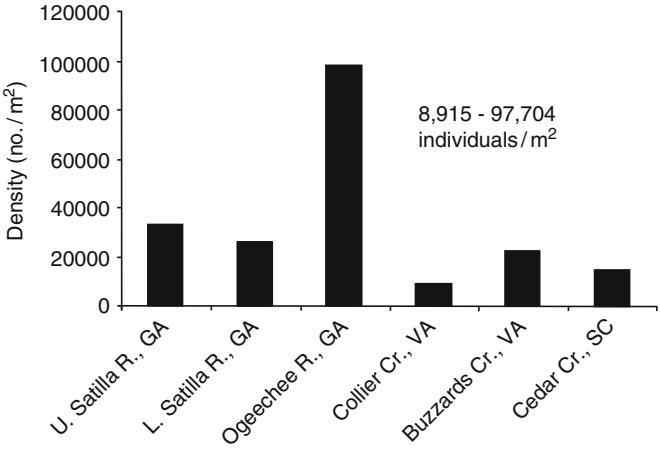

Fig. 10.10 Aquatic invertebrate density on instream wood surfaces in selected southern U.S. Coastal Plain streams and rivers (Compiled from Benke and Wallace 2003)

on large aquatic invertebrates such as crayfish and terrestrial insects (Warren 2009). Similarly, one of the most species-rich group of fishes in southern waters, the darters (e.g., *Etheostoma* spp., *Nothonotus* spp., *Percina* spp.) feed extensively and at times almost exclusively on the aquatic larvae and pupae of flies and midges living on and around hard substrates (e.g., logs, sticks, rocks) in streams. Species in another large family, the minnows (family Cyprinidae), exploit aquatic insects on hard surfaces as well as those drifting in the water column and on the surface.

The riparian zone contributes large instream wood in the form of trees or parts of trees to stream and river channels, providing substrate for aquatic organisms (e.g., bacteria, fungi, and invertebrates) to colonize and foraging habitat for fishes (Nilsen and Larimore 1973; Benke et al. 1984, 1985; Lehtinen et al. 1997) (Fig. 10.6). Instream wood can collect other organic material (e.g., leaves, twigs) to form organic debris dams, which also are colonized by aquatic organisms that decompose wood, shred organic matter, and filter small organic particles from the water column. Establishment of these communities ultimately results in diverse, highly productive, and complex wood-associated food webs (e.g., Anderson et al. 1978; Harmon et al. 1986; Wallace et al. 1992; Benke et al. 2001; Benke and Wallace 2003).

Wood is especially important to invertebrates in habitats with fine, mobile bottom substrates and few other streambed geomorphic controls (Angermeier and Karr 1984; Benke et al. 1984, 1985; Benke and Wallace 2003), a common feature of lowland southern U.S. streams. In sand-bed streams and rivers, wood surfaces and debris dams often support the highest densities and diversity of invertebrate species and contribute the greatest amount of secondary production (e.g., Smock et al. 1989; Drury and Kelso 2000; Johnson et al. 2003). Wood surfaces in southern US Coastal Plain streams support 9,000–98,000 invertebrates m^{-2} (Fig. 10.10). Snags in Georgia's Savannah River supported densities of net-spinning caddisfly larvae that

ranged from 6,000 to 22,000 individuals m^{-2} (Cudney and Wallace 1980). Sampling of the immersed surfaces of snags in the well-studied Ogeechee River system of Georgia yielded 108 invertebrate species but only 70 species occurred exclusively in the sandy stream bed (Benke and Wallace 2003). Similarly, 11 of 12 samples yielded greater percentages of invertebrates from gravel and wood than from sand substrate in six streams on Louisiana's coastal plain, where gravel is scarce and wood likely supports the greatest secondary production (Drury and Kelso 2000).

