4.7 Aquatic Resources

4.7.1 Introduction

Resource Issues

- Biodiversity
- Sport fisheries
- Commercial fisheries
- Biological conditions
- Fish spawning

Aquatic resources occurring in the TVA region are important from local, national, and global perspectives. Tennessee has approximately 319 fish species, including native and introduced species, and 129 freshwater mussels (Etnier and Starnes 1993, Parmalee and Bogan 1998). The Tennessee-Cumberland Rivers have the highest number of endemic fish, mussel, and crayfish species in North America (Schilling and Williams 2002). This is the most diverse temperate freshwater ecosystem in the world. In reservoirs, largemouth bass, crappie, and striped bass are highly sought game species. Trout provide popular tailwater fisheries below tributary cold-water discharge dams; sauger, white bass, striped bass, and catfish fisheries occur below tributary and mainstream warm-water discharge dams.

Prior to construction of the TVA reservoir system, aquatic communities were structured by water quality and physical habitat condition, which were driven by physiographic region and climate. Streamflow was proportional to rainfall, and flow regime followed the same trends as the annual rainfall pattern. Flow established physical habitat conditions (depth, velocity) within a stream and maintained stream shape and other habitat conditions (substrate). Relatively infrequent high-flow events (flows that only occur every 1 to 2 years) were responsible for maintaining large-scale habitat patterns such as the number of riffles or pools (Rosgen 1996). High flows clean substrate by flushing out fine sediments, which may suffocate fish eggs or mussels and fill in the spaces between rocks needed by aquatic insects. Because historical flow was proportional to rainfall, over short time intervals, such as days, flow was relatively predictable—meaning that yesterday's flow was likely to be similar to today's flow and from hour to hour there was little change, except during storm events.

Floods were common during spring, and flows decreased throughout the year with the lowest typically occurring August through October, the warmest part of the year. Spring flooding was an important component in the life cycles of some fish species that use flooded overbank areas for spawning or nursery areas. The Tennessee River was shallow, with expansive areas of rocky or gravel shoals—critical features contributing to the great diversity of aquatic life (Etnier and Starnes 1993). Two of the purposes of the TVA system of dams and reservoirs were to provide year-round navigation on the river and control flooding. Achieving these objectives required modifying the river environment described above to which the pre-impoundment aquatic community was adapted (see Chapter 2, The Water Control System). For example, most of the shoal habitat was eliminated by impoundments, and seasonal flow patterns were greatly modified by capturing high spring flows in upstream impoundments and increasing late summer/fall flows with drawdown releases from those reservoirs. Thermal regimes were also changed.

4.7 Aquatic Resources

The purpose of this section is to describe the aquatic communities of the regulated portion of the Tennessee River basin and the habitats in which they exist today. Changes in the way TVA operates its water control system could result in further modifications to the aquatic environment, with consequences to animals that now inhabit it. Three aspects of aquatic resources were identified as key areas of concern for this resource: biotic community quality (status of native fishes, mussels, and aquatic insect communities, including biodiversity), sport fisheries, and commercial fisheries (Table 4.7-01). These aquatic resources were chosen because they represent socially important resources and the broad spectrum of resources occurring in the system, and the potential for their status to change under different policy alternatives can be measured.

The ROS classifications shown in Table 4.1-02 were used to facilitate the assessment of potential impacts on aquatic resources. This classification system groups reservoirs by their mode of operation, physiographic region, and position in the stream network (mainstem or tributary). Tailwaters were grouped by their existing faunal types that related to maximum summer temperatures. Temporal scope was through year 2030. Data sources reviewed to characterize the status of aquatic resources were summarized by waterbody type in Table 4.7-02.

4.7.2 Regulatory Programs and TVA Management Activities

State and federal laws regulate actions that potentially affect aquatic species. These include limiting the harvest of non-rare species (e.g., sport fishing), regulating actions that affect individuals or habitats for rare species designated as threatened or endangered (see Section 4.13, Threatened and Endangered Species), and establishing water quality criteria (see Section 4.4, Water Quality). In addition, protected habitats (e.g., mussel sanctuaries) have been established under the supervision of various state agencies (see Section 4.14, Managed Areas and Ecologically Significant Sites).

TVA has also implemented a variety of programs to improve conditions for aquatic resources. TVA implemented the RRI Program to improve water quality and aquatic habitat in tributary tailwaters by providing minimum flows and increasing DO concentration (see Section 4.4, Water Quality). TVA's commitment to established minimum flows and minimum DO concentrations in tailwaters would not be changed among project alternatives. Another TVA activity attempts to stabilize reservoir levels for a 2-week period when water temperatures reach 65 °F at a depth of 5 feet. Stabilizing reservoir levels aids fish spawning success. This fish spawning operation minimizes water level fluctuations during the peak spawning period to avoid more than a 1-foot-per-week change (either lowering or rising) in pool levels. This program will be adjusted beginning spring 2004 to stabilize levels at 60 °F in order to better include crappie, smallmouth bass, and early largemouth and spotted bass spawning. TVA conducts regular ecological monitoring of reservoirs and tailwater fauna.

Table 4.7-01 Key Issues Identified for Assessment of Potential Impacts on Aquatic Resources in the TVA Reservoir System

Programmatic Issue	Component	Location	Species/Community Aspect
Biodiversity	Resident fish community	Reservoirs and tailwaters	Status of community
	Mussel community	Reservoirs and tailwaters	Status of community
	Resident aquatic insect community	Reservoirs and tailwaters	Status of community
Sport fisheries	Warm-water fisheries	Reservoirs	Largemouth bass, smallmouth bass, spotted bass, white crappie, and black crappie
		Tailwaters	Smallmouth bass
	Cool-water fisheries	Reservoirs	Striped bass, white crappie, sauger, and walleye
	Cold-water fisheries	Reservoirs	Rainbow, brown, and lake trout
		Tailwaters	Rainbow and brown trout
Commercial fisheries	Fishes	Reservoirs	Catfish (channel, blue, flathead), buffalo (smallmouth, bigmouth), freshwater drum, paddlefish, carp, and suckers
	Mussels	Reservoirs	Ebony shell, washboard, threeridge, southern mapleleaf, mapleleaf, and Wabash pigtoe

