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SUMMARY OF PRE-OPERATIONAL MONITORING OF THE MUSSEL FAUNA IN THE UPPER CHICKAMAUGA RESERVOIR (TENNESSEE RIVER) IN THE VICINITY OF TVA'S WATTS BAR NUCLEAR PLANT, 1983-1993

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ABSTRACT – The populations of three freshwater mussel beds were sampled to provide information on the occurrence, relative abundance, distribution and condition of mussels in the upper Chickamauga Reservoir near Watts Bar Nuclear plant. Historically, 64 mussel species were documented in the study area before the river was substantially affected by human activities. The present fauna consists of only 30 species (13,455 specimens) including four federally listed species (*Dromus dromas, Cyprogenia stegaria, Lampsilis abrupta* and *Pleurobema plenum*). Shell-length measurement data for 6,067 specimens (30 species) shows that only larger size-classes of mussels remain. Thin-sectioning of mussel valves confirmed relatively old ages (33-49 years) for five common species. Eighty-four quadrat excavations (0.25 meter square) and sieving of river substrate produced evidence of recent reproduction for only one species (*Anodonta imbecillis*). Available evidence indicates that the mussel fauna in upper Chickamauga Reservoir is old, largely nonreproducing, and remnant from pre- and post-impoundment of the river.

Key words: Tennessee River, Unionidae, monitoring.

INTRODUCTION

Freshwater mussel populations at three mussel beds in upper Chickamauga Reservoir were sampled twice each year from 1983-1985 as part of pre-operational monitoring for Watts Bar Nuclear Plant (WBN) (TVA, 1986). This study provided baseline information on the occurrence, relative abundance, distribution and condition of mussels in this reach of the Tennessee River.

From 1986-1992, following delays in completion of WBN, pre-operational monitoring of the three mussel beds was reduced to biennial sampling to monitor changes or trends in mussel populations prior to operation of WBN (Ahlstedt, 1989, 1991). These efforts have re-vealed no statistically significant variation in the mussel communities of upper Chickamauga Reservoir. To supplement monitoring activities, two additional studies were conducted in 1993 to document the apparent lack of recruitment (reproduction) on all three mussel beds and determine the age structure

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of five mussel species common to these beds.

The pre-impoundment richness of the mussel fauna was documented by Ortmann (1918) who recognized 88 mussel species occurring in the Tennessee River upstream from Chattanooga. At least 64 species probably occurred near the Watts Bar Nuclear Plant site before the river was affected by substantial human impacts. Excavations of aboriginal shell mounds located along the banks of the river in this area attest to the extreme diversity and abundance of mussels that existed before impoundment of the river (Parmalee et *al.*, 1982). Quantitative data from excavated material indicate that the five most abundant species (*Dromus dromas, Elliptio dilatata, Actinonaias ligamentina, Elliptio crassidens* and *Pleurobema plenum*) comprised approximately 66% of the mussel community. With the exception of *E. crassidens,* these species are presently rare in the Tennessee River. Post-impoundment studies of the mussel fauna in upper Chickamauga Reservoir are largely limited to those conducted by Scruggs (1960), Isom (1969), Bates (1975), Pardue (1981) and TVA (1979) before 1978. Although sampling methods and area covered differed from present monitoring studies, it remains clear that the mussel fauna has declined by 50% from what was reported historically.

SITE DESCRIPTION

The reach of the Tennessee River included in this study meanders southwest from near Spring City towards Chattanooga, Tennessee. Two dams constructed and operated in this reach of the river by the Tennessee Valley Authority (TVA) for hydroelectric power, flood control and navigation have substantially altered the diverse and abundant freshwater mussel fauna reported historically from the river. Chickamauga Dam, located on the Tennessee River at mile 471, closed for filling in 1940 and impounds 58.9 miles of the river upstream to the base of Watts Bar Dam. Watts Bar Dam, located just upstream of our study reach at mile 529.9, closed in 1942.

The most upstream of the three mussel beds sampled (TRM 528-529L) is located on the opposite side of the river (left descending bank) and upstream from WBN (Fig. 1). The middle bed (TRMs 526-527R) is on the same side of the river as WBN (right descending bank), just downstream from the mouth of Yellow Creek and the WBN diffuser. The lowermost bed (TRMs 520-521L) is located six river miles downstream from WBN on the left descending side of the river. All three mussel beds were sampled near the overbank along the inside edge of the navigation channel. Substrates generally consisted of gravel, cobble, sand and relic shells of the Asian clam, *Corbicula fluminea.*

