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By

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C O N T E N T S

A B S T R A C T

Since 1942, the mainstream reservoirs of the Tennessee River have served as the nation's most important source of fresh-water mussel shell. Mussels are harvested in the Tennessee River by the crowfoot brail method. Because of its natural abundance and good quality shell, the pigtoe mussel Pleurobema cordatum is the most important species to the commercial fishery.

During 1956 and 1957, a study was undertaken to determine the level of abundance, rate of exploitation by fishing, age composition and potential for natural replacement of the pigtoe mussel on specific beds in the Tennessee River. The distribution of mussels on bottom areas was not random but concentrated on specific beds. Population estimates were made by the tag and recovery method and by actual count in bottom samples using SCUBA gear. Measured drags were made with a crowfoot brail over beds where the numbers of mussels were estimated to determine the correlation between catch per unit of effort and population density. Catch records provided a reliable estimate of the number of mussels harvested by the commercial fishery from beds in Wheeler Reservoir during 1956 and 1957. Catch per unit of effort varied in direct proportion to the size of the available population during a given season of the year; however, the catch rate differed on a seasonal basis, being highest in April and declining as the season progressed. The brail method of fishing was selective for certain size groups of pigtoes and for certain species of mussels. Total catch, catch per unit of effort, and fishing effort decreased on Wheeler Reservoir between 1956 and 1957. This decrease was attributed to the high rate of exploitation in 1956 which reduced the population available to the fishery in 1957. The age structure of the populations studied showed that old age stocks (over 15 years of age) supplied the major support to the commercial fishery. The rate of exploitation on beds in Wheeler Reservoir during a two-year period (1956-1957) accounted for almost 23 percent of the available population.

Recruitment to the population during this same period amounted to less than 1.0 percent. Poor survival of young mussels appears to be the chief problem in replacement of the populations. The pigtoe mussel reproduced successfully in 1956 and 1957. The spawning season extended from May 15 to October 4 in 1957. Results of a search for a suitable host fish, which is presumed necessary to complete the life-cycle of the pigtoe, were inconclusive. Survival of juvenile mussels was not found to be related to the intensity of commercial fishing as low survival occurred on beds subjected to fishing for many years, as well as on new beds which were recently discovered. The life-history of the pigtoe mussel is complex and unfavorable environmental changes have occurred since the river was impounded which may account for low survival of juvenile mussels. Extensive deposits of silt covered most of the bottom areas studied.

The results of this study do not indicate that restrictions on the commercial harvesting of mussels in the study area would offer any promise of success in restoring depleted mussel populations to previous levels of abundance.

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INTRODUCTION

The National Association of Button Manufacturers, confronted with a decrease in the available supply of fresh-water mussel shells, requested the United States Fish and Wildlife Service to investigate the condition of the resource and recommend measures which would favor an increase in mussels valuable to the industry.

Because of cheaper manufacturing costs, plastic material has replaced shell material to a large extent in the manufacture of buttons. However, the market demand for good quality pearl shells is high. The economic level of the shell industry will depend on the continued availability of an adequate supply of preferred mussels. There is a good export market for shells, which are shipped to Japan where they are processed into tiny beads and used in the artificial culture of pearls, in addition to their use in the button industry.

The objectives of the study reported here were to determine the level of abundance, exploitation rate by fishing, age composition, and natural replacement potential of mussel stocks in the Tennessee River. The program began in 1956 and was concerned primarily with stocks in a 6-mile stretch of the river impounded by Wheeler Dam in Alabama. Special emphasis was given to studies of the pigtoe, *Pleurobema cordatum*, because of its natural abundance and economic value. This report discusses the observations and findings resulting from studies conducted during 1956 and 1957.

MUSSEL SHELL INDUSTRY

Historical significance.--The mussel shell industry began in the United States about 1891 when J. F. Boepple established a pearl button plant at Muscatine, Iowa. An abundant supply of good shells available from the Mississippi River encouraged the growth of the new industry. As the market expanded, an extensive search was made to find new beds in other streams throughout the nation.

During the period from 1897 to 1937, the U. S. Bureau of Fisheries engaged in various studies of the life history, habits, distribution, and methods of propagating certain species of mussels. Coker (1914), Coker, Shira, Clark, and Howard (1921), and Howard (1922), have described the early industry and the results from these studies.

Since 1942 the Tennessee River has become the nation's most important source of fresh-water shell. This stream was intensively developed by the Tennessee Valley Authority between 1936 and 1944 for hydroelectric power, flood control, and navigation. The development program included the construction of seven dams which impounded 580 miles of stream. Two other dams completed earlier (1913 and 1925) impounded 55 miles of stream. Development of the mussel fishery began on the lower section of the river, gradually extending upstream as new productive beds were found. During 1956 and 1957, the bulk of the catch was taken at four locations: Kentucky Reservoir (mile 190 to 196), Wheeler Reservoir (mile 308 to 316), Guntersville Reservoir (mile 379 to 389), and Chickamauga Reservoir (mile 498 to 519). (See figure 1.)

The importance of fishing areas depends on the abundance and quality of the shells produced. Shells of good quality have thick valves of pearly white and lustrous nacre, free from spots or stains and of a firm but not brittle texture. The pigtoe mussel, *Pleurobema cordatum*, and the niggerhead mussel, *Fusconaia ebena*, meet these requirements.

Method of harvest.--Mussels are harvested commercially in the Tennessee River by crowfoot brail. This device was first used in 1897 on the Mississippi River and has become the usual method of harvest on many large streams. Coker, Shira, Clark, and Howard (1921) described this device in detail, along with other types of shell-fishing equipment. The brail assembly used on areas where most of the present studies were carried out has been modified to some extent and warrants a brief description.

The brail consists of a wooden bar 18 to 21 feet long to which chains are attached at 4-inch intervals; each chain is approximately 18 inches long and bears a cluster of several multipronged hooks linked to its free end. The prongs of the hooks are straight instead of curved, and each prong has a small knob on the tip. The hooks are made of heavy-gauge wire, and the number used may vary up to 720 for brails 21 feet long. A rope bridle is attached for towing the brail downstream.

The brails are fished from flat-bottomed "john" boats 20 to 25 feet long. Most of the larger boats fish two brails at a time, keeping a spare for replacement when one of the other brails is lifted to remove the catch. Power is provided by an underwater sail, made of canvas, called a "mule." The rate of speed can be adjusted to some extent by changing the pitch of the sail in the current (figure 2).