Table 4.7-02 Data Sources Used to Characterize Existing Conditions of Key Issues

Programmatic Issue	Components	Location	Data Sources Used to Characterize Existing Condition
Biodiversity	Aquatic habitat	Reservoirs	TVA Vital Signs Monitoring Program data: water quality (temperature, DO, and chlorophyll-a), benthic (bottom life) monitoring, Reservoir Fisheries Assemblage Index (RFAI); hydrology data (1991-2000); federal/state, university, or other research studies; TVA Shoreline Aquatic Habitat Index (SAHI)
		Tailwaters	TVA monitoring: fish Index of Biotic Integrity (IBI) and Benthic (bottom life) Index of Biotic Integrity (BIBI) data; federal/state, university, or other research studies
	Fish community	Reservoirs	TVA monitoring: RFAI; federal/state, university, or other research studies
		Tailwaters	TVA monitoring: fish IBI; federal/state, university, or other research studies
	Mussel community	Reservoirs	TVA and federal/state, university, or other research studies; TVA Vital Signs Monitoring Program data (bottom life assessment); consultation with academic researchers
		Tailwaters	TVA and federal/state, university, or other research studies; TVA BIBI; consultation with academic researchers
	Aquatic insect community	Reservoirs	TVA Vital Signs Monitoring Program data: benthic monitoring; federal/state, university, or other research studies
		Tailwaters	TVA monitoring: BIBI; federal/state, university, or other research studies

Table 4.7-02 Data Sources Used to Characterize Existing Conditions of Key Issues (continued)

Programmatic Issue	Components	Location	Data Sources used to Characterize Existing Condition
Sport fisheries	Warm-water fisheries	Reservoirs	TVA Sport Fish Index (SFI) data; federal/state, university, or other research studies; aquatic plant investigations; consultation with academic researchers
		Tailwaters	TVA monitoring: fish IBI; federal/state, university, or other research studies
	Cool-water fisheries	Reservoirs	TVA SFI data; federal/state, university, or other research studies
		Tailwaters	Federal/state, university, or other research studies
	Cold-water fisheries	Reservoirs	TVA SFI data; federal/state, university, or other research studies
		Tailwaters	Federal/state, university, or other research studies
Commercial fisheries	Fishes	Reservoirs	State commercial fisheries reports
	Mussels	Reservoirs	State commercial mussel reports

The Vital Signs Monitoring Program (described in Section 4.4, Water Quality) rates environmental conditions in reservoirs using fish and benthic Indices of Biotic Integrity (IBI) (Dycus and Meinert 1994). TVA also monitors sport fish populations using the Sport Fish Index (SFI), which incorporates the status of population quantity and quality along with available angler catch and use information (Hickman 2000). Within a reservoir, SFI scores monitor positive or negative trends in population status, relative to fishing experience. Beyond the SFI monitoring program, TVA operates certain hydropower operations in a manner that provides important flow levels for spring spawning grounds of certain fishes. For example, below Watts Bar reservoir, prescribed spring flows are provided to enhance sauger spawning.

4.7.3 General Description of Aquatic Resources

Construction of the TVA reservoir system significantly altered both the water quality and physical environment of the Tennessee River (Table 4.7-03), with little regard at the time for aquatic resources (Voigtlander and Poppe 1989). Aquatic resources were generally not a consideration for many types of river projects then because flood control, navigation, and hydroelectric power for economic stimulation were more highly valued.

The primary impact of the reservoir system was to convert free-flowing river habitat into reservoir pools and regulated stream reaches. Virtually all of the mainstem Tennessee River was impounded to maintain navigation channel depth. The dams became obstacles to migratory species. Differences in goals and, consequently, operation of reservoirs became important factors in determining water quality and associated impacts on resident aquatic communities in tributary and mainstem reservoirs and downstream tailwaters (see Section 4.4, Water Quality). Low concentrations of DO in summer and fall virtually eliminated aquatic communities from the pool area in the lowest layer of the reservoir that is characterized by relatively cool water. Before the RRI Program, similar impacts occurred in downstream tailwaters because water was released from the lower layer of the upstream reservoir.

The large differences between summer and winter pool levels of some tributary reservoirs also created environmental hardships for aquatic resources in these reservoirs. Benthic organisms requiring re-colonization each summer cannot survive in bottom areas exposed to drying during winter. This exposure, in association with DO stratification impacts, severely limits benthic communities in many tributary reservoirs. Aquatic communities in and downstream of mainstem reservoirs are also affected by poor water quality conditions, but impacts are less severe. Taking advantage of modified habitat conditions (reservoir pools and dam tailwaters), state agencies introduced numerous sport and some prey fishes, including rainbow trout *(Oncorhynchus mykiss)*, brown trout *(Salmo trutta)*, lake trout *(Salvelinus namaycush)*, cutthroat trout *(Salmo clarki)*, kokanee *(Oncorhynchus nerka)*, striped bass, striped bass hybrids, muskellunge *(Essox masquinongy)*, northern pike *(Esox lucius)*, cisco *(Coreogonus artedii)*, rainbow smelt *(Osmerus mordax)*, alewife *(Alosa pseudoharengus)*, yellow perch *(Perca flavescens)*, and walleye (northern strains) *(Stizostedion vitreum)* (Voigtlander and Poppe 1989). Not all introductions have led to self-sustaining populations, and state agencies continue stocking many popular fishes. Stocking has in itself led to changes to aquatic communities or created new community types in areas they did not exist (e.g., trout in tailwater river reaches).