Annual production estimates of aquatic invertebrates in sand-dominated systems range from 72 $g\,m^{-2}$ on snags in large rivers to 36 $g\,m^{-2}$ in debris dams in headwater streams, which usually represents >20% of the total invertebrate numbers and >30% of invertebrate biomass in these systems (Smock and Gilinsky 1992; Benke and Wallace 2003). About 60% of in-channel invertebrate biomass is associated with snags in Georgia's Satilla River where four of eight large-bodied fish species obtained at least 60% of their prey biomass during non-flood conditions from snag-dwelling invertebrates in the river (Benke et al. 1985). The 'snag fauna-sunfish' food chain represented an essentially completely separate trophic pathway from the 'bottom fauna-small fish-piscivore' food chain (Benke et al. 1985; Benke and Wallace 2003). Other work similarly indicates stream and riverine fishes often show higher abundances, higher foraging success, and increased growth in association with the invertebrate fauna supported by instream wood (Angermeier and Karr 1984; Angermeier 1985; Lehtinen et al. 1997; Crook and Robertson 1999; Quist and Guy 2001). Clearly, the abundance and production of fishes in rivers and streams is directly enhanced by the contribution of instream wood to fish food production.

10.6 Instream Wood as a Spawning Substrate

Many fishes attach their eggs to instream wood, which is considered an adaptation to decrease silting and potential smothering of eggs (Gale and Gale 1977; Burkhead and Jelks 2001; Fletcher et al. 2004; Sutherland 2007). For example, tree trunks with cracks, loose bark, or deeply ridged bark provide suitable spawning habitat for crevice spawning minnows of the genus *Cyprinella* (Pflieger 1997) (Table 10.1). The relatively large range of the blacktail shiner, *Cyprinella venusta*, across southeastern U.S. coastal plain, sand-bed streams is partially attributable to its use of wood (and bridge abutments) for egg attachment (Pflieger 1997). Several darters (*Etheostoma* spp.) adapted to sand-bottomed habitats (Table 10.1) also deposit their eggs on wood, almost exclusively so for the lake-dwelling Waccamaw darter, *Etheostoma perlongum*, a threatened species, and the glassy darter, *Etheostoma vitreum* (Fig. 10.11) (Winn and Picciolo 1960; Lindquist et al. 1981). Female relict darters (*Etheostoma chienense*) attach their eggs in clusters to the underside of logs and large sticks; individual males then guard the resulting clusters until the eggs hatch. Lack of spawning substrate resulting from extensive channel and riparian modification is a primary factor limiting recruitment of this endangered species

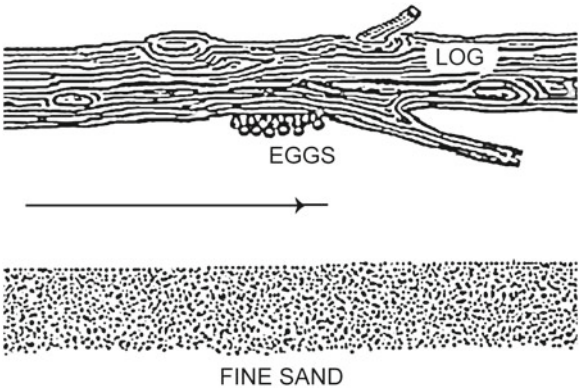

Fig. 10.11 Fishes, like the glassy darter (*Etheostoma vitreum*), attach their eggs to the undersides of logs as a presumable adaptation to increase oxygenation and prevent silting of eggs (*arrow* indicates direction of current) (Redrawn from Winn and Picciolo 1960)

(Piller and Burr 1999). The pirate perch (*Aphredoderus sayanus*) deposits its eggs in canals within underwater root masses of riparian vegetation created by it or salamanders and dobsonfly larvae (Fig. 10.12) (Fletcher et al. 2004). The species is specially adapted to lay eggs in the backs of the canal because its urogenital pore, where eggs and sperm are released, is located under its head. As such the species can thrust its head deep in a canal and release the eggs or sperm away from water currents and egg predators. Several species of madtom catfishes (genus *Noturus*), the most diverse group of catfishes in North America, establish nests under large wood and provide extensive care to nests, eggs, and young (Burr and Stoeckel 1999). Use of wood (e.g., standing timber, downed trees, root wads) for egg attachment or nesting cover is common among important southern U.S. game (e.g., the black basses, *Micropterus* spp.), commercial (catfishes, *Ictalurus* spp., *Pylodictus* sp.) and nongame fishes (Warren 2009; Table 10.1).