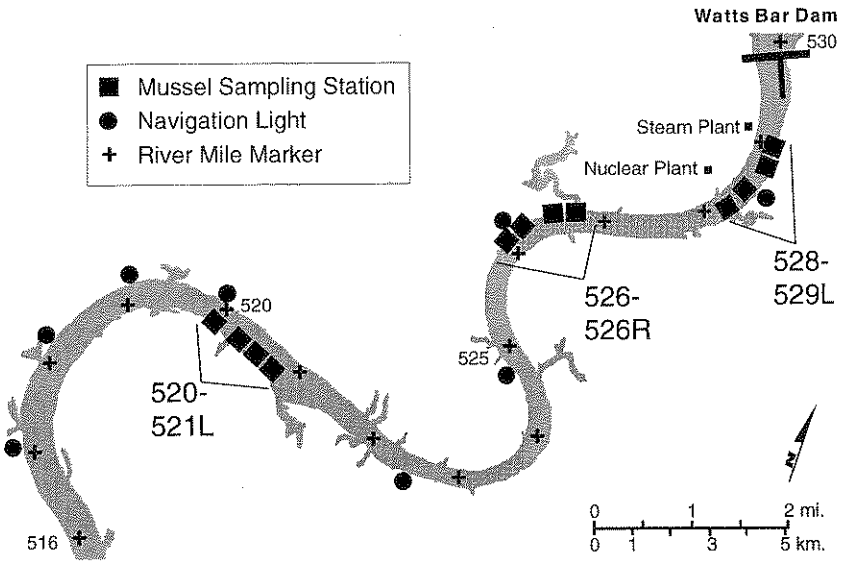

FIG. 1. Tennessee River downstream from Watts Bar Dam showing the locations of the three mussel sampling stations.

METHODS

Between 1983 and 1992, all live mussels were collected by four divers using scuba or surface-supplied air (hooka) during 11-minutes of bottom time at each sample location. Four sites were sampled in each of the three mussel beds for a total of 12 timed dives. Each sampling site was located using river mile markers, navigation buoys and bankside landmarks. Mussel specimens (excluding *Corbicula fluminea*) found were placed in mesh bags and brought to the dive boat at the end of each timed dive. All mussels were sorted, counted and identified to species. At each sampling site, up to 50 specimens of each species were measured (length, height and thickness) in millimeters using a dial caliper. All specimens were returned to the substrate in the collection vicinity. In 1993, at each sample location, a 0.25 square-meter quadrat sampler was used to determine the extent of recent successful mussel reproduction (Ahlstedt, 1991). The quadrat sampler was randomly placed on top of the substrate by divers and excavated by hand using a small garden shovel. All substrate within the sampling frame was removed to a depth of approximately 100-150 mm and placed in 5-gallon buckets. The buckets were attached to a cable and lifted by electric winch to a surface boat for processing.

Processing involved dumping the contents of the bucket into a series of three, stacked, rectangular box sieves (25, 13, 6 mm mesh sizes) mounted on a stand along the side of the boat. Contents were rinsed with river water using a battery operated pump. All size-classes of mussels were hand picked from the sieve screens. Live mussels were identified to species, counted and measured. A representative sample of the five most abundant species were collected for age determinations from each of the 12 sites. In previous studies, mussels have not been aged because of shell erosion and extremely close annulus formation near the ventral margin of the shell. Specimens were sacrificed and taken to TVA's Aquatic Biology Laboratory in Norris, Tennessee, for thin-sectioning of shell valves.

Thin-sectioning of valves involved the use of an Isomet low-speed saw and diamond wafering blade. Procedures used for thin-sectioning generally followed those used by Clark (1974), and Neves & Moyer (1988). The initial saw-blade cut was positioned anterior to the umbone so that it would pass cross-sectionally through the chondrophore, posterior to the ventral margin of the shell. The thickness of the valve cross-sections was 280 µm. Shell thin-sections were immersed in glycerine which helped to delineate or magnify growth lines. Specimens were then aged using 4X magnification.

RESULTS AND DISCUSSION

Twenty-two mussel species were reported during the 1990 mussel survey and only 16 species were found in 1992 (Table 1). This represents a loss of seven species of which six were reported as single specimens in 1990. One species was collected in 1992 that was not collected in 1990. All

TABLE 1. Total numbers and percent composition of mussel species at three sites (TRMs 520-521L, TRMs 526-527R, and TRMs 528-529L) in upper Chickamauga Reservoir in the vicinity of Watts Bar Nuclear Plant, 1990 and 1992.

Species	1990	(percent)	1992	(percent)
Actinonaias ligamentina	5		1	
Amblema plicata	10		13	
Anodonta grandis	20		5	
Anodonta imbecillis	1		0	
Anodonta suborbiculata	1		0	
Cyclonaias tuberculata	90	(9)	68	(10)
Ellipsaria lineolata	28		14	
Elliptio crassidens	524	(53)	424	(60)
Elliptio dilatata	1		0	
Lampsilis abrupta E	4		6	
Lampsilis ovata	1		0	
Leptodea fragilis	8		0	
Ligumia recta	2		3	
Megalonaias nervosa	3		4	
Obliquaria reflexa	11		6	
Plethobasus cyphyus	0		1	
Pleurobema cordatum	139	(14)	82	(12)
Pleurobema oviforme C	1		0	
Potamilus alatus	45		16	
Ptychobranchus fasciolaris	1		0	
Quadrula metanevra	8		8	
Quadrula pustulosa	79	(8)	48	(7)
Tritogonia verrucosa	9		9	
Total Specimens	991		708	
Total Species	22		16	

C - Cumberlandian Species
E - Endangered Species

TABLE 2. Relative abundance or presence of freshwater mussel species found in the vicinity of Watts Bar Nuclear Plant (generally Tennessee River Miles 470-529) during various surveys. Substantial variations exist in the methods employed, areas of coverage and amount of collection effort expended in these collections. Numbers in the table indicate the percentage composition of each species encountered in surveys which included quantitative results. Symbols: C–Cumberlandian Species; E–Endangered Species; T–Trace (less than 0.01 percent); X–Present but not counted.