When one of the trailing hooks of the brail passes between the slightly gaping valves of a feeding mussel, reflex action causes the

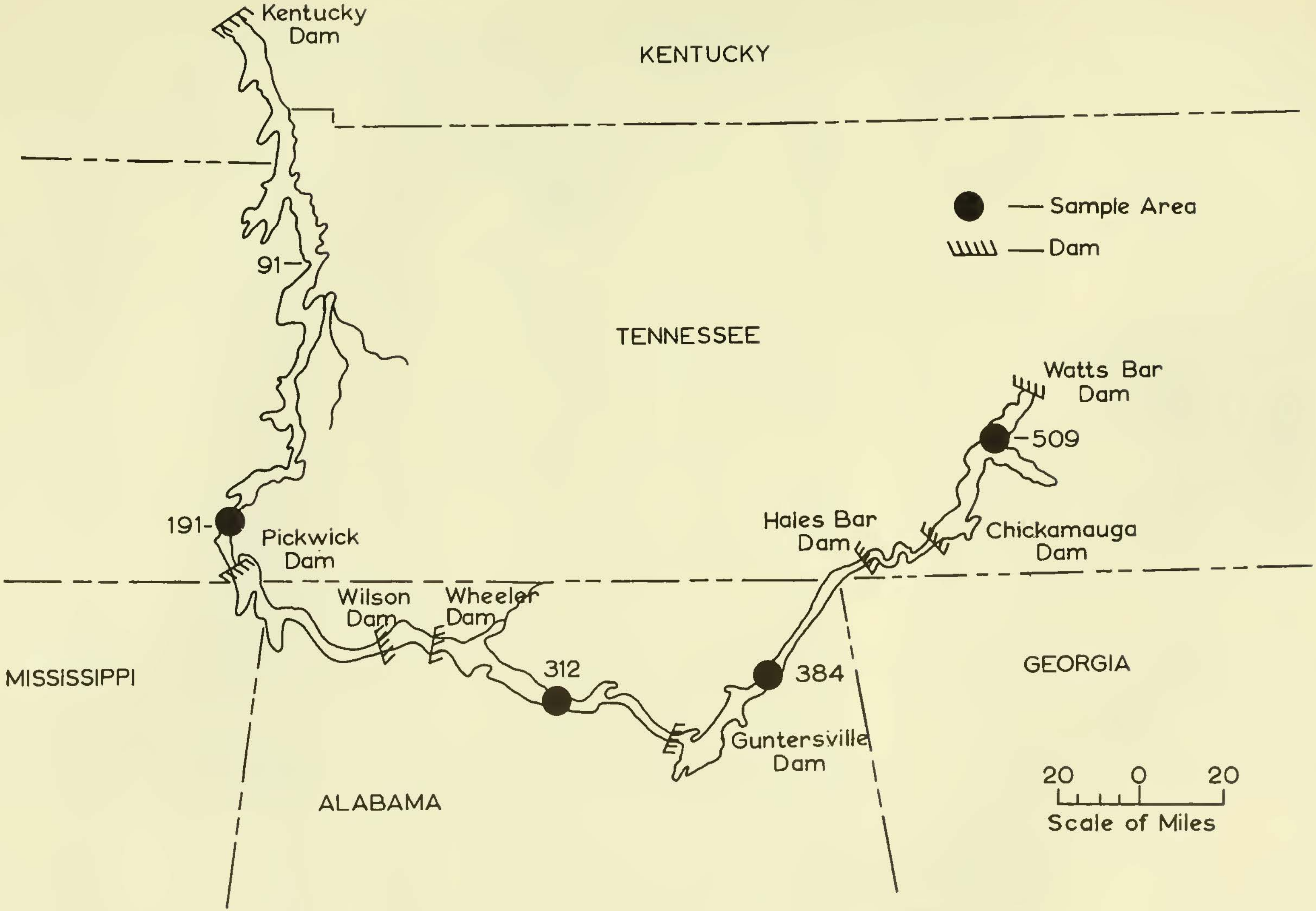

Figure 1.--Map of the Tennessee River Reservoir System showing the location of mussel fishing areas where studies were conducted in 1956 and 1957. Mileage numbers on the stream correspond to the center of each fishing area.