10.7 Forests and Stream Temperature

The role of the riparian forest in regulating stream temperature and damping extremes in temperature is most pronounced in small headwater streams (e.g., Brown and Krygier 1970; Swift and Messer 1971; Swift 1982; Isaak and Hubert 2001; Wehrly et al. 2006). Removal of riparian forests along small upland streams in the southern Blue Ridge can alter both maximum and minimum stream temperatures for several years (Swift 1982) with summer extremes up to 6.7 °C above pre-harvest levels of 19 °C (Swift and Messer 1971). Even in lowland streams, removal of riparian shade produces larger diurnal temperature extremes than observed in shaded streams (Huish and Pardue 1978) which in summer could result in dissolved oxygen levels below critical thresholds for fishes (Smale and Rabeni 1995). Although temperature effects from riparian forest removal are best documented in coldwater fishes, particularly

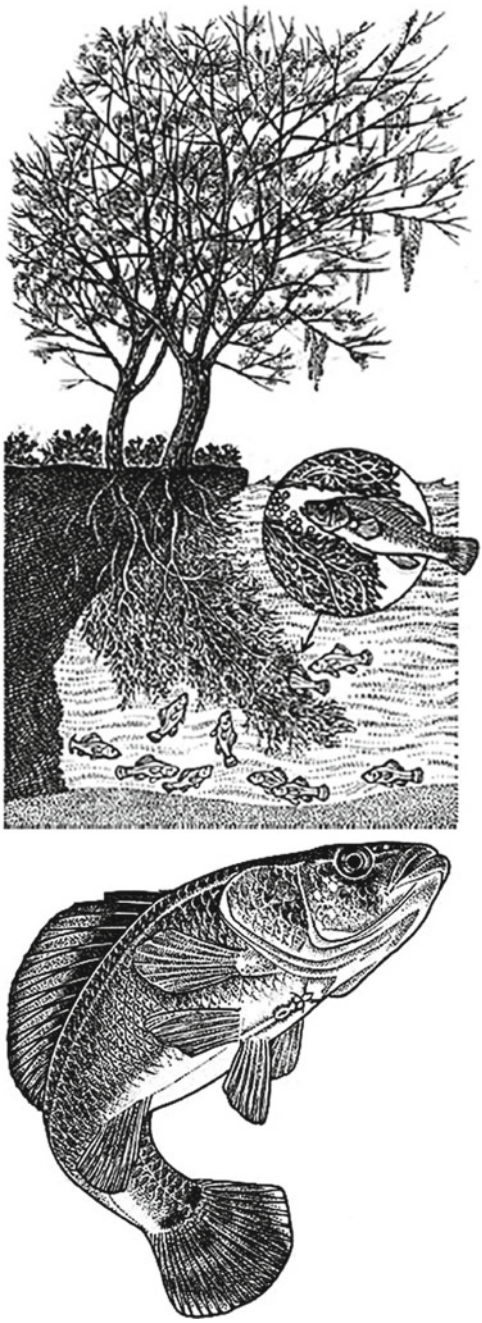

Fig. 10.12 The male pirate perch prepares for spawning by burrowing into the rootlet masses of riparian vegetation (*upper panel*). The female noses into the burrow, deposits eggs in the back of the burrow via a specially adapted urogenital opening located under her throat (*lower panel*), and leaves. The male then enters the burrow and fertilizes the eggs by releasing sperm from his urogenital pore, which like the female is located under his throat. (Fletcher et al. 2004, used with permission of Dean Fletcher)