Species	AD 1-1600	1850-1918	1956-1957	1965	1972-1974	1975-1977	1978	1983-1992
Actinonaias ligamentina	7.49	X	0.1	–	–	0.17	–	0.26
Actinonaias pectorosa C	–	X	–	–	–	–	–	–
Alasmidonta marginata	–	X	–	–	–	–	–	–
Amblema plicata	0.33	X	X	–	X	2.04	0.93	1.80
Anodonta grandis	–	–	–	X	–	–	0.21	0.87
Anodonta imbecillis	–	–	–	–	–	–	–	0.04
Anodonta suborbiculata	–	–	–	X	–	–	–	0.01
Cumberlandia monodonta	–	X	–	–	–	–	–	–
Cyclonaias tuberculata	3.19	X	2.0	12.71	–	10.22	6.84	5.95
Cyprogenia stegaria E	0.20	X	–	–	–	–	0.06	0.04
Dromus dromas CE	35.25	X	–	–	–	–	0.06	0.01
Ellipsaria lineolata	–	X	0.2	–	–	4.77	2.41	1.78
Elliptio crassidens	6.11	X	12.9	18.78	X	42.08	63.04	62.71
Elliptio dilatatus	11.36	X	1.1	6.08	–	0.34	0.21	0.13
Epioblasma arcaeformis C	1.37	X	–	–	–	–	–	–
Epioblasma capsaeformis C	0.27	X	–	–	–	–	–	–
Epioblasma flexuosa	0.09	–	–	–	–	–	–	–
Epioblasma florentina C	0.05	–	–	–	–	–	–	–
Epioblasma haysiana C	0.37	X	–	–	–	–	–	–
Epioblasma interrupta C	0.03	X	–	–	–	–	–	–
Epioblasma lenior C	–	X	–	–	–	–	–	–
Epioblasma lewisi	–	X	–	–	–	–	–	–
Epioblasma obliquata E	T	–	–	–	–	–	–	–
Epioblasma propinqua	2.70	X	–	–	–	–	–	–
Epioblasma stewardsoni C	0.44	X	–	–	–	–	–	–

TABLE 2. (cont.)

Species	AD 1-1600	1850-1918	1956-1957	1965	1972-1974	1975-1977	1978	1983-1992
Epioblasma torulosa/propinqua	0.11	–	–	–	–	–	–	–
Epioblasma triquetra	0.02	X	–	–	–	–	–	–
Epioblasma turgidula CE	0.06	–	–	–	–	–	–	–
Epioblasma/Villosa	0.12	–	–	–	–	–	–	–
Fusconaia barnesiana C	0.06	X	–	–	–	–	–	–
Fusconaia cor CE	–	X	–	–	–	–	–	–
Fusconaia cuneolus CE	–	X	–	–	–	–	–	–
Fusconaia ebena	–	–	0.1	–	–	–	–	–
Fusconaia subrotunda	4.97	X	–	–	–	–	–	0.01
Hemistena lata E	–	X	–	–	–	–	–	–
Lampsilis abrupta E	–	X	–	–	–	0.08	0.57	0.42
Lampsilis fasciola	0.01	X	–	–	–	–	–	–
Lampsilis ovata	0.20	X	X	–	–	–	0.09	0.19
Lasmigona complanata	–	–	–	X	–	–	–	0.01
Lasmigona costata	T	X	–	–	–	–	–	0.01
Lemiox rimosus CE	0.09	X	–	–	–	–	–	–
Leptodea fragilis	–	X	–	–	–	–	0.03	0.33
Leptodea leptodon	–	X	–	–	–	–	–	–
Lexingtonia dolabelloides C	0.63	X	–	–	–	–	–	–
Ligumia recta	0.03	X	X	–	–	0.51	0.42	0.48
Medionidus conradicus C	–	X	–	–	–	–	–	–
Megalonaias nervosa	–	–	–	–	–	–	0.15	0.23
Obliquaria reflexa	–	X	1.0	6.08	X	1.02	0.87	0.59
Obovaria olivaria	–	–	0.2	–	–	–	–	–
Obovaria retusa E	1.64	X	–	–	–	–	–	–
Obovaria subrotunda	0.64	X	–	–	–	–	–	–
Plethobasus cicatricosus E	0.73	–	–	–	–	–	–	–
Plethobasus cooperianus E	0.88	X	X	–	–	–	–	–

TABLE 2. (cont.)