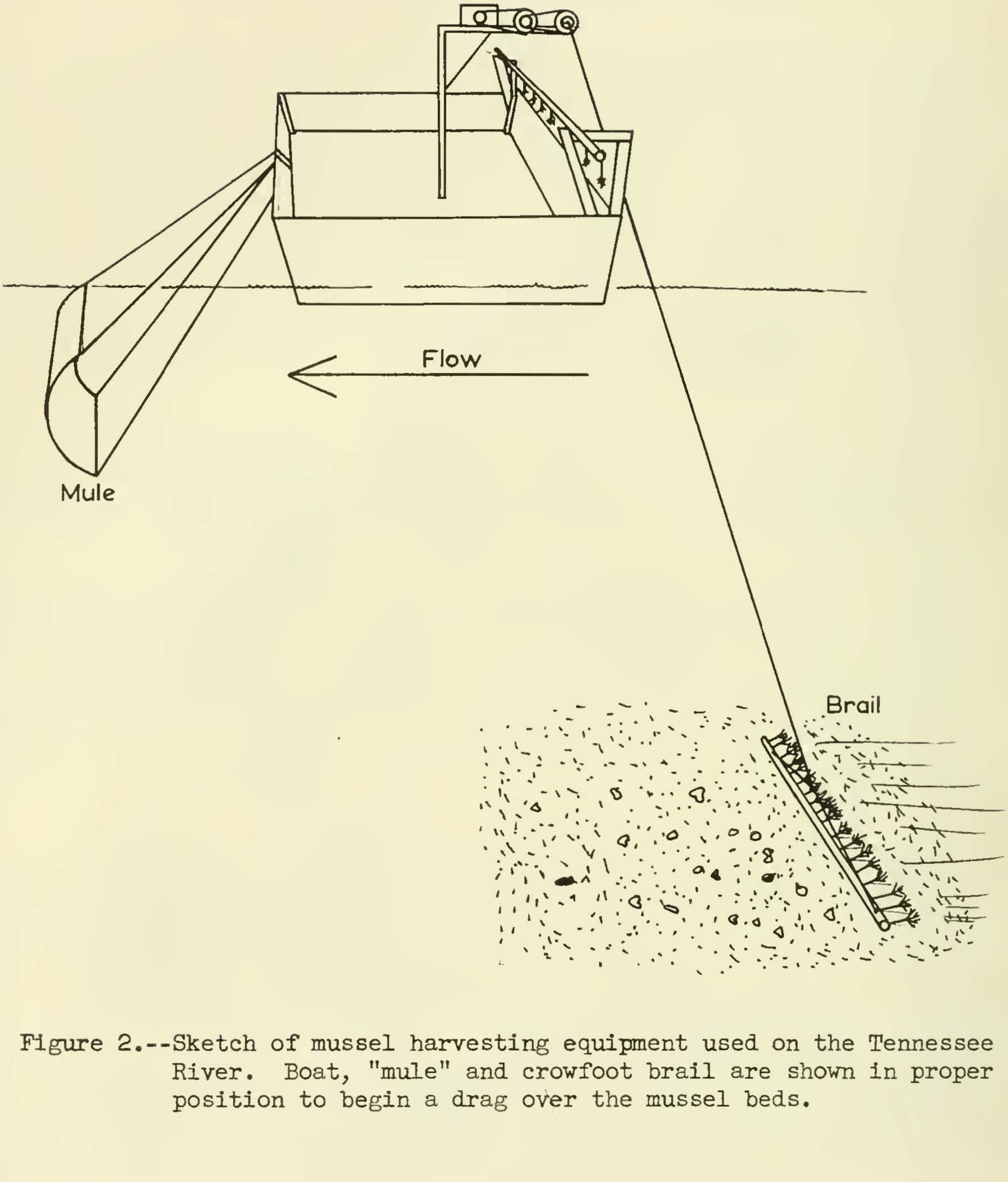

Figure 2.--Sketch of mussel harvesting equipment used on the Tennessee River. Boat, "mule" and crowfoot brail are shown in proper position to begin a drag over the mussel beds.

valves to close. The mussel remains on the hook until forcibly removed. Because of the numerous hooks used, almost complete coverage is achieved when the brail is dragged over the bottom. Catch success is dependent upon the characteristic habit of mussels to embed with their posterior end oriented upstream with valves open to feed. However, only a portion of a population at a given time may feed and be oriented in a vulnerable position when a brail traverses their bed. In spite of these limitations, the crowfoot brail is an effective method of harvesting from areas containing an abundant population of mussels.

METHODS AND MATERIALS

Most of the studies described in this report were carried out on Wheeler Reservoir between mile points 308 and 316 (see figure 1). A limited amount of material was collected on Chickamauga (mile 498 to 519), Guntersville (mile 379 to 389), and Kentucky (mile 190 to 196) Reservoirs, all impoundments of the Tennessee River. Methods used in the studies are briefly described:

Commercial catch.--Monthly catch records were obtained from a mussel camp on Wheeler Reservoir. These records represented the total catch of all mussels of commercial value harvested from the river between mile points 308 and 316 during the years of 1956 and 1957. The total available harvest area was estimated by planimetric method using a detailed stream map provided by the Tennessee Valley Authority. The fishing area was calculated to be 7,480,000 square yards. Mussel catch was measured by boxloads; a standard box holds approximately 200 pounds of mussels. An estimate was made of the number of pigtoe mussels harvested, based on sample counts of 28 representative boxloads; the average number per boxload was then multiplied by total boxloads to calculate the total catch of pigtoes. The total number caught was then divided by the total fishing area (in square yards) to calculate the total catch of pigtoes per square yard for 1956 and 1957.

Brail sampling.--Quantitative sampling was accomplished with a crowfoot brail to determine the rate of catch per drag from a given area. All equipment was rented from and fished by a commercial fisherman. Each brail sample consisted of dragging a measured distance of 100 yards, then sorting and counting the catch. The area sampled was calculated in square yards by multiplying the length of the brail by 100 yards. Catch success was expressed in terms of the average catch of mussels per square yard per drag. Brail sampling was randomized within fishing areas and by time periods during two complete harvest seasons (March through August) with 142 samples taken in 1956 and 149 samples taken in 1957 from Wheeler Reservoir.

Brail samples were also taken in commercial fishing areas on Chickamauga, Guntersville, and Kentucky Reservoirs in 1957. Collections consisted of 11,401 mussels from all locations.

Length measurements were recorded from 11,658 pigtoes taken from Chickamauga, Wheeler, Guntersville, and Kentucky Reservoirs during 1956 and 1957. The length was measured along the anteroposterior axis of the left shell valve of each specimen.

An estimate was made of the total fishing effort expended on Wheeler Reservoir in 1956 and 1957, as indicated by the total number of drags made by fishermen. The total number of drags was estimated by dividing the average catch of pigtoes per square yard per drag into the total catch of pigtoes per square yard harvested from the available fishing area.

Population sampling.--Two methods were used to estimate the size of the population and the rate of exploitation of pigtoe mussels in Wheeler Reservoir (mile 308 to 316). The first method consisted in a mark and recapture study carried on for a total of 9 months during the fishing seasons of 1956 and 1957. The second method consisted in taking randomized bottom counts of mussels in square yard plots within the harvest area using SCUBA (self-contained underwater breathing apparatus) diving gear.

During May, 1956, 1,000 pigtoes were marked by drilling a small hole through the umbo (beak) of one valve; a nickel pin was then inserted through the hole to attach a plastic disk tag. The tagged mussels were transplanted at random in the commercial fishing area. Tagged recaptures were reported on a voluntary basis in 1956; fishermen were paid a 50-cent reward per tag in 1957. An additional 100 mussels were marked for controls and confined in a protected area to estimate mortality caused by the tagging method. Data from tag recaptures and catch records of the total number of unmarked pigtoes caught were used to calculate the size of the population at the end of the 1957 harvest season using the Petersen formula.

SCUBA equipment was used to hand-collect all mussels found in 96 square yards of bottom area at 48 stations during June and July of 1957. A cluster of 2 square yard subsamples was taken per station, and the mean number per square yard was determined by taking the combined average from both samples. Equipment consisted of a Scott Hydropac with tanks of compressed air, a portable iron frame to form a quadrat of 1 square yard, a waterproof sealed beam light (6 volt), a boat, safety line, and an anchor. Sampling was done in water varying from 20 to 29 feet in depth, with a current velocity averaging 0.7 miles an hour. The procedure used at each collecting station consisted in first fanning the area free of silt, then probing into the soil to uncover all embedded specimens. The size of the population was estimated by multiplying the mean number per square yard of the sample by the total number of square yards of fishing area (7,480,000). The population at the end of the 1957 harvest season was estimated by deducting the number harvested after the population estimate was made.

The number of pigtoe mussels available to the fishery at the start of the 1956 season was estimated by adding the total number harvested during the 2-year period to the estimated escapement population at the end of the 1957 season. This estimate is somewhat low since natural mortality was not included in the estimate. The author believes that natural mortality was slight, except in the youngest age groups, which comprised a small percentage of the total population.

The total population of all species and available sizes in Wheeler Reservoir was also estimated from data gathered using SCUBA gear. Length data were recorded from all pigtoe mussels collected in the SCUBA samples to determine the size composition of the population on the Wheeler beds. Measurements were taken to the nearest millimeter.

Relation of abundance and catch.--The relation of population size to catch success by crowfoot brail was studied on two 5,000 square yard test areas in Wheeler and Chickamauga Reservoirs during August and September of 1957. One area was at mile 309 on Wheeler Reservoir, the other at mile 515 on Chickamauga Reservoir. The population on the Wheeler beds had been fished intensively for 12 years. In contrast, the beds on Chickamauga were discovered in 1956 and had been fished for only 5 months.