Table 4.7-03 Potential Impacts of Reservoirs on Aquatic Environment of Regulated Rivers

Location	Environmental Component	Effect	Environmental Impact
Reservoir	Habitat	Conversion of riverine habitat to reservoir pool habitat	Loss of riverine habitat and associated species
		Conversion of floodplain to reservoir pool	Loss of seasonal floodplain habitat and associated species
		River sections become fragmented	Migrations not possible or limited
		Seasonal fluctuations of pool levels	Seasonal drying of habitat reduces abundance and diversity of species
	Temperature	Stratification (layering) of temperature for certain dam types	Stress or mortality of organisms or sensitive life stages
	DO	Seasonal DO depletion in temperature stratified water	Stress or mortality of organisms or sensitive life stages
	Ammonia	Release created by presence of DO-depleted water	Stress or mortality of organisms or sensitive life stages
	Substrate	Trapping of sediment	Disruption of stream transport of sediment
			Captures toxic substances associated with substrate
	Toxic substances	Release created by presence of DO-depleted water	Stress or mortality of organisms or sensitive life stages
	Nutrients	Cultural enrichment of nutrients (eutrophication)	Increases productivity, increases plant and algae growth, changes habitat quality and associated species

Table 4.7-03 Potential Impacts of Reservoirs on Aquatic Environment of Regulated Rivers (continued)

Location	Environmental Component	Effect	Environmental Impact
Tailwater	Temperature: average	Deep-water dam discharges lower water temperature	Loss of warm-water streams, creation of cold- and cool-water streams
	Temperature: pattern	Hydropower peaking operation results in strong daily fluctuations	Stress or mortality or organisms
	Flow alteration: average	Flows are no longer proportional to rainfall	Habitat loss, loss of flow cues for migration
		Generally more low-flow days, less high-flow days	Habitat loss, loss of flow cues for migration
	Flow alteration: frequency	Hydropower peaking operation results in large flow changes daily	Habitat loss, stranding of species, flushing of small-bodied species, bed scour
	Flow alteration: duration	Duration of flow is compressed (more rapid)	Length of events does not match life cycle needs of species
	Flow alteration: timing	Flows no longer match historical pattern	Habitat changes, interference with life cycles of species
		Low flows occur in summer, high releases in fall	Habitat changes, interference with life cycles of species
	Flow: diversion	Some power generation structures divert water from streambed	Habitat loss
	Substrate	Bed scoured in areas closer to dam	Poor substrate habitat leads to lowered diversity and abundances
	DO: average	Deep-water dam discharges are seasonally DO-depleted	Poor water quality causes loss of diversity and lowers species abundance
			DO-depleted waters may allow formation of toxic compounds
	DO: pattern	Seasonal large daily fluctuation caused by hydropower peaking operation	Stress or mortality of organisms or sensitive life stages.
	Nutrients	Nutrient-enriched water	Stimulates growth of algae and plants, changes habitat

Beyond changes in water quality, flood control activities and hydropower generation have purposefully altered the flow regime (the master variable in aquatic systems) to benefit human demands (Cushman 1985). These changes have not been beneficial to many native aquatic resources. Flow is no longer proportional to rainfall, and it fluctuates rapidly and largely over short time periods. High flow in winter and spring is captured to fill reservoir pools. Hydropower peaking operations cause unnatural extremes in daily flow levels, from flood to drought conditions. Generally, only minimal releases occur during summer when not generating power (June and July), with high discharges occurring during periods of naturally low flow (August to October) as reservoir pools are lowered to prepare for capturing winter/spring precipitation. Typically, water quality and physical habitat conditions are worst at the dam and improve with increasing distance downstream. It may take many river miles for changes to reach levels approaching no change. In a system with multiple reservoirs like the Tennessee River, impacts may propagate downstream without returning to natural conditions.

Many riverine species could not adapt to the changes brought about by the switch to reservoir environments and became locally extinct from impounded river sections and tailwaters, especially mussels, minnows, and darters (Garner and McGregor 2001, Voigtlander and Poppe 1989). For a number of species, habitat alterations affected species abundance such that they become rare and are now listed as threatened or endangered species under state or federal law (see Section 4.13, Threatened and Endangered Species). Some riverine species continue to live in remnant river-like habitats (i.e., the flooded river channel and riverine sections with adequate water quality), although their abundances and distributions have been reduced. In contrast, other species that prefer pond conditions have increased their abundances and expanded ranges in the system—primarily shad, sunfishes, and basses. In addition, popular sport fisheries were created in both reservoirs and cold-water tailwaters. Recent improvements by TVA's RRI Program have positively affected tailwater water quality conditions and the status of aquatic communities in affected river reaches (see Section 4.4, Water Quality) (Scott and Yeager 1997). In some areas, state agencies are reintroducing rare native species (Kirk pers. comm.). The specific conditions of the key issue areas in the reservoir system are described below.

4.7.4 Reservoir Biodiversity

Existing Conditions

Reservoir aquatic communities were primarily characterized using the Reservoir Fish Assemblage Index (RFAI) and the reservoir benthic community index of TVA. Both indices are components of the Vital Signs Monitoring Program (see Section 4.4, Water Quality). These methods are described in Appendix D3.

Tributary Reservoirs

Benthic aquatic insect and mussel communities are strongly affected by seasonal thermal stratification and resulting low DO concentration, and by large water level fluctuations

(Table 4.7-04). Aquatic insect communities are low in diversity and comprised of only tolerant taxa. Mussel communities virtually do not exist because of water quality conditions and pool fluctuations. Benthic communities were rated an average of poor in Blue Ridge and Interior Plateau waterbodies and for Ridge and Valley tributary reservoirs. However, these conditions are typical of tributary reservoir projects, and improvements would probably require substantial changes in reservoir operations.

Fish communities of tributary reservoirs generally rate fair or good on the RFAI, depending on sampling location in reservoirs (Table 4.7-05). However, 11 percent of samples scored poor or very poor. Tributary reservoir inflows are monitored in feeder streams just above the confluence with reservoir, using IBI methods.

Table 4.7-05 Summary of Scores for the Reservoir Fish Assemblage Index Samples (1993 to 2001)

Waterbody Type	Zone	Reservoir Fish Assemblage Index Rating					Number of Samples
		Very Poor	Poor	Fair	Good	Excellent	
Mainstem	Inflow	0	4	17	25	4	50
	Transition	0	3	14	22	3	42
	Forebay	0	1	13	33	0	47
	Embayment	0	3	7	12	2	24
Tributary	Transition	0	3	31	35	3	72
	Forebay	0	13	38	26	5	82
	Embayment	0	1	2	1	0	4
Total		**0**	**28**	**122**	**154**	**17**	**321**

Mainstem Reservoirs

Aquatic insect communities generally rated fair for inflow, transition, and forebay zones (Table 4.7-05). Index ratings for forebays of Fort Loudoun, Melton Hill, Watts Bar, and Wilson Reservoirs since the TVA monitoring program began have averaged poor. On average, good scores were obtained for the forebay of Chickamauga, Guntersville, and Nickajack Reservoirs. Six different reservoirs scored good ratings for inflow, transition, or forebay zones. Figure 4.7-01 shows the flow zones used in the reservoir ecological monitoring. Overall, aquatic insect communities were fair.