Species	AD 1-1600	1850-1918	1956-1957	1965	1972-1974	1975-1977	1978	1983-1992
Plethobasus cyphyus	0.10	X	1.0	X	X	0.17	–	0.02
Pleurobema clava E	0.70	–	–	–	–	–	–	–
Pleurobema cordatum	4.88	X	74.6	31.49	X	14.99	12.50	14.34
Pleurobema oviforme C	–	X	–	–	–	–	0.09	0.06
Pleurobema plenum E	5.58	X	–	–	–	–	–	0.04
Pleurobema rubrum	2.20	X	–	–	–	–	0.03	0.03
Pleurobema spp.	2.26	–	–	–	–	–	–	–
Potamilus alatus	0.01	X	X	6.08	–	2.39	1.27	2.61
Ptychobranchus fasciolaris	0.91	X	0.01	–	–	–	–	0.01
Ptychobranchus subtentum C	0.06	X	–	–	–	–	–	–
Quadrula cylindrica	0.12	X	–	–	–	–	–	–
Quadrula intermedia CE	0.23	X	–	–	–	–	–	–
Quadrula metanevra	0.68	X	2.9	–	–	2.39	1.81	0.86
Quadrula pustulosa	0.34	X	2.2	18.78	X	17.55	8.10	5.42
Quadrula spp.	0.02	–	–	–	–	–	–	–
cf. *Strophitus undulatus*	T	X	–	–	–	–	–	–
Toxolasma lividus C	–	X	–	–	–	–	–	–
Tritogonia verrucosa	–	–	0.01	–	–	0.68	0.30	0.77
Truncilla donaciformis	–	–	0.01	–	–	–	–	–
Truncilla truncata	–	X	X	–	–	–	–	–
Villosa fabalis	–	X	–	–	–	–	–	–
Villosa nebulosa C	–	X	–	–	–	–	–	–
Villosa vanuxemensis C	0.06	X	–	–	–	–	–	–
Total Specimens	27,875	–	–	–	–	587	3,320	13,455
Species Listed	45	58	22	10	6	15	21	30
Combined Species	64			23				

seven species are now considered uncommon in upper Chickamauga Reservoir.

The total number of mussels found in 1992 (708 mussels) was 35% less than the numbers reported in 1990. The loss of mussel species and total numbers collected has continued to decline since sampling began in 1983 (TVA, 1986; Ahlstedt, 1989, 1991). Overall, relative abundance or presence of freshwater mussels has changed considerably in upper Chickamauga Reservoir, based upon pre- and post-impoundment studies (Table 2). Most of the declines in number of mussels reported since 1983 result from reduced abundance of four of the most common species (*Elliptio crassidens, Pleurobema cordatum, Cyclonaias tuberculata* and *Quadrula pustulosa*). Trend analysis of mussel abundance from 1983 to 1992 indicated few statistically significant differences because the losses have occurred gradually and trends are overridden by sampling error (Table 3).

Shell length measurement data indicate continued slow growth for seven of the 16 species since 1990. Remaining species had slightly lower mean lengths than reported in 1990 (Table 4). These results parallel those of

TABLE 3. Results of linear regression analyses testing for trends in number of mussels collected in Watts Bar Tailwater, 1983-92.

Species	Correlation coefficient		
	TRM 520	TRM 526	TRM 528
Actinonaias ligamentina	0.03	0.00	-0.03
Amblema plicata	0.08	-0.20	0.03
Anodonta grandis	0.05	0.09	-0.04
Cyclonaias tuberculata	0.31	-0.03	-0.15
Ellipsaria lineolata	-0.02	-0.08	0.08
Elliptio crassidens	-5.32*	-1.76	-1.39
Elliptio dilatata	-0.04	0.00	-0.01
Lampsilis abrupta	-0.02	0.02	0.08
Lampsilis ovata	-0.04*	0.00	-0.03
Leptodea fragilis	0.02	0.02	0.00
Ligumia recta	-0.03	-0.01	-0.03
Megalonaias nervosa	0.05	0.02	0.03
Obliquaria reflexa	0.02	-0.14	0.03
Pleurobema cordatum	-1.73*	-0.92	-0.57
Pleurobema oviforme	0.00	0.00	0.00
Pleurobema plenum	-0.04	0.00	-0.01
Potamilus alatus	0.12	0.11	0.09
Quadrula metanevra	-0.15*	0.01	0.04
Quadrula pustulosa	-0.33	-0.33	0.03
Tritogonia verrucosa	0.05	0.12	0.00
All mussels	-7.04**	-3.05	-1.87

* $P < 0.05$
** $P < 0.01$

other studies in the upper Chickamauga Reservoirm (Scruggs, 1960; TVA, 1975-1977; Bates, 1975; TVA, 1979; Pardue, 1981; TVA, 1983-1985, 1986, 1986-1992; Ahlstedt, 1989, 1991). Abundant species continued slow growth; however, mean shell length of some rarer species decreased slightly possibly due to low numbers sampled or overall poor condition (emaciated soft parts and shell erosion) which inhibits shell growth (Tables 5 and 6).

Shell measurement data from 1983-1992 included three species (An*odonta imbecillis, Obliquaria reflexa* and *Quadrula pustulosa*) which were represented by specimens in the 30 mm group (Table 7). All other mussel species were over 40 mm in length indicating lack of recruitment for several years.

Between 1956 and 1957, Scruggs (1960) studied commercial mussels stocks of the pigtoe, *Pleurobema cordatum,* in four Tennessee River

TABLE 4. Mean shell lengths (mm) of measured freshwater mussel species obtained during the 1990 and 1992 surveys from upper Chickamauga Reservoir near the Watts Bar Nuclear Plant site.