The sizes of the populations on these small areas were estimated by taking 10 random SCUBA samples, covering 20 square yards of bottom within each area. After the density of the respective populations was determined, 16 brail samples were made in each area to measure the correlation between population density and the mean catch per drag.

Length frequency data for all pigtoes collected by SCUBA sampling in Wheeler and Chickamauga were compared with length data from brail samples taken in the same areas to determine the selectivity of the harvest method on different size groups. The sample from Wheeler consisted of 313 mussels taken by SCUBA and 530 by brail, while Chickamauga was represented by 212 collected using SCUBA and 262 collected by brail.

Habitat conditions.--The correlation between population density and the physical character of the bottom was determined by comparing bottom conditions at the 48 sampling stations in Wheeler Reservoir with the number of mussels found at each station. Distribution of the population was determined with respect to the availability of three major bottom types: rubble--gravel--sand, solid marl, and mud-gravel.

Age and growth of the pigtoe.--A total of 236 pigtoes from Wheeler Reservoir and 242 pigtoes from Chickamauga Reservoir, represented by all available sizes in SCUBA and brail samples, were examined and their age determined by a method described by Isely (1914), Howard (1922), and Chamberlain (1931). The left valve of each specimen was cleaned with a wire brush, then measured along the axis. Age was determined by the number of annuli and growth by the increment distance between successive annuli.

The age composition of the pigtoe populations in Wheeler and Chickamauga Reservoirs was estimated by converting length frequencies to corresponding age frequencies. The age composition of the pigtoe stocks was based on the specimens collected in SCUBA samples, 313 from Wheeler and 212 from Chickamauga.

Reproduction of the pigtoe.--Samples of pigtoes were collected from Wheeler Reservoir, confined, and examined periodically during the months of April through September of 1957, to determine sexual development in the females and define the duration of their spawning season. A sample of 100 mussels was collected on each of 14 days during the 6-month period. Sexual development was determined by microscopic inspection of the marsupia (brood pouches in gills) of gravid females. Stages of development were classified as follows: 1. fertilized eggs; 2. immature glochidia (in membrane); 3. free glochidia (out of membrane). The effect of water temperature on sexual development was observed during the spawning season. The age at which female pigtoes started and stopped reproducing was also determined by examining several hundred small and large mussels collected during the spawning season.

Surber (1915) described the glochidia of the pigtoe mussel based on size dimensions and shape. During the course of the present study, measurements were taken from 100 glochidia selected at random from marsupia to check the dimensions described in Surber's Key.

During the spawning seasons of 1956 and 1957, efforts were made to find the natural host-fish which may be necessary for the pigtoe glochidia to survive. Fish collections were made with hoop nets, gill nets, and rotenone. A total of 283 fish composed of 17 species were used in 1956 and 330 fish composed of 16 species in 1957. Gill filaments were inspected by microscope, and all encysted glochidia found were closely examined to identify them.

When applicable, standard statistical methods and procedures as described by Snedecor (1956) were used in the analyses of data in this report.

ANALYSES OF DATA

Commercial catch.--Catch records from Wheeler Reservoir showed that 6,118 boxloads of mussels were harvested in 1956 and 3,108 boxloads in 1957 (table 1), a decline of 49.2 percent. On the basis of box-count samples, the mean number of pigtoes per boxload was found to be 653 (620 - 688; 95% confidence intervals). The mean number per box multiplied by the total boxloads caught each year, resulted in an estimate of 3,995,054 pigtoes harvested in 1956 and 2,029,524 harvested in 1957. When converted to a catch per unit of area basis, the harvest amounted to 0.534 pigtoes per square yard in 1956 and 0.271 in 1957 (table 2).

TABLE 1.

Record of the Total Catch of All Commercial Species of Mussels and the Estimated Number of Pigtoes Harvested in Wheeler Reservoir (Mile 308-316) During 1956 and 1957.

	1956		1957	
onth	Catch (Box-loads)	Number of * Pigtoes	Catch (Box-loads)	Number of * Pigtoes
arch			324	211,572
pril	1,940	1,266,820	1,352	882,856
ay	1,347	879,591	302	197,206
une	1,420	927,260	529	345,437
uly	879	573,987	475	310,175
ugust	532	347,396	126	82,278
OTALS	6,118	3,995,054	3,108	2,029,524

Based on average of 653 per box.

TABLE 2.

Commercial Catch of Pigtoe Mussels, Converted to Number Harvested per Square Yard, in Wheeler Reservoir (Mile 308-316) in 1956 and 1957.

Year	Harvest Area (Square Yards)	Catch per Square Yard
1956	7,480,000	0.534
1957	7,480,000	0.271

In general, the catch by month declined as the season advanced during both years. With the exception of the low catch in March of 1957, the catch started at a high level in April of both years and declined to a low level during August.

Brail sampling.--Twenty-three species of mussels were represented in brail samples made in the commercial fishing areas on Chickamauga, Guntersville, Wheeler, and Kentucky Reservoirs during 1957 (table 3). Of these, 15 species are of commercial value to the industry. Although the pigtoe is the most abundant species in the catch from the lower part of the river, abundance of this species increased at upstream locations.

The more intensive sampling program on Wheeler Reservoir provided a comparison of the catch per square yard per drag between the harvest seasons of 1956 and 1957. A total of 15 species occurred in the 1956 samples and 16 species in the 1957 samples (table 4). The catch per drag, for all species combined, declined 29 percent from 1956 to 1957. The seasonal catch per drag was highest in April and, in general, declined as the season progressed.

Although the pigtoe accounted for over 80 percent of the commercial catch in Wheeler Reservoir in both 1956 and 1957, brail samples showed that the mean catch per drag in 1957 (0.264 per square yard) decreased by 33.4 percent below the level for 1956 (0.391 per square yard).

Statistical analysis showed that the difference represented by the decrease during the second year was highly significant (table 5).

The number of brail drags made over the harvest area in Wheeler Reservoir during 1956 and 1957 was estimated to determine the degree of fishing effort. Based on the total number of pigtoes harvested per square yard (table 2) and the mean number caught per drag (table 5), the result indicates that an average of 13.7 drags was made over the entire fishing area in 1956 and 10.4 drags in 1957. This suggests that fishing effort declined approximately 24 percent during the latter year.

The data arrayed in table 6 and illustrated in figure 3, demonstrate the relationship among total catch per unit area, catch per unit of effort, and fishing effort. From observation, approximately 25 boats per day fished the area in April while the catch rate was high, and only 4 or 5 boats operated per day when the catch rate declined during the latter part of the season.