The status of mussels is considered poor in the mainstem, with the status of individual populations varying by species. Mussel species adapted to pool conditions (including many commercial species) have been doing well, while those adapted to riverine conditions were doing poorly. Previously mentioned water quality impairments and loss of necessary fish hosts (needed to complete the life cycle) have contributed to the decline of mussel populations.

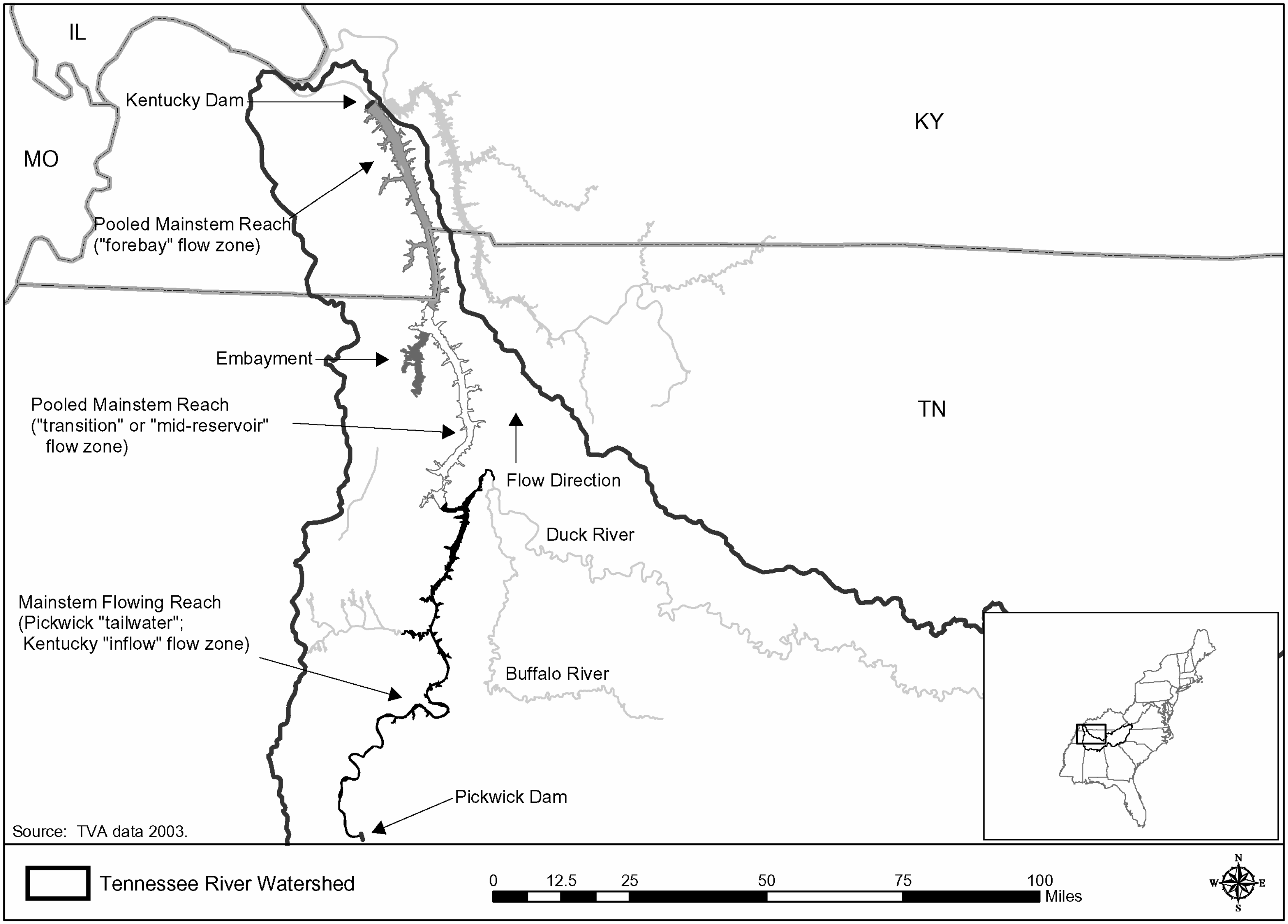
Table 4.7-04 Average Benthic Metric Score for Reservoir Samples Collected (1994 through 2001)

Waterbody Type	Reservoir	Forebay	Forebay Rating	Mid-Reservoir	Mid-Reservoir Rating	Inflow	Inflow Rating
Blue Ridge	Apalachia	19.8	Fair				
	Blue Ridge	24.3	Fair				
	Chatuge	15.6	Poor				
	Fontana	7.5	Poor	15.0	Poor		
	Hiwassee	10.6	Poor	12.3	Poor		
	Nottely	15.4	Poor	25.5	Fair		
	Parksville	9.9	Poor				
	Watauga	8.2	Poor	17.3	Fair		
	Group average	**13.9**	**Poor**	**17.5**	**Fair**		
Ridge and Valley	Boone	14.0	Poor	12.1	Poor		
	Cherokee	20.7	Fair	18.3	Fair		
	Douglas	17.7	Fair	18.3	Fair		
	Fort Patrick Henry	18.1	Fair				
	Norris	20.3	Fair	25.7	Fair		
	South Holston	10.6	Poor	10.6	Poor		
	Group average	**16.9**	**Fair**	**17.0**	**Fair**		

Table 4.7-04 **Average Benthic Metric Score for Reservoir Samples Collected (1994 through 2001) (continued)**