	1990		1992	
Species	Number	Mean	Number	Mean
Actinonaias ligamentina	5	110.38	1	94.80
Amblema plicata	10	102.16	13	105.46
Anodonta grandis	20	135.42	5	130.06
Anodonta imbecillis	1	52.00	–	–
Anodonta suborbiculata	1	126.20	–	–
Cyclonaias tuberculata	69	79.65	68	80.10
Ellipsaria lineolata	28	85.42	14	90.49
Elliptio crassidens	160	115.21	137	112.26
Elliptio dilatata	1	94.60	–	–
Lampsilis abrupta	4	105.95	6	108.85
Lampsilis ovata	1	121.70	–	–
Leptodea fragilis	8	110.46	–	–
Ligumia recta	2	172.60	3	157.27
Megalonaias nervosa	3	166.60	4	173.35
Obliquaria reflexa	11	55.06	6	57.17
Plethobasus cyphyus	–	–	1	91.40
Pleurobema cordatum	132	97.37	82	98.53
Pleurobema oviforme	1	72.80	–	–
Pleurobema rubrum	1	88.30	–	–
Potamilus alatus	45	142.78	16	142.99
Ptychobranchus fasciolaris	1	116.80	–	–
Quadrula metanevra	8	84.27	8	78.61
Quadrula pustulosa	78	57.56	48	56.37
Tritogonia verrucosa	9	107.59	9	106.24
Measured Specimens	598		421	
Average Mean Lengths		99.26		97.67
Species Total	22		16	

TABLE 5. Mean shell lengths (mm) of freshwater mussel species collected during various surveys from upper Chickamauga Reservoir near the Watts Bar Nuclear Plant Site.

Species	1957 (Scruggs, 1960)		1975-1977		1983-1985		1986-1992	
	No.	Mean	No.	Mean	No.	Mean	No.	Mean
Actinonaias ligamentina	–	–	–	–	18	105.06	17	102.01
Amblema plicata	–	–	4	88.75	125	99.36	118	103.13
Anodonta grandis	–	–	–	–	47	122.67	70	128.46
Anodonta imbecillis	–	–	–	–	2	53.60	3	48.40
Anodonta suborbiculata	–	–	–	–	–	–	2	117.00
Cyclonaias tuberculata	–	–	37	71.70	413	77.87	355	78.32
Cyprogenia stegaria	–	–	–	–	5	55.02	–	–
Dromus dromas	–	–	–	–	1	60.10	–	–
Ellipsaria lineolata	–	–	19	73.42	137	85.00	102	86.11
Elliptio crassidens	–	–	212	96.59	912	109.25	752	117.00
Elliptio dilatata	–	–	2	105.50	10	100.51	7	103.66
Fusconaia subrotunda	–	–	–	–	2	61.40	–	–
Lampsilis abrupta	–	–	2	97.50	26	97.41	30	102.99
Lampsilis ovata	–	–	–	–	18	126.99	7	133.86
Lasmigona complanata	–	–	–	–	1	180.20	–	–
Lasmigona costata	–	–	–	–	–	–	1	122.10
Leptodea fragilis	–	–	–	–	15	100.39	29	101.83
Ligumia recta	–	–	–	–	34	159.66	30	152.97
Megalonaias nervosa	–	–	–	–	9	174.44	22	161.49
Obliquaria reflexa	–	–	4	44.25	43	54.28	36	55.39
Plethobasus cyphyus	–	–	1	72.00	2	91.80	1	91.40
Pleurobema cordatum	574	81.71	55	85.22	774	95.62	577	95.55
Pleurobema oviforme	–	–	–	–	3	70.83	5	71.00
Pleurobema plenum	–	–	–	–	5	65.40	–	–

TABLE 5. (cont.)

Species	1957 (Scruggs, 1960)		1975-1977		1983-1985		1986-1992	
	No.	Mean	No.	Mean	No.	Mean	No.	Mean
Pleurobema rubrum	–	–	–	–	3	87.97	1	88.30
Potamilus alatus	–	–	6	128.00	167	139.48	183	141.63
Ptychobranchus fasciolaris	–	–	–	–	1	94.40	1	116.80
Quadrula metanevra	–	–	10	71.10	78	77.47	38	79.38
Quadrula pustulosa	–	–	70	50.94	450	56.64	275	57.00
Tritogonia verrucosa	–	–	1	117.00	47	116.04	57	110.00
Measured Specimens	574		423		3348		2719	
Total Species	1		13		28		25	

TABLE 6. Results of linear regression analyses testing for trends in lengths of mussels collected in Watts Bar Tailwater, 1983-92.

Species	Correlation coefficient		
	TRM 520	TRM 526	TRM 528
Actinonaias ligamentina	-1.22	1.22	1.94
Amblema plicata	2.41*	0.69	-0.35
Anodonta grandis	8.71	1.43*	3.14*
Cyclonaias tuberculata	0.38**	0.18	0.16
Ellipsaria lineolata	0.48	0.28	0.27
Elliptio crassidens	0.50***	0.42**	0.89***
Elliptio dilatata	-0.91		0.57
Lampsilis abrupta	5.97	0.28	2.27**
Lampsilis ovata	-1.58	0.00	-0.34
Leptodea fragilis	0.00	0.04	2.60
Ligumia recta	0.56	1.89	1.22
Megalonaias nervosa	5.00*	0.17	2.60
Obliquaria reflexa	0.78	0.35	1.13***
Pleurobema cordatum	-0.02	0.80***	0.23
Pleurobema oviforme			0.53
Pleurobema plenum	-4.00		0.00
Potamilus alatus	1.67*	0.07	0.56
Quadrula metanevra	0.93	-0.14	-0.33
Quadrula pustulosa	0.05	0.17	0.14
Tritogonia verrucosa	3.36	-1.31	3.44

* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

impoundments. He concluded that *P. cordatum* had ceased reproduction in the Tennessee River as only larger adults were present. Based upon his measurement data of pigtoes from upper Chickamauga Reservoir, average mean lengths of 574 specimens was 81.71 mm. Studies by TVA from 1975-1977 and 1983-1993 report greater mean lengths of pigtoes at 85.22 mm (55 specimens) and 95.60 mm (1351 specimens), respectively. Our findings support Scruggs' conclusions that successful pigtoe reproduction has not occurred since the mid-1950's.