Length frequency data from 11,658 pigtoe mussels, selected at random from the commercial catch in 4 mainstream reservoirs, provided a comparison of the size distribution of different populations at locations between river mile 190 and river mile 519 (table 7). The mean lengths varied from 71.1 mm. in Wheeler, to 83.8 mm. in Chickamauga. The samples from Guntersville and Kentucky Reservoirs had mean lengths between

TABLE 3.

Species Composition and Percentage of Catch in Crowfoot Brail Samples From Four Mainstream Reservoirs of the Tennessee River During 1957.

		Reservoir			
Scientific Name	Common Name	Kentucky	Wheeler	Guntersville	Chickamauga
* Plagiola lineolata	Butterfly	8.6	1.7	0.5	0.2
* Plethobasus cyphus	Bullhead	0.2	0.1	0.1	1.0
Elliptio crassidens	Elephant-ear	16.3	2.0	6.5	12.9
* Obovaria olivaria	Egg-shell	2.9	0.1	...	0.2
Truncilla donaciformis	Deer-toe	...	0.1	0.3	0.1
Proptera alata	Heelsplitter	0.2	...	...	...
Elliptio dilatatus	Ladyfinger	0.1	0.7	...	1.1
* Quadrula fragosus	Maple-leaf	0.1	0.4	0.2	...
* Quadrula metanevra	Monkeyface	3.5	1.9	2.3	2.9
* Actinonaias car. gibba	Mucket	0.1	...	...	0.1
* Fusconaia ebena	Niggerhead	19.6	...	0.1	0.1
* Ptychobranchus fasciolare	Kidneyshell	0.1	...	...	0.1
* Pleurobema cordatum	Pigtoe	37.3	65.5	60.1	74.6
* Plethobasus cooperianus	Pimpleback	0.1	0.2	0.2	...
* Tritigonia verrucosa	Pistolgrip	0.1	0.1	0.3	0.1
Lampsilis ovata	Pocketbook	0.1	...	...	...
* Ligumia recta	Sandshell-black	0.1	...	...	...
* Lampsilis anodontoides	Sandshell-yellow	0.1	...	...	...
* Obliquaria reflexa	Three-horn	1.3	5.1	3.0	1.0
Amblema costata	Three-ridge	0.1	6.3	4.2	1.3
Megalonaias gigantea	Washboard	2.0	0.1	0.3	...
Cyclonaias tub. granifera	Wartyback-pink	2.0	10.3	15.4	2.0
* Quadrula pustulosa	Wartyback-white	5.1	5.4	6.4	2.2
Totals		100.0	100.0	100.0	100.0

* Commercial species

TABLE 4.

Species Composition and Average Catch per Drag From Brail Sampling in Wheeler Reservoir (Mile 308-316) During 1956 and 1957.

Species	1956 Tot. No. Caught	1956 Percent of Catch	1956 No. Per Sq. Yd.	1957 Tot. No. Caught	1957 Percent of Catch	1957 No. Per Sq. Yd.
Butterfly	76	1.4	0.00080	67	1.7	0.00070
Bullhead	5	0.1	0.00005	5	0.1	0.00005
Elephant ear	127	2.2	0.00120	80	2.0	0.00008
Eggshell	5	0.1	0.00005	5	0.1	0.00005
Deertoe	5	0.1	0.00005	5	0.1	0.00005
Ladyfinger	33	0.6	0.00030	29	0.7	0.00030
Maple leaf	5	0.1	0.00005	17	0.4	0.00020
Monkeyface	58	1.1	0.00055	72	1.9	0.00070
Pigtoe	3713	68.8	0.03910	2622	65.5	0.02640
Pimpleback	4	0.06	0.00003	8	0.2	0.00008
Pistolgrip	3	0.04	0.00002	4	0.1	0.00004
Three-horn	219	4.1	0.00230	203	5.1	0.00210
Three-ridge	332	6.2	0.00350	253	6.3	0.00250
Washboard	...	...	...	5	0.1	0.00005
Wartyback-pink	413	7.7	0.00440	414	10.3	0.00410
Wartyback-white	399	7.4	0.00420	216	5.4	0.00220
Totals	5397	100.0	0.05660	4009	100.0	0.04032

TABLE 5.

Analysis of Brail Sampling in Wheeler Reservoir to Compare the Catch per Drag for Pigtoe Mussels Taken During the 1956 and 1957 Harvest Seasons.

Year	Number Samples	Area Sampled (Square Yards)	Number Pigtoes	Number per Square Yard	Standard Deviation	Standard Error
1956*	142	94,566	3,713	0.039	0.0192	0.0016
1957*	149	99,274	2,622	0.026	0.0145	0.0012

*For months of April, May, June, July, and August.

TABLE 6.

Comparison of the Pigtoe Catch Per Square Yard, Catch Per Drag, and Number of Drags Made in Wheeler Reservoir During the 1956 and 1957 Harvest Seasons.

Year	Month	Total Catch Per Square Yard	Catch Per Drag Per Square Yard	Number of Drags Per Square Yard
1956	April	0.169	0.051	3.3
	May	0.118	0.041	2.9
	June	0.124	0.044	2.8
	July	0.077	0.041	1.9
	August	0.047	0.027	1.7
1957	March	0.028	0.032	0.9
	April	0.118	0.034	3.5
	May	0.026	0.021	1.2
	June	0.046	0.028	1.6
	July	0.041	0.023	1.8
	August	0.011	0.016	0.7