Waterbody Type	Reservoir	Forebay	Forebay Rating	Mid-Reservoir	Mid-Reservoir Rating	Inflow	Inflow Rating
Interior Plateau	Tims Ford	9.0	Poor	8.6	Poor		
	Bear Creek	18.4	Fair				
	Cedar Creek	18.7	Fair				
	Little Bear Creek	15.5	Poor				
	Normandy	13.0	Poor				
	Upper Bear Creek	23.0	Fair				
	Group average	**16.3**	**Poor**				
Mainstem	Chickamauga	27.9	Good	25.1	Fair	25.0	Fair
	Fort Loudoun	12.3	Poor	21.9	Fair	9.3	Poor
	Guntersville	31.0	Good	32.5	Good	24.3	Fair
	Kentucky	23.2	Fair	31.0	Good	23.0	Fair
	Melton Hill	15.4	Poor			9.5	Poor
	Nickajack	30.7	Good	16.0	Poor	31.0	Good
	Pickwick	21.9	Fair	29.8	Good	23.4	Fair
	Watts Bar	13.3	Poor	23.0	Fair	14.3	Poor
	Wheeler	18.3	Fair	23.1	Fair	24.7	Fair
	Wilson	15.5	Poor			27.8	Good
	Group average	**21.0**	**Fair**	**25.3**	**Fair**	**21.2**	**Fair**

Note: Blank entries reflect that some reservoirs do not have all possible pool zones. The number of macroinvertebrate samples per reservoir varied but not usually less than five samples per year. Rating categories represent a tri-section of the total range of possible scores.



Source: TVA data 2003.

Figure 4.7-01 Diagram of Flow Zones Used in TVA Reservoir Ecological Monitoring

Fish communities of mainstem reservoirs generally rated good or fair based on attained RFAI scores. In general, more than one-half of all samples scored good or excellent for inflow, transition, forebay, and embayment areas. There were roughly an equal number of both poor (7 percent of samples) and excellent (5 percent of samples) scores.

Future Trends

Biodiversity of tributary reservoirs is not anticipated to change because of strong seasonal stratification and operational differences between summer and winter pool levels. Mussel communities would remain relatively nonexistent in tributary reservoirs. In mainstem reservoirs, degraded biodiversity may occur during dry years when stratification of the reservoirs becomes more severe. Under current operations, the biodiversity of benthic invertebrate and fish communities is not expected to change. However, the biodiversity of mussel communities in mainstem reservoirs is anticipated to continue the long-term trend of decline in abundance and diversity.

4.7.5 Tailwater Biodiversity

Existing Conditions

Tributary tailwater biodiversity improved for both fish and aquatic insect communities after the RRI Program. Prior to implementation, most tailwaters scored poor or very poor for fish and insect communities. With maintenance of established minimum flows and DO levels, more fair and good ratings were obtained (Tables 4.7-06 and 4.7-07). Poor ratings after implementation were generally at sites closest to dams with factors other than minimum flow or DO concentrations affecting aquatic communities, such as large flow fluctuations due to hydropower generation. Recovery was most pronounced in warm tailwaters.

Cold-Water Tailwaters

Downstream from dams with cold-water discharges, conditions for native fish communities were always rated poor. State fisheries agencies took advantage of the unnatural conditions and created cold-water fisheries by introducing cold-water-tolerant sport fish such as rainbow and brown trout (see Section 4.7.8). For benthic invertebrates, conditions varied by dam tailwater and by distance from the dam, but generally status was improved at least to fair after implementation of the RRI Program. Mussel communities in these areas were also poor or non-existent. Native mussels were adapted to the natural warm-water conditions and could not maintain diverse populations.

In the cool-to-warm tailwaters, fish communities close to dams were rated poor. Fish community ratings were mostly good or fair farther downstream from these dams since 1997, which indicates improvement in flow and DO concentration of tailwaters. The status of benthic invertebrates in recent years was fair for all sites in cool-water tailwaters. The status of mussel communities is rated poor in cool-to-warm tailwaters.

Table 4.7-06 Number of Sites in Each Scoring Category in Tailwaters Using the Fish Index of Biotic Integrity

Reservoir Release Improvement Program Phase	Year	Index of Biotic Integrity Rating					
		Samples	Very Poor	Poor	Fair	Good	Excellent
Pre-Program	1987	1		1			
	1988	3	1	2			
	1989	3	1	2			
	1990	3	1	1		1	
	1991	3		2	1		
	1992	2		2			
	Total	**15**	**3**	**10**	**1**	**1**	**0**
Transition: Implementation of Reservoir Release Improvement Program	1993	8		5	3		
	1994	5		2	1	1	1
	1995	7	2	4	1		
	1996	6		5	1		
	Total	**26**	**2**	**16**	**6**	**1**	**1**
Post-Reservoir Release Improvement Program	1997	13		8	5		
	1998	7	1	4	2		
	1999	9	1	2	5	1	
	2000	9		3	3	3	
	2001	6		2	3	1	
	2002	14		6	3	5	
	Total	**58**	**2**	**25**	**21**	**10**	**0**

Note: Samples classified at the edge of two categories were assigned to the lower category.

Table 4.7-07 Number of Sites in Each Scoring Category of the Tailwater Benthic Index Samples

Reservoir Release Improvement Program Phase	Year	Index of Biotic Integrity Rating					
		Samples	Very Poor	Poor	Fair	Good	Excellent
Pre-Program	1987	0					
	1988	3	1	2			
	1989	3	1	2			
	1990	3	1	1		1	
	1991	3		2	1		
	1992	2		2			
	Total	**14**	**3**	**9**	**1**	**1**	**0**
Transition: Implementation of Reservoir Release Improvement Program	1993	10	1	6	3		
	1994	7		4	1	1	1
	1995	7	2	4	1		
	1996	8		7	1		
	Total	**32**	**3**	**21**	**6**	**1**	**1**
Post-Reservoir Release Improvement Program	1997	14		7	7		
	1998	8	1	5	2		
	1999	8	1	2	5		
	2000	9		3	3	3	
	2001	6		2	3	1	
	2002	15	1	6	3	5	
	Total	**60**	**3**	**25**	**23**	**9**	**0**

Note: Samples classified at the edge of two categories were assigned to the lower category.

Tributary Warm-Water Tailwaters

Both before and after tailwater improvements, sites close to dams were generally poor, with sites farther from dams being fair or good, and sites furthest downstream rated good. The distances downstream from the dam where fish communities rated poor decreased considerably after implementation of the RRI Program. The best surviving mussel communities below tributary dams occur in warm-water tailwaters.