Shell length measurement data for practically all mussel species examined in upper Chickamauga Reservoir indicate only remnant populations of larger individuals from pre-and immediate post-impoundment of the river. In order to determine if successful reproduction has recently occurred, 84 quadrat excavations were made throughout the three mussel beds. Of the 63 mussel specimens found during quadrat excavations, all were large adults with only one small (30 mm) *Anodonta imbecillis* found (Table 7).

Historically, the only age-class information existing for mussels from upper Chickamauga is reported by Scruggs (1960). In 1957, Scruggs aged

TABLE 7. Freshwater mussel frequency of occurrence by shell lengths from 1983-1985 and 1986-1993 surveys of the Tennessee River miles 520-521L, 526-527R, and 528-529L.

		Shell length in 10 millimeter intervals																	Mean	
	Period	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	length	Totals
Actinonaias ligamentina	1983-85							5	8	5									105.06	18
	1986-93						1	10	1	3	2								102.02	17
Amblema plicata	1983-85					8	16	43	32	21	2	3							99.36	125
	1986-93				2	3	11	29	32	33	6	2							103.13	118
Anodonta grandis	1983-85						1		8	9	15	10	3	1					122.67	47
	1986-93						3		7	10	18	14	12	6					128.46	70
Anodonta imbecillis	1983-85			2															53.60	2
	1986-93	1		2															48.40	3
Anodonta suborbiculata	1986-93								1		1								117.00	2
Cyclonaias tuberculata	1983-85			2	52	194	140	25											77.87	413
	1986-93			2	47	151	137	17		1									78.32	355
Cyprogenia stegaria	1983-85			4	1														55.02	5
Dromus dromas	1983-85				1														60.10	1
Ellipsaria lineolata	1983-85			4	15	18	40	52	8										85.00	137
	1986-93			2	9	17	30	37	4	3									86.11	102
Elliptio crassidens	1983-85						7	117	356	333	90	9							109.25	912
	1986-93						3	71	222	337	101	14	3	1					111.74	752
Elliptio dilatata	1983-85							4	5	1									100.51	10
	1986-93							3	2	2									103.66	7
Fusconaia subrotunda	1983-85			1	1														61.40	2

TABLE 7. (cont.)

	Shell length in 10 millimeter intervals																	Mean	
	Period	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	length	Totals
Lampsilis abrupta	1983-85					2	4	8	10	2									97.41	26
	1986-93						2	11	9	7	1								102.99	30
Lampsilis ovata	1983-85								1	3	6	6	2						126.99	18
	1986-93									1	1	3	1	1					133.86	7
Lasmigona complanata	1983-85																1		180.20	1
Lasmigona costata	1986-93										1								122.10	1
Leptodea fragilis	1983-85			1			4	1	3	6									100.39	15
	1986-93					4	4	2	9	5	4	1							101.83	29
Ligumia recta	1983-85												8	8	10	6	2		159.66	34
	1986-93								1		1	4	7	4	7	6			152.97	30
Megalonaias nervosa	1983-85														2	4	2	1	174.44	9
	1986-93										1		4	5	3	7	2		161.49	22
Obliquaria reflexa	1983-85	1	10	24	8														54.28	43
	1986-93		7	21	8														55.35	36
Plethobasus cyphyus	1983-85						1	1											91.80	2
	1986-93							1											91.40	1
Pleurobema cordatum	1983-85				2	29	159	352	192	32	2	2	1	1	2				95.62	774
	1986-93			1	4	24	119	233	157	37	2								95.55	577
Pleurobema oviforme	1983-85				1	2													70.83	3
	1986-93				2	3													71.00	5
Pleurobema plenum	1983-85			2	2		1												65.40	5

TABLE 7. (cont.)

		Shell length in 10 millimeter intervals																	Mean	
	Period	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	length	Totals
Pleurobema rubrum	1983-85						1	2											87.97	3
	1986-93						1												88.30	1
Potamilus alatus	1983-85		1					4	6	12	18	37	35	26	22	4	2		139.48	167
	1986-93					1	1	1	3	12	15	40	47	46	15	1	1		141.63	183
Ptychobranchus fasciolaris	1983-85							1											94.40	1
	1986-93									1									116.80	1
Quadrula metanevra	1983-85		1	1	10	36	25	5											77.47	78
	1986-93			1	7	9	15	5	1										79.38	38
Quadrula pustulosa	1983-85		50	256	138	5	1												56.64	450
	1986-93	2	30	151	85	5	2												57.00	275
Tritogonia verrucosa	1983-85					1	1	8	8	7	13	6	3						116.04	47
	1986-93					3	2	12	14	9	9	6	2						110.00	57

TABLE 8. Age and shell length measurement data for five common mussel species in upper Chickamauga Reservoir near the Watts Bar Nuclear Plant site.