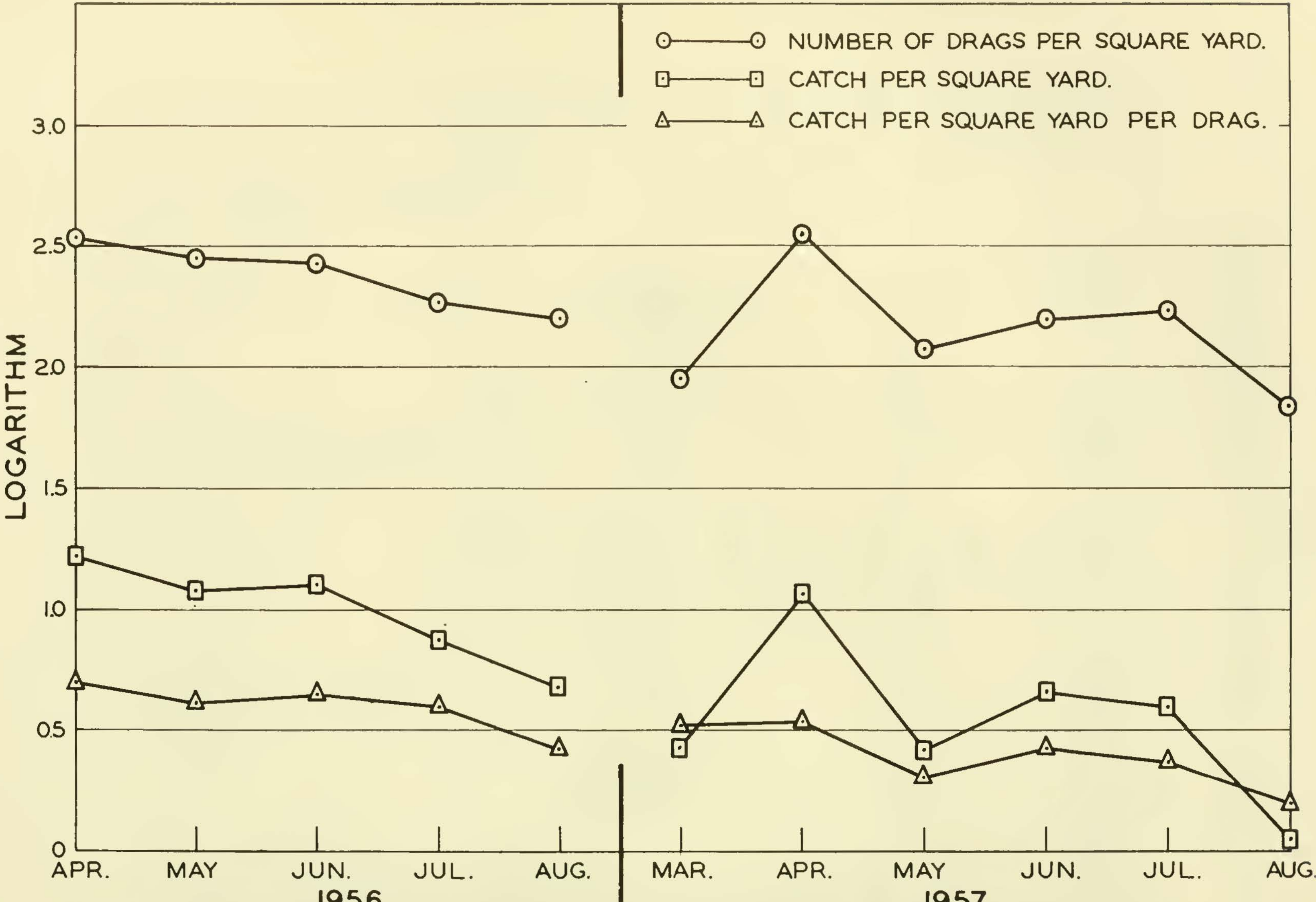

Figure 3.--Comparison of the pigtoe mussel catch, fishing effort and catch per unit of effort by time periods in Wheeler Reservoir during 1956 and 1957.

TABLE 7.

Size Composition of Pigtoe Mussels Taken by the Commercial Fishery in Four Reservoirs of the Tennessee River During 1956 and 1957.

	Wheeler		Guntersville		Chickamauga		Kentucky	
	1956	1957	1956	1957	1956	1957	1956	1957
Number measured	3,453	1,833	1,493	1,355	523	1,518	439	1,044
Length range (mm.)	20-110	30-105	30-120	35-115	50-120	50-120	45-105	50-105
Mean length (mm.)	71.1	72.4	78.8	79.1	83.8	82.3	77.7	77.9
Standard deviation (mm.)	10.4	10.2	11.7	12.8	9.5	8.0	7.8	7.3
Standard error (mm.)	0.18	0.24	0.31	0.35	0.41	0.21	0.37	0.23

these extremes. The samples in 1956 and 1957 indicated that the size distribution for each reservoir remained approximately the same for both years. The difference in mean lengths between the different locations was highly significant, indicating that a real difference exists in the size composition of the catch. However, the data from each location, when plotted, fit a normal distribution curve (figure 4).

Population sampling.--After the mark and recapture study was initiated on May 15, 1956, in Wheeler Reservoir, 33 tags were recovered during the remaining 3-month period in 1956 and 54 tags during the 6-month harvest season of 1957 (table 8). The data from tag returns and the catch of unmarked pigtoes by the commercial fishery were subjected to a chi-square test to determine if the rate of tag recovery was random by time periods in proportion to the total catch. The test showed that the difference in the ratio of tagged to untagged pigtoes caught for the various months was not significant ($X^2 = 8.17$; $P = 0.25$). Based on the mortality rate of the 100 tagged specimens used as controls (25 per cent in a confined area), the total number of tagged survivors available to the fishery was estimated at 750.

Using the Petersen method, the pigtoe population was estimated at 29,554,000, with upper and lower limits of 37,500,000 and 21,600,000 at the 95-percent level (table 9). This estimate represents the escapement population in the 7,480,000 square yards of fishing area as of August 31, 1957, after subtracting the commercial catch for the previous 9-month period.

The pigtoe population size by the area-density method, based on the 48 random SCUBA samples in Wheeler Reservoir, was estimated to be 20,566,000 with an upper limit of 28,199,000 and a lower limit of 12,940,000 at the 95-percent level (table 10).

Since SCUBA sampling provided a direct method of measuring abundance, the population estimate by this method was accepted as being more representative of the true population than that arrived at by the Petersen method. In addition, bottom sampling provided the only means of studying the total population, composed of all species and available sizes.

The best estimate of the size of the total population of all species and sizes on the Wheeler beds in August 1957 was 38,970,000 (table 11). The population was composed of 18 species, 11 of which are of commercial value. The pigtoe accounted for 52.7 percent of the total population. The rest of the population was mostly of six other species: pink wartyback (8.8 percent), white wartyback (7.8 percent), three-horn (7.4 percent), three-ridge (6.6 percent), elephantear (5.8 percent), and butterfly (4.4 percent).

The population was not distributed at random on the bottom area but was concentrated on specific beds. Mussels were found at only 39 of the 48 stations sampled; density at populated stations varied from 1 to 21 mussels per square yard. The pigtoe occurred at 37 stations; density varied from 1 to 16 per square yard.