Flowing Mainstem Reaches

For this discussion, the flowing mainstem reaches below dams were considered as tailwaters. Fish and benthic communities in these reaches were good and fair, respectively (Tables 4.7-06 and 4.7-07). This was to be expected as riverine conditions provide a variety of habitat for fish not available in the main body of the reservoir. Lower water quality has limited the less mobile invertebrate community. Mainstem tailwaters were areas of highest mussel diversity in the regulated TVA system. Riverine mussel species reach greater abundance and diversity in flowing mainstem reaches, but their status remains only fair due to overall low diversity, low abundances, and low reproductive success for some species. Pool-adapted mussels still occur but with lower abundance than in pooled mainstem areas. Because of the complexity of mussel life cycles, the status of flowing mainstem mussel communities was driven by a complex set of environmental changes imposed by reservoir operations. These include flow peaking, habitat alteration, and shifts in fish communities that also were added to prior impacts of overharvesting prior to dam construction (Anthony and Downing 2001).

Future Trends

Given the status of fish, benthic invertebrates, and mussel communities, overall conditions in tailwaters were generally fair, and in some places good. Fish and benthic invertebrate communities rated good to fair, and the status of mussel communities was fair to poor. The anticipated trend for mussels was continued change in the composition of mussel communities (higher numbers of tolerant species with a reduction of riverine specialist species). Recent improvements in aquatic biodiversity and abundance in several tributary tailwaters achieved by the RRI Program and reintroductions of both fish and mussel species in some tailwaters suggested that these trends were continuing to improve in the modified habitats.

4.7.6 Commercial Fishing Operations

Existing Conditions

Jobs are provided directly by commercial fisheries for mussels, fish, and turtles, and indirectly through many services related to recreational or commercial activities. Commercial fishing operations consist of one or more commercially licensed fishers (or helpers) using a small boat to set and retrieve various permitted traps or nets. Gill nets, trotlines, slat baskets, trammel nets, and hoop nets have been common gear types (TWRA 1993) used to harvest the commercial fish species listed in Table 4.7-01. Few commercial fishers worked full time, and some portion of fishers did not work for one or more yearly quarters (TWRA 1993). License sales varied from nearly 1,250 commercial licenses issued in 1990 (TWRA 1993) to 435 licenses in 2000, not including helpers (TWRA 2002). In Tennessee, portions of 14 reservoirs and 14 major rivers were open to commercial fishing. Permitted reservoirs included Barkley (15,900 acres), Cherokee (30,200 acres), Chickamauga (34,500 acres), Douglas (30,400 acres), Fort Loudoun (14,600 acres), Guntersville (2,170 acres), Kentucky (108,040 acres), Nickajack (10,800 acres), and Pickwick (6,160 acres).

Based on recent harvest data, the populations of commercial fish populations were good. The estimated commercial fish harvest in 2000 was 8,021,129 pounds (24.1 pounds per acre). Catfishes comprised a majority of catch followed by buffalo, fresh-water drum, carp, paddlefish, yellow bass, gar, suckers, and other fishes (TWRA 2003a). Kentucky Reservoir produced 41 percent of the 2000 harvest; Douglas Reservoir, 20 percent; Fort Loudoun, 16 percent; and Barkley Reservoir (located on the Cumberland River) contributed 6 percent to the total harvest. The composition of harvest and location of commercial fishing activity throughout the 1990s was similar to data for 2000.

Future Trends

Based on recent harvest data, the populations of commercial fish were healthy. Status of species important to commercial fishing operations is not expected to change through 2030; populations would primarily respond to interannual climatic variation that drives mainstem reservoir stratification. Under the Base Case, fisheries potentially could experience declines only following dry years when mainstem stratification would be more likely to occur. Wet years that create more mainstem flow would produce better conditions for commercial fish populations.

4.7.7 Commercial Mussel Operations

Existing Conditions

Commercial mussels are harvested by a few individuals working as a team and using permitted gear types to catch targeted species. Commercial harvest of mussels has been permitted by Tennessee, Kentucky, and Alabama in the Tennessee and Cumberland Rivers. Combined size of harvest reported in Alabama was small relative to harvest in Tennessee. No commercial harvest was permitted by Virginia, North Carolina, or Mississippi. Because most harvest occurs in Tennessee, this assessment focused on its waters as representative.

Since 1988, harvest pressure was variable and showed dramatic changes (Hubbs 2002). Harvest decreased in 1996 due to market influences on demand and has remained low (below 2,000 tons). Mussel harvest (total harvest weight) in Tennessee declined in 2002, ending an upward 3-year trend. The only quality commercial shell stocks were located in Kentucky Reservoir, as evidenced by the annual harvest from Kentucky Reservoir representing over 98 percent of total weight for the industry (Hubbs 2003).

Future Trends

Commercial mussel stocks primarily occur in mainstem reservoirs, and harvest of commercial species is driven by market influences—not environmental conditions. The abundance of commercial species also is determined more by harvest pressure than environmental conditions. These trends are not expected to change through 2030 under the existing harvest regulations and reservoir operations policy.

4.7.8 Sport Fisheries

Existing Conditions

Sport fish populations in tributary reservoirs experience highly variable recruitment related to complex habitat and species interactions. Changes in the reservoir operations policy could affect pool levels and water quality, two habitat-related issues that could potentially influence recruitment success. Factors controlling recruitment vary by species.

Wilson, Douglas, Great Falls, Watts Bar, Wheeler, Guntersville, and Cherokee Reservoirs all averaged high Sport Fishing Index (SFI) scores for largemouth bass (Table 4.7-08). Smallmouth bass populations averaged higher SFI scores in mainstem reservoirs and in Ridge and Valley tributary reservoirs. However, the best smallmouth bass reservoirs were spread out across waterbody categories and included Watauga, Boone, South Holston, Wilson, Fort Patrick Henry, Wheeler, Pickwick, and Fontana Reservoirs.