	P. cordatum TVA (1993)	*C. tuberculata* TVA (1993)	*Q. pustulosa* (TVA (1993)
Number measured	33	27	17
Length range (mm)	88. 7-110.5	55.3-92.4	52.2-70.8
Mean length (mm)	98.5	80.1	59.9
Number aged	32	23	17
Age range	28-64	26-50	23-44
Mean age	49	34	33

	E. lineolata TVA (1993)	*E. crassidens* TVA (1993)
Number measured	7	28
Length range (mm)	57.5-97.0	97.2-122.1
Mean length (mm)	87.3	112.1
Number aged	7	28
Age range	27-51	30-46
Mean age	34	36

	P. cordatum (Scruggs) 1957	*P. cordatum* TVA (1983-1992)	*P. cordatum* (TVA 1993)
Number measured	574	1351	33
Length range (mm)	40-119	–	88.7-110.5
Mean length (mm)	81.71	95.6	98.5
Number aged	212	–	32
Range	6-32	–	28-64
Mean age	22	–	49

212 specimens of *Pleurobema cordatum* by counting external growth rests on the shell and reported that the average age was 22 years. Based upon thin-sectioning of valves, the average age for 32 pigtoe specimens collected in 1993 was 49 years. Age determinations in 1993 for four other species revealed mean ages for *Cyclonaias tuberculata* (34 years), *Quadrula pustulosa* (33 years), *Ellipsaria lineolata* (34 years) and E*lliptio crassidens* (36 years) (Table 8). Scruggs findings that the pigtoe population was old and non-reproducing in 1957 further supports recent findings that the pigtoe population is now considerably older and other mussel species are suffering a similar fate.

Fourteen federally listed endangered species are documented from upper Chickamauga Reservoir prior to extensive modifications of the river (Table 2). Since sampling was begun in 1983, only four species (*Cyprogenia stegaria, Dromus dromas, Lampsilis abrupta* and *Pleurobema plenum*) have been found and exist as relict populations. Two of the four species (*D. dromas* and *P. plenum*) were once considered the most abundant

TABLE 9. Freshwater mussel species reported from the Tennessee River (A = Archaeological).

		Pre-(1960)	Pre-(1970)	Pre-(1980)	Pre-(1990)	(1993)	Status
Actinonaias ligamentina	A	X	X	–	X	X	relict
Actinonaias pectorosa	A	X	–	–	–	–	extirpated
Alasmidonta marginata	A	–	–	–	–	–	extirpated
Alasmidonta viridis	A	–	–	–	–	–	extirpated
Amblema plicata	A	X	X	X	X	X	reproducing
Anodonta grandis	A	X	X	X	X	X	reproducing
Anodonta imbecillis	–	X	X	X	X	X	reproducing
Anodonta suborbiculata	–	–	X	X	X	X	reproducing
Arcidens confragosus	–	–	X	X	X	X	reproducing
Cumberlandia monodonta	–	X	X	X	X	X	relict
Cyclonaias tuberculata	A	X	X	X	X	X	reproducing
*Cyprogenia stegaria**	A	X	X	X	X	X	relict
*Dromus dromas**	A	X	X	X	X	–	extirpated
Ellipsaria lineolata	A	X	X	X	X	X	reproducing
Elliptio crassidens	A	X	X	X	X	X	reproducing
Elliptio dilatata	A	X	X	X	X	X	relict
Epioblasma arcaeformis	A	–	–	–	–	–	extinct
Epioblasma biemarginata	A	X	–	–	–	–	extinct
Epioblasma brevidens	A	–	–	–	–	–	extirpated
Epioblasma capsaeformis	A	X	–	–	–	–	extirpated
Epioblasma flexuosa	A	X	–	–	–	–	extinct
*Epioblasma f. florentina**	A	–	–	–	–	–	extinct
*Epioblasma haysiana**	A	X	–	–	–	–	extinct
*Epioblasma o. obliquata**	A	X	–	–	–	–	extirpated
Epioblasma personata	A	–	–	–	–	–	extinct
Epioblasma propinqua	A	X	–	–	–	–	extinct
Epioblasma stewardsoni	A	X	–	–	–	–	extinct
*Epioblasma t. torulosa**	A	X	–	–	–	–	extinct
Epioblasma triquetra	A	X	–	–	–	–	extirpated
*Epioblasma turgidula**	A	–	–	–	–	–	extinct
Fusconaia barnesiana	A	X	–	–	–	–	extirpated
*Fusconaia cor**	A	X	–	–	–	–	extirpated
*Fusconaia cuneolus**	A	X	–	–	–	–	extirpated
Fusconaia ebena	–	X	X	X	X	X	reproducing
Fusconaia flava	–	–	–	X	X	X	reproducing
Fusconaia subrotunda	A	X	X	X	X	X	reproducing
*Hemistena lata**	–	X	–	X	–	–	relict
*Lampsilis abrupta**	–	X	X	X	X	X	relict
Lampsilis fasciola	A	X	–	–	–	–	extirpated
Lampsilis ovata	A	X	X	X	X	X	relict
Lampsilis teres	–	X	X	X	X	X	relict
*Lampsilis virescens**	A	–	–	–	–	–	extirpated
Lasmigona complanata	–	–	X	X	X	X	reproducing
Lasmigona costata	A	X	–	–	X	–	extirpated
Lasmigona holstonia	–	X	–	–	–	–	extirpated
*Lemiox rimosus**	A	X	–	–	–	–	extirpated
Leptodea fragilis	A	X	X	X	X	X	reproducing

TABLE 9. (cont.)