increased temperature effects on salmonids (trout and salmon) (e.g., Meehan 1991), many species of southern US fishes thrive only in streams with densely forested and vegetated riparian zones and in heavily shaded spring-heads and spring runs. The distribution of some species is restricted because they are adapted to or benefit from the generally cooler temperature regimes in these habitats (e.g., Peterson and Rabeni 1996; Flebbe et al. 2006). When forest cover in riparian areas is removed and water temperatures rise, it may be energetically impossible for a fish species or life stage with lower temperature requirements to continue living in the system, regardless of other apparently favorable conditions (e.g., food availability). For example, adult brook trout (*Salvelinus fontinalis*), an important native sport fish in the southern Appalachian Mountains, are limited to cool waters (<19 °C) in mature forests (Cherry et al. 1977; Meisner 1990; Clark et al. 2001; Flebbe et al. 2006). However, mortality and growth rates of young of this species can be affected negatively by slight increases in water temperatures that are tolerated by the adults (McCormick et al. 1972; Clark et al. 2001). Spatial modeling of climate change across the range of the southern Appalachians projects a 53–97% loss of trout habitat, leaving populations fragmented, isolated, and subject to stochastic extirpation (Flebbe et al. 2006). Similar losses might be expected for other headwater species in the Appalachians. Loss of riparian vegetation simply exacerbates the problem. Similarly, late twentieth century decreases in distribution and abundance of smallmouth bass (*Micropterus dolomieu*), another important sport fish, in streams in the prairie-Ozark ecotone of Missouri were related in part to maximum summer water temperature, an effect attributable to removal of riparian forest (Sowa and Rabeni 1995). Other fishes in the southern United States, many of which are of conservation concern, also appear to be limited to forested habitats at least in part by the lower temperatures produced by shading, including species restricted to upland headwater streams, spring heads, or spring runs. Proportionally, spring-dependent fishes are one of the most jeopardized groups of fishes in the region (Etnier 1997). Removal of riparian vegetation is implicated in extirpation of populations (e.g., Tennessee dace, *Chrosomus tennesseensis*, laurel dace, *Chromsomus saylori*, spring pygmy sunfish, *Elassoma alabamae*) and replacement of species with more thermally tolerant congeners (e.g., blackside dace, *Chrosomus cumberlandensis* replaced by redbelly dace, *Chrosomus erythrogaster*) (e.g., Starnes and Starnes 1981; Starnes and Jenkins 1988; Burkhead and Jenkins 1991; Skelton 2001; Warren 2004).

10.8 Fringing Forests, Fish Foraging, and Reproduction

The benefits of forests to fishes are realized well beyond the stream banks. Forested floodplains also are sites of high production of both terrestrial and aquatic invertebrates (Gladden and Smock 1990; Anderson et al. 1998; Braccia and Batzer 2001) and can harbor denser populations of potential fish food organisms than adjacent stream channels (O'Connell 2003). Fishes can quickly move onto the floodplain