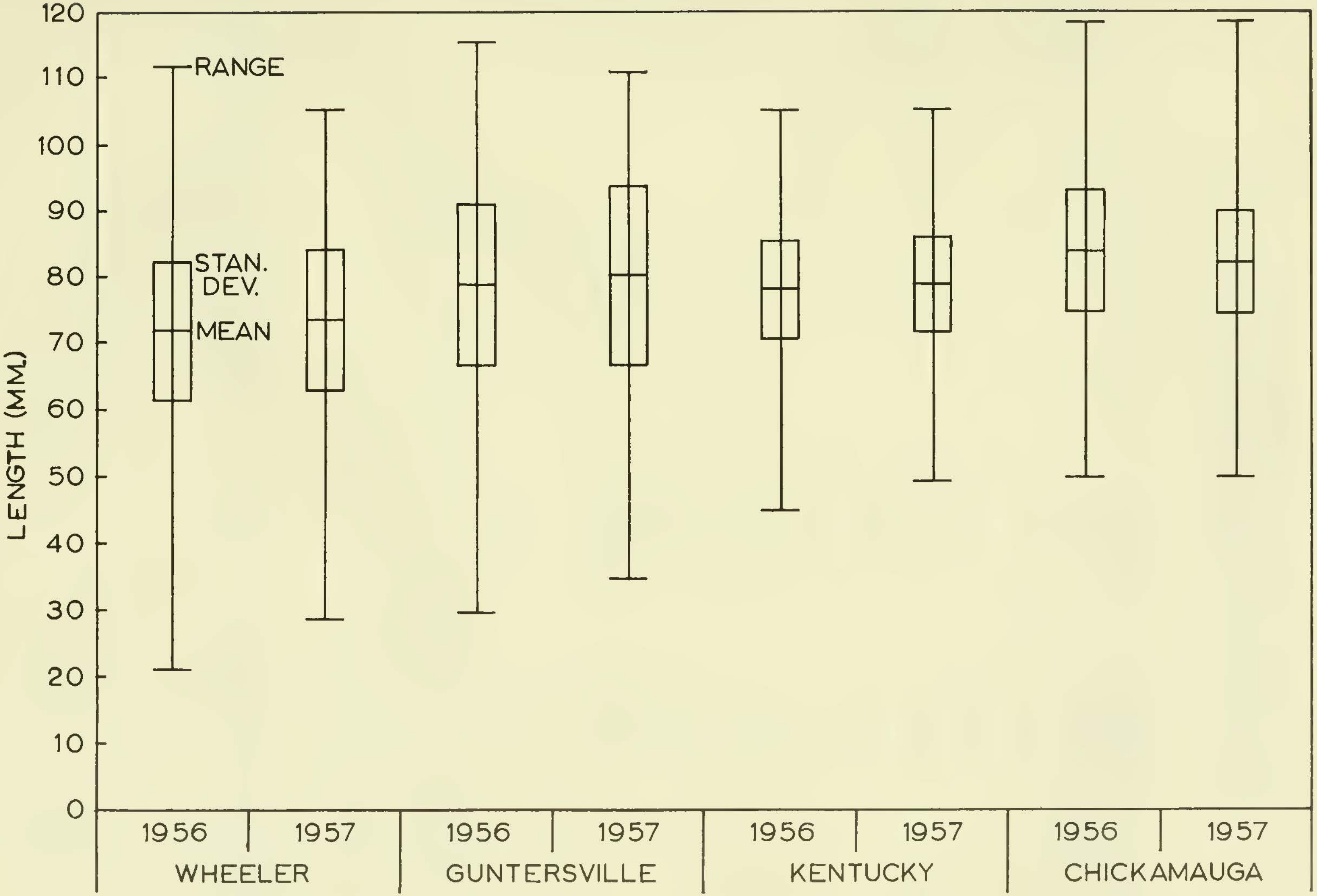

Figure 4.--Comparison of the length frequency distribution of pigtoe mussels taken by brail fishing from four mainstream reservoirs on the Tennessee River during 1956 and 1957.

TABLE 8.

Record of Tag Recaptures and Commercial Catch of Pigtoe Mussels in Wheeler Reservoir (Mile 308-316) by Time Periods.

Year	Month	Catch	Tag Recaptures
1956	June	927,000	12
	July	574,000	16
	August	347,000	5
1957	March	211,000	4
	April	883,000	22
	May	197,000	3
	June	345,000	9
	July	310,000	13
	August	82,000	3
	TOTALS	3,876,000	87

TABLE 9.

Estimate of the Population of Pigtoe Mussels in Wheeler Reservoir (Mile 308-316) by Mark-and-Recovery Method. Recaptures by Crowfoot Brail from June 1, 1956 to August 31, 1957. (Estimate as of August 31, 1957 with Poisson Distribution Assumed for the Recaptures).

Number tagged	Estimated* survival	Number of recaptures	Number caught	Petersen estimate of population**		
				Lower limit	Mean	Upper Limit
1,000	750	87	3,876,000	21,600,000	29,554,000	37,500,000

*Mortality estimated at 25 percent.
**Confidence limits - 95 percent.

TABLE 10.

Estimate of the Population of Pigtoe Mussels in Wheeler Reservoir (Mile 308-316) by Random Counts in Square Yard Bottom Samples Taken With SCUBA Gear. (Estimate as of August 31, 1957).

Total area (square yds.)	Area sampled (square yds.)	Mean per square yd.	Standard error	Population estimate*		
				Lower limit	Mean	Upper limit
7,480,000	96	2.75	0.51	12,940,000	20,566,000	28,199,000

* Confidence limits - 95 percent.

TABLE 11.

Estimate of the Total Population of Mussels in Wheeler Reservoir (Mile 308-316) as of August 31, 1957. Estimates Based on Bottom Sampling With SCUBA Gear. Population Estimated for 7,480,000 Square Yards of Bottom Area.

Species	Number Per Square Yard	Estimated Population	Percent of Population
*Butterfly	0.23	1,720,400	4.4
*Bullhead	0.01	74,800	0.2
Elephant ear	0.30	2,244,000	5.8
*Eggshell	0.01	74,800	0.2
Deertoe	0.03	224,400	0.6
Heelsplitter	0.02	149,600	0.4
*Kidney shell	0.01	74,800	0.2
Ladyfinger	0.02	149,600	0.4
*Maple leaf	0.02	149,600	0.4
*Monkeyface	0.04	299,200	0.8
*Pigtoe	2.75	20,566,000	52.7
*Pimpleback	0.05	374,000	1.0
*Pistolgrip	0.01	74,800	0.2
*Three-horn	0.39	2,917,200	7.4
Three-ridge	0.34	2,543,200	6.6
Washboard	0.11	822,800	2.2
Wartyback-pink	0.46	3,440,800	8.8
*Wartyback-white	0.41	3,066,800	7.8
TOTALS	5.22	38,966,800	100.0

* Commercial species

A total of 313 pigtoes were measured to determine the size composition of the population on the Wheeler beds. Sizes ranged from 15 to 105 millimeters, with a mean of 70.7 mm. Analysis of the length data appears below.

Number examined	Length range (mm.)	Mean (mm.)	Standard deviation	Standard error
313	15-105	70.7	12.9	0.8

The data approach a normal distribution with some negative skewness; over 60 percent of the samples were larger than the mean length and less than 40 percent were smaller than the mean.

The frequency of occurrence of small-sized mussels on bottoms at the 48 sampling stations was extremely low. Pigtoes less than 30 mm. in length occurred at only 3 stations. The number of mussels less than 30 mm. in size collected from the 96 square yards of bottom area was as follows: 5 pigtoe, 12 deertoe, 3 white wartyback, 2 heelsplitter, 2 washboard, and 1 three-horn.