		Pre-(1960)	Pre-(1970)	Pre-(1980)	Pre-(1990)	(1993)	Status
Leptodea leptodon	–	X	–	–	–	–	extirpated
Lexingtonia dolabelloides	A	X	X	X	X	–	extirpated
Ligumia recta	A	X	X	X	X	X	relict
Medionidus conradicus	–	X	–	–	–	–	extirpated
Megalonaias nervosa	–	X	X	X	X	X	reproducing
Obliquaria reflexa	A	X	X	X	X	X	reproducing
Obovaria olivaria	–	X	X	X	–	–	extirpated
*Obovaria retusa**	A	X	X	X	X	–	relict
Obovaria subrotunda	A	X	–	X	–	–	relict
*Pegias fabula**	A	X	–	–	–	–	extirpated
Plectomerus dombeyanus	–	–	–	–	X	X	reproducing
*Plethobasus cicatricosus**	A	–	X	X	X	–	relict
*Plethobasus cooperianus**	A	X	X	X	X	X	relict
Plethobasus cyphyus	A	X	X	X	X	X	relict
*Pleurobema clava**	A	X	–	–	–	–	extirpated
Pleurobema coccineum	–	X	–	X	X	X	reproducing
Pleurobema cordatum	A	X	X	X	X	X	relict
Pleurobema oviforme	A	–	X	X	X	–	relict
*Pleurobema plenum**	A	X	–	X	X	–	relict
Pleurobema pyramidatum	A	X	X	X	X	–	relict
Potamilus alatus	A	X	X	X	X	X	reproducing
Potamilus ohiensis	–	–	X	X	X	–	reproducing
Ptychobranchus fasciolaris	A	X	X	X	X	–	relict
Ptychobranchus subtentum	A	X	–	–	–	–	extirpated
Quadrula apiculata	–	–	–	–	X	X	reproducing
Quadrula cylindrica	A	–	–	–	X	–	relict
*Quadrula fragosus**	–	X	–	–	–	–	extirpated
*Quadrula intermedia**	A	X	–	–	–	–	extirpated
Quadrula metanevra	A	X	X	X	X	X	reproducing
Quadrula nodulata	–	–	–	–	X	X	reproducing
Quadrula pustulosa	A	X	X	X	X	X	reproducing
Quadrula quadrula	–	X	X	X	X	X	reproducing
*Quadrula sparsa**	A	–	–	–	–	–	extirpated
Strophitus undulatus	A	X	–	–	–	–	extirpated
Toxolasma lividus	A	–	–	X	X	X	relict
Toxolasma parvus	–	–	X	X	X	X	reproducing
Tritogonia verrucosa	–	X	X	X	X	X	reproducing
Truncilla donaciformis	–	X	X	X	X	X	reproducing
Truncilla truncata	–	X	X	–	X	X	reproducing
Villosa fabalis	A	–	–	–	–	–	extirpated
Villosa iris	A	X	–	–	–	–	extirpated
Villosa taeniata	A	X	–	–	–	–	extirpated
*Villosa trabalis**	–	X	–	–	–	–	extirpated
Villosa vanuxemensis	A	–	–	–	X	–	extirpated
Total number of species	64	67	42	46	51	39	

*Federally listed endangered species are marked with an asterisk.

Total number of mussel species reported from Tennessee River (91); federally listed endangered (23); extinct (10); extirpated (32); relict (21); reproducing (28).

of five species which comprised 66% of all shell material excavated from aboriginal shell mounds in the reservoir (Parmalee *et al.*, 1982). These findings are not unique to upper Chickamauga Reservoir. Of the 91 mussel species reported historically in the river, only 28 species are considered reproducing. Reproduction is largely limited to mussel species and their fish host(s) which have adapted to impoundment conditions, especially in the lower 350 miles of the river downstream from Guntersville Dam. At least 19 of the 28 reproducing species are taken commercially for the cultured pearl industry. Other mussel species documented from the river have been reduced to relict status because of their scarcity and apparent lack of reproduction. Still others have been extirpated from the mainstem river fauna, or are extinct (Table 9).

SUMMARY AND CONCLUSIONS

Mussel populations in upper Chickamauga Reservoir have suffered serious declines from a high of 64 species reported historically near the Watts Bar Nuclear Plant to approximately 30 species present today. Total number of mussels found since sampling began in 1983 have continued to decline between sampling years. Few of these are statistically significant because the losses have occurred gradually and trends are overridden by sampling error.

Shell length measurement data show continued slow growth for the more abundant species; however, rarer species decreased in mean lengths, possibly due to the low numbers of mussels sampled or overall poor condition (emaciated soft parts and shell erosion). Only three species were reported in the 30 mm size grouping. All other mussel species measured since sampling began in 1983 were over 40 mm in length. Quadrat excavations support our findings that little or no recruitment to the fauna has taken place for several years.

Age-class determinations for five of the most common mussel species adds further support that mussel populations are old and are remnants from pre-and post-impoundment periods. Conditions which caused the demise of the mussel fauna in upper Chickamauga Reservoir and elsewhere on the Tennessee River are poorly understood. Likely factors include loss of fish host, substrate scouring, sediment toxicity, thermal and dissolved oxygen problems, and settling of detrital material in upstream reservoirs. Mussel populations near the Watts Bar Nuclear Plant will continue to age, add shell growth for some species, and gradually dieoff over time.

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