Striped bass populations, an introduced non-native sport species, were maintained by stocking in selected mainstem and tributary reservoirs. Stocking success was a major factor influencing striped bass populations. Populations were limited by habitat availability due to stratification during late summer as they seek cool water with higher DO concentration (Crance 1984). Reservoir stratification forced striped bass into physiologically stressful habitat, which may result in mortality—especially under severe low flow conditions (Schaffler et al. 2002). Stratification mostly depended on annual rainfall under the present operations policy; therefore, population status presently depended on climatic variation and impacts of fishing (harvest) on the population. Average SFI scores for striped bass were highest in Cherokee, Nottely, Boone, Watts Barr, and Tims Ford Reservoirs, respectively (Table 4.7-08). Tributary reservoirs averaged higher scores than mainstem reservoirs, which was not unexpected since tributary reservoirs typically have cooler summer water temperatures due to their deeper pools.

Although walleye were present prior to reservoir construction, walleye populations in some tributary reservoirs have been maintained by stocking. Introduction of alewife in several TVA reservoirs degraded natural reproduction of walleye (O'Bara et al. 1999). Walleye year-class strength was highly variable prior to annual stocking efforts in recent years. Like striped bass, walleye in reservoirs were mostly limited by late summer habitat quality, which varied depending on climatic variation. High walleye SFI scores were attained at Fontana, Watauga, and Hiwassee Reservoirs—all in the Blue Ridge ecoregion (Table 4.7-08).

Table 4.7-08 Average Reservoir Scores for Sport Fishing Index Based on Samples from 1997 to 2000

Waterbody Type	Reservoir	Largemouth Bass	Smallmouth Bass	Crappie	Striped Bass	Walleye	Sauger
Mainstem	Chickamauga	34.5	21.5	31.0	27.5	20.0	33.5
	Fort Loudoun	35.5	32.3		30.0	20.0	38.5
	Guntersville	36.3	27.5		20.0	25.0	37.7
	Kentucky	33.8	30.8	48.5	20.0	20.0	40.0
	Melton Hill	31.0	20.5		22.0	20.0	15.0
	Nickajack	37.0	20.0		20.0		19.0
	Pickwick	32.3	39.8	21.0	20.0		42.0
	Tellico	29.5	27.5	35.0	32.0	30.0	20.0
	Watts Bar	37.5	30.3	36.8	32.8		31.5
	Wheeler	36.5	42.0		20.0		28.0
	Wilson	42.0	44.7				20.0
Average		**35.1**	**30.6**	**34.5**	**24.4**	**22.5**	**29.6**
Blue Ridge	Apalachia	20.0	20.0			20.0	
	Blue Ridge	20.0	30.0			27.0	
	Chatuge	25.5	20.0			23.5	
	Fontana	33.0	39.0			47.0	
	Hiwassee	28.0	25.0			34.0	
	Nottely	25.5	21.5		39.0	25.3	
	Parksville	25.0					
	Watauga	33.5	46.5	21.7		40.3	
Average		**26.3**	**28.9**	**21.7**	**29.5**	**31.0**	

Table 4.7-08 Average Reservoir Scores for Sport Fishing Index Based on Samples from 1997 to 2000 (continued)

Waterbody Type	Reservoir	Largemouth Bass	Smallmouth Bass	Crappie	Striped Bass	Walleye	Sauger
Ridge and Valley	Boone	30.0	46.0		37.0	20.0	20.0
	Cherokee	35.8	26.0	37.5	49.3	29.6	24.0
	Douglas	40.8	25.0	38.0		20.7	27.3
	Fort Patrick Henry	26.0	42.0		20.0		
	Norris	26.0	29.3	28.5	26.3	26.8	20.8
	South Holston	33.0	45.8	21.8	10.0	28.5	20.0
Average		**31.9**	**35.7**	**31.5**	**28.5**	**25.1**	**22.4**
Interior Plateau	Bear Creek	28.0					
	Cedar Creek	20.0					
	Great Falls	38.0					
	Little Bear	20.0	20.0				
	Normandy	32.8	22.5	28.7		23.0	22.5
	Tims Ford	25.7	24.8	22.0	28.0	25.3	20.0
	Upper Bear						
Average		**27.4**	**22.4**	**25.4**	**28.0**	**24.2**	**21.3**
All	**Average**	**30.7**	**30.4**	**30.9**	**26.3**	**26.3**	**23.0**

Note: Higher numbers represent relatively better sport fishing.

Mainstem reservoirs were most important to sauger populations. Important spawning sites were located on historical shoal areas downstream of mainstem dams. Recruitment was highly variable for these populations and largely depended on flow conditions in tailwaters during March and April (Hickman and Buchanan 1996) and habitat quality in late summer (flow and water quality). Most importantly, sauger abundance was strongly correlated to increased tailwater discharge during March and April. During low-flow conditions, sauger experience potentially limiting late-summer habitat conditions. High rating reservoirs on the SFI system include Pickwick, Kentucky, Fort Loudoun, Guntersville, and Chickamauga (Table 4.7-08).

Excellent trout fisheries have been created in several cool- and cold-water tailwaters through stocking programs (Bettinger and Bettoli 2002). Programs were put-and-take or put-grow-and-take fisheries, mostly for brown trout and rainbow trout. In 2001, the TWRA stocked 1.3 million fingerlings in 13 tailwaters (TWRA 2003b). The major concern for trout fisheries was summer/fall water quality (temperature and DO). Since institution of minimum flow and minimum DO levels under the RRI Program, river conditions have improved and trout populations have positively responded (Bettinger and Bettoli 2000). Hence, DO should be a minimal concern for tailwater fisheries, although incidental increases in DO levels above present minimums due to ROS alternatives may benefit trout fisheries, as trout in natural cold-water streams prefer relatively higher DO levels (Raleigh et al. 1986). Water temperatures in some tailwaters presently exceed temperature ranges beneficial for growth or survival during summer (Bettoli 2000, Luisi and Bettoli 2001), but other factors were also contributing to poor trout conditions at these sites. In the Hiwassee River, low productivity of the system, stocking mortality from transfer, over-stocking, and physical habitat conditions were also identified as contributing to poor growth and survival (Luisi and Bettoli 2001). In contrast, environmental conditions in a minimum of three cold-water tailwater fisheries were sufficient to support high growth rates or high biomass (TWRA 2002). Improvements in summer water temperature (decreases in temperature) would benefit cold-water tailwater fisheries; conversely, actions leading to increases in water temperature could adversely affect trout populations.