during flooding to avoid high currents of flood waters and to exploit floodplain food resources (Guillory 1979; Ross and Baker 1983; Kwak 1988; Eggleton and Schramm 2004). Direct benefits to fish growth can accrue. Growth in blue catfish (*Ictalurus furcatus*), a species that exploits flooded habitats, was related positively to areal extent and duration of flooding along the Mississippi River, a direct benefit of the higher energy food sources provided in flooded off-channel habitats (Eggleton and Schramm 2004; Schramm and Eggleton 2006). Even short-term inundation of forested fringing floodplains, a relatively common phenomenon after storm events in many small streams of the southern United States, can provide important food resources to fishes. During 4–5 day overbank flood events, stream fishes moved rapidly onto and extensively within a forested fringing floodplain of a small blackwater creek on the lower Coastal Plain of southern Mississippi. Fish captured on the floodplain had full stomachs, indicative of rapid exploitation of floodplain associated food. In the same stream system, more food was available and more food was consumed (especially Collembola, springtails, from the forest floor) by cherryfin shiners (*Lythrurus roseipinnis*) on the inundated floodplain than was available in the stream at low flow (O'Connell 2003). The correlation of high spring discharge with summer spawning success suggested that some species, such as the weed shiner (*Notropis texanus*), obtain direct energy subsidies from exploitation of floodplain food resources (terrestrial and floodplain pool invertebrates) that are important for subsequent reproduction (Ross and Baker 1983) (Table 10.1). Even more direct reproductive benefits can accrue from inundated floodplains.

At least 76 fish species are characteristic residents within southern forested wetlands (Hoover and Killgore 1998), and these species and many other southern U.S. fishes use seasonally inundated forests for spawning and nursery areas (Hoover and Killgore 1998; Guillory 1979; Finger and Stewart 1987; Baker et al. 1991; Turner et al. 1994; Killgore and Baker 1996) (Table 10.1). Over half the fishes known from the large Atchafalaya Basin of Louisiana use flooded forests for spawning or rearing of young (Lambou 1990). During spring and early summer, catches of larval fishes were nearly four times greater in flooded *Quercus* forest than in the main channel of the Cache River, Arkansas (Killgore and Baker 1996). Relative to the channel, the larval catch in flooded forests yielded large numbers of sunfishes (Centrarchidae), minnows (Cyprinidae), and darters (Percidae). In the lower Yazoo River basin, Mississippi, abundance of native sport, commercial, and nongame larval fishes was much higher in flooded forests than flooded agricultural land, particularly so for black basses, darters, and sunfishes (Fig. 10.13).

10.9 Conclusions

Rapid growth of the human population in the southern United States places ever growing demands on water and other natural resources and significantly challenges aquatic resource management and conservation (Cordell et al. 1998; Wear et al. 1998;

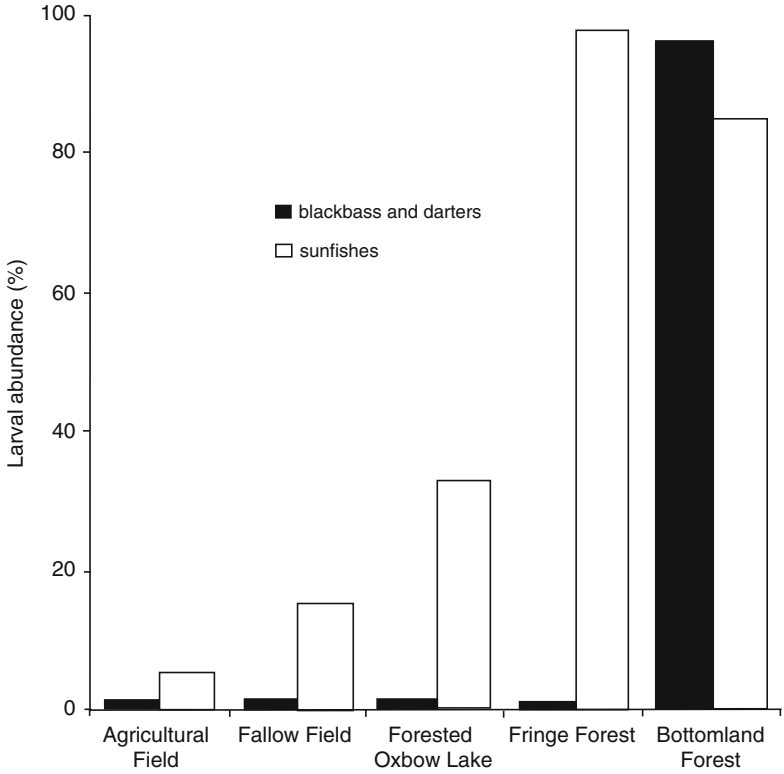

Fig. 10.13 Abundance of larval fishes in agricultural and forested habitats in the Yazoo River Basin, Mississippi (Redrawn from Hoover and Killgore 1998)