Factors Affecting Fish Spawning Success

Adult crappie may positively respond to conditions similar to natural flooding in unaltered river environments (i.e., nutrient levels increased) that would provide beneficial habitat to juvenile fish in reservoirs (Maceina 2003). High late winter/early spring flow also provides good spawning and juvenile fish habitat in reservoirs. However, Maceina (2003) also showed that decreased recruitment may result from high reservoir inflows that are not retained (probably from increased turbidity, which reduces food availability and feeding efficiency) and may physically remove young fish from reservoirs. Maceina and Stimpert (1998) found that higher water levels due to wet winters before crappie spawning (at water temperatures ranging from 16 to 20 °C) resulted in strong crappie year-classes in Alabama reservoirs, but only when followed by a post-winter reservoir retention time of 11 days or longer.

Sammons et al. (2002) reported crappie year-class strength varied significantly with reservoir hydrology, and their status in tributary reservoirs has been poor in recent years. Spring hydrology, specifically high flow and low retention time during pre-spawn periods (January to

March), has been identified as strongly correlated with recruitment of crappie in tributary reservoirs. Allen and Miranda (1998) reported that climatic conditions influencing annual flow regime appear to be the driving factor of crappie abundance in tributary reservoirs, with recruitment varying in boom or bust cycles—wet years as booms and dry years as busts. Sammons et al. (2002) suggested that rarely will strong crappie populations simultaneously occur over a wide geographic area or single watershed. In mainstem reservoirs, late summer water quality and change in aquatic plant abundance influenced abundance more than hydrology (Buchanan and McDonough 1990). Crappie received their highest average SFI scores in Kentucky, Watts Bar, Douglas, and Cherokee Reservoirs (Table 4.7-08).

Black bass can also benefit from high water levels during and after the spawning season. When water levels are high, more of the floodplain is made accessible—thereby providing expanded spawning and nursery habitat, providing more foraging opportunities, and reducing mortality due to predation (Raibley et al. 1997, Sammons et al. 1999, Yeager et al. 1992). Aggus and Elliott (1975) determined that the relationship between the duration of flooded terrestrial vegetation and the survival of largemouth young during the first summer is highly correlated. They suggested that the inundated vegetation provides essential protective cover that can significantly reduce mortality due to predation. During a year of stable water levels with no flooding on Bull Shoals Lake in Arkansas and Missouri, only 38 largemouth were collected per acre in cove samples. During a wet year in which 20,000 acres of vegetation were flooded for most of the summer, 1,789 largemouth per acre were collected. Increased survival as a result of high summer water levels has been shown in a variety of other studies (Bross 1967, Jackson 1957, von Geldern 1971, Keith 1975). Gutreuter and Anderson (1985), Olson (1996), Pine et al. (2000), and Sammons et al. (1999) found that early-hatched fish generally make an earlier change in diet to fish and grow faster than late-hatched fish, in effect ensuring their recruitment into the population. Heidinger (1975) suggested that these faster-growing bass are likely to reach sexual maturity sooner. Sammons and Bettoli (2000) reported that black bass survival appeared limited by the length of the summer growing season and suitable refuge habitat for young fishes. Water quality also affected black bass survival, especially smallmouth and spotted bass.

The rate at which reservoirs are raised and lowered can also affect fish survival. Rapidly falling water during the spawning season may force bass to abandon their nests or cause fish that have hatched successfully to be carried away from the nest (Kohler et al. 1993, Raibley et al. 1997). The wave action of receding water also deposits sand and silt in the nests, and can even completely remove the eggs from the nest (Summerfelt 1975). Rapidly rising water over nests causes the water temperature on the nest to drop, resulting in reduced protective behavior, increased predation, and nest abandonment (Mitchell 1982). However, Maceina and Bettoli (1998) found that water level fluctuations during April-May in four TVA mainstem reservoirs while largemouth were spawning were not related to subsequent recruitment.

Some researchers (Aggus and Colvin pers. comms.) stress that water levels in themselves are not the key to enhancing development of good numbers of fish that ultimately reach catchable sizes. Increased nutrient inflow caused by flood flows in the late winter/early spring is of high importance as these floods provide productivity increases necessary for good food production, starting with microscopic animals. Simply raising water levels without nutrient increases, such as would occur if water levels are kept artificially high during dry winter/early spring periods, would not provide the necessary productivity boost to support large numbers of juvenile fish. Keith (1975) indicated that flooding of terrestrial vegetation on the shoreline increases the water's productivity by initiating the decomposition of the vegetation and release of nutrients. If water levels are kept high late into the year in storage reservoirs, the amount of vegetation capable of establishing in the ultimately exposed shoreline area is greatly reduced. Drawing water levels down in the late summer is necessary for terrestrial vegetation to re-establish on shoreline areas (Yeager et al. 1992). Without a sufficient period of regrowth, the vegetation would not be present the following spring to benefit coming year-classes and would likely result in increased shoreline erosion problems.

Future Trends

Reservoir hydrology (stratification and spring flow rates) is a complex driving factor in determining recruitment of sport fishes. Wet late winter/early spring periods produce a higher abundance of juvenile fish, and their survival increases when the shallow zone incorporates various forms of cover during summer. Lower recruitment rates of a number of littoral or shoreline zone spawners are expected in dry years when little suitable habitat is flooded during and after the spawning period. However, dry years that increase aquatic plant production in warm-water tailwaters and mainstem reservoirs would benefit warm-water sport fish populations, except when mainstem reservoirs stratify such that poor water quality (low DO) degrades conditions. Dry years, depending on individual reservoir operations, could also reduce preferred habitat for cool-water species in large tributary reservoirs—as increased stratification can cause summer/fall water quality problems. During dry spring periods, less water would be discharged from mainstem reservoirs, which could decrease migratory spawning recruitment. Warm tailwaters would benefit from reduced peaking flows during dry years, as more stable flow would be provided. Cold-water tailwaters would be degraded during dry years due to higher water temperatures during summer and fall. In tailwaters, minimum flows and DO concentrations provided through the RRI Program would continue to prevent poor water quality in dam releases such that sport fisheries would have available habitat. In general, sport fish would show variable responses to inter-annual variation in rainfall, depending on species water temperature preference (cold or warm) and habitat type (reservoir or tailwater). These trends are not expected to change under the existing reservoir operations policy.