Wear and Greis 2002). Land ownership patterns further confound conservation of aquatic resources in the region, where <12% of the land base lies in the public domain. Because most of the biologically significant streams in the region are found in predominantly forested watersheds, most jeopardized fishes and their habitats are not afforded protection through federal or state land ownership (Neves et al. 1997; Master et al. 1998). About 71% of forested land in the region is owned by thousands of non-industrial private landowners, mostly in small parcels of one to several hundred ha (Conner and Hartsell 2002). These owners, many of whom do not live on their land, vary greatly in their knowledge and attitudes towards the environment and their reasons for land ownership (Cordell et al. 1998; Tarrant et al. 2002), which further complicates effective watershed-scale or even local restoration.

Nevertheless, forest restoration, especially restoration of riparian forests, can provide multiple benefits to stream fishes in the southern United States. Indirect benefits include reduced sediment and nutrient inputs, stream bank stabilization, and temperature moderation, all factors that can affect fish production, physiology,

reproduction, and assemblage composition. Direct inputs of leaves and wood into streams provide the primary energy base and substrate for production of macroinvertebrates, the food base for fishes (Dolloff and Webster 2000; Benke and Wallace 2003; Dolloff and Warren 2003). Wood derived from forested riparian areas also provides general cover for at least 131 southern fishes (22% of total native fauna) (Table 10.1). Wood is used as spawning or nesting cover for at least 42 species (7%) and egg attachment sites by at least 38 species (6%). Water temperature moderation provided by riparian shading is critical for at least 9 species (2%), but riparian shading is also important as cover to many fishes (e.g., Helfman 1981). Wood is documented as a primary feeding site for 11 fish species (2%). In addition at least 74 species (12%) access and use seasonally flooded forest for at least a portion of their life cycle. Many fishes derive multiple benefits from instream wood (Table 10.1).

The taxonomic, geographic, and ecological diversity of the region's fishes provides a template to highlight potential benefits of forest landscape restoration aimed at maintaining fish biodiversity in a variety of biological, ecological, and physical contexts. Clearly, the southern United States faces major challenges in conserving not only native fishes but the entire richly diverse system of streams, rivers, and wetlands in the region (Benz and Collins 1997; Master et al. 1998; Ricciardi and Rasmussen 1999; Veery et al. 2000). I believe forest landscape restoration could be an extremely positive tool in meeting these challenges.

Rehabilitation of warmwater streams is possible with current knowledge but not without major shifts in stream corridor management strategies. Watershed-scale forest restoration needs to emphasize establishing and maintaining viable forested riparian corridors. This could complement instream habitat restoration, which needs to focus on factors such as re-operation of dams to provide environmental flows and restoration of more natural geomorphology (e.g., sinuosity) and hydrology (e.g., levee setbacks for overbank flows, Richter and Thomas 2007) in channelized or dredged rivers. In agricultural and urban areas, emphasis on restoring forests or minimally vegetated buffer zones on riparian corridors should become an increasingly important element of region-wide restoration of fish habitat. Forested riparian corridors also will likely be necessary to maintain water quality and quantity and help mitigate extreme hydrologic events affecting life and property (e.g., high storm flows and flooding, excessive erosion, dewatering, infrastructure damage) (Brown et al. 2005b) in both urban and rural settings. However, implementing forest restoration in these environments is a major challenge given their past and current uses and management, regardless of the potential ecological services it could provide (Naiman et al. 2005). Further, even when established, the long-term challenge will be managing riparian forests sustainably in a landscape composed of highly differing land uses overlain by a highly fragmented matrix of landownership.

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