Relation between abundance and catch.--The results from SCUBA samples in 5,000 square yard test areas in 2 reservoirs showed that population densities varied from 6.7 mussels per square yard in Wheeler to 16.7 per square yard in Chickamauga Reservoir. The population density for the pigtoe was 2.5 per square yard in Wheeler and 10.7 per square yard in Chickamauga.

Brail samples taken in these areas during August and September provided a comparison of catch rates from different populations. In Wheeler Reservoir the mean catches per drag per square yard were 0.024 for all species and 0.011 for the pigtoe; in Chickamauga they were 0.056 for all species and 0.039 for the pigtoe (table 12). The rates of depletion per drag for the different populations amounted to 0.36 percent in Wheeler and 0.34 percent in Chickamauga for all species combined. For the pigtoe, populations were depleted at the rate of 0.44 percent per drag in Wheeler and 0.37 percent in the Chickamauga test area. These rates are valid only for the specified sampling periods (August and September) because of seasonal variations in the effectiveness of the harvest method.

In the treatment of the data for regression analysis, four variables were used to define the correlation between population density and catch success (table 13). The test for correlation resulted in a significant positive coefficient ($r = 0.98$). Using the linear regression method, a line was fitted to the plotted points with the formula $Y = -0.001 + 0.0036X$ (figure 5). The results indicate that fluctuations in catch per drag are directly proportional to changes in the level of abundance during a given time period.

TABLE 12.

Analysis of SCUBA and Crowfoot Brail Samples From 5,000 Square Yard Test Areas in Wheeler and Chickamauga Reservoirs in August and September 1957. Data for Total Mussels and Pigtoes Treated Separately.

	Wheeler		Chickamauga	
	SCUBA	Brail	SCUBA	Brail
Number of samples	10	16	10	16
Area Sampled (Sq. yds.)	20	10,526	20	9,996
Total Mussels	133	249	333	562
Number of Species	16	11	17	16
Mean Per Sq. Yd.	6.7	0.024	16.7	0.056
Standard Deviation	2.04	0.011	7.6	0.036
Standard Error	0.64	0.003	2.1	0.009
....				
Total Pigtoes	50	118	214	389
Mean Per Sq. Yd.	2.5	0.011	10.7	0.039
Standard Deviation	1.3	0.005	6.5	0.029
Standard Error	0.39	0.001	1.82	0.007

TABLE 13.

Variables Used in the Regression Analysis of Population Density and Catch Per Drag for 5,000 Square Yard Test Areas in Wheeler and Chickamauga Reservoirs during 1957.

	X - Density Per Square Yard	Y - Catch Per Drag Per Square Yard
Wheeler (Pigtoe)	2.5	0.011
Wheeler (Other species combined)	4.2	0.013
Chickamauga (Pigtoe)	10.7	0.039
Chickamauga (Other species combined)	6.0	0.017

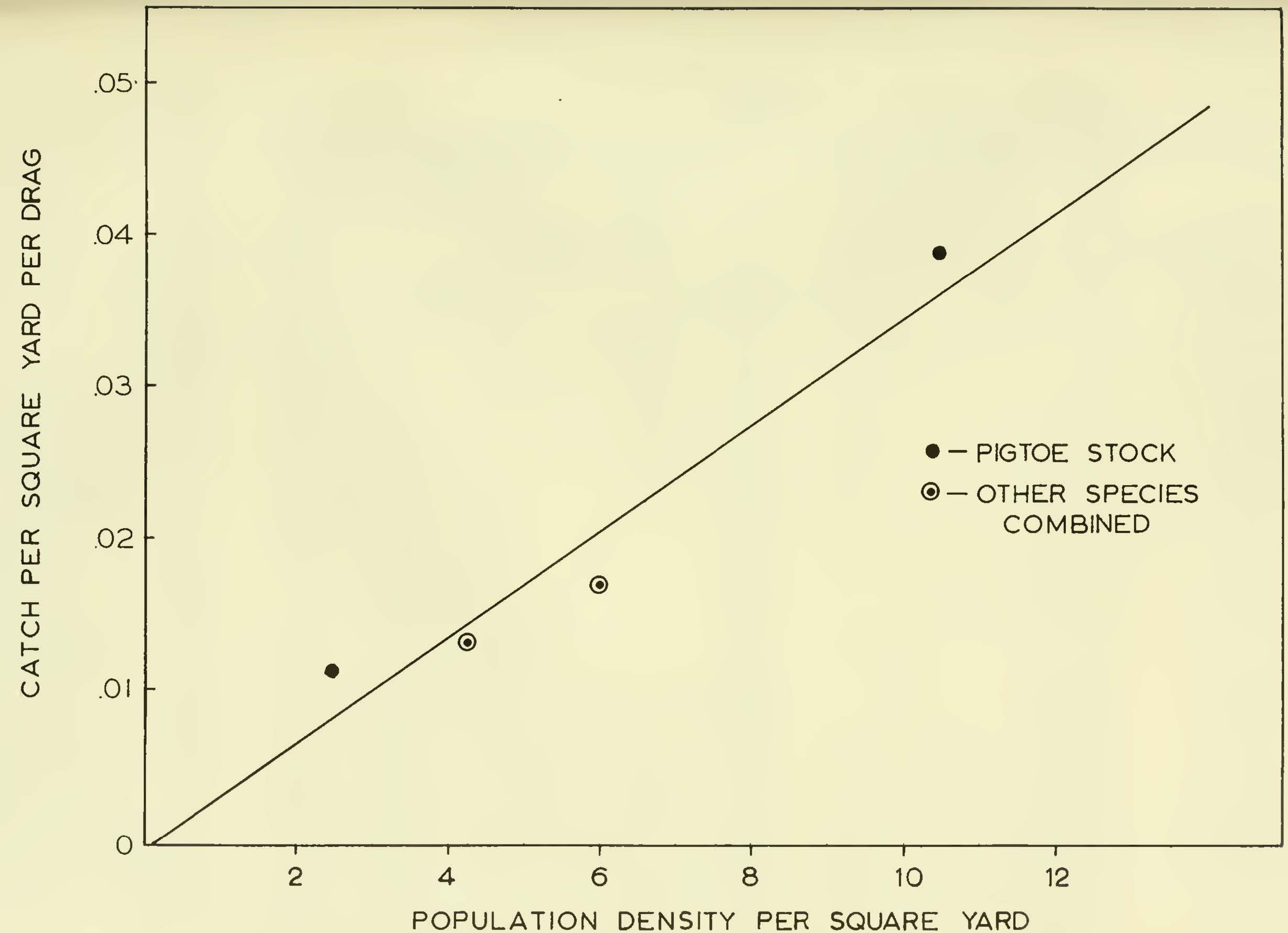

Figure 5.--Correlation of the catch per drag by crowfoot brail with the density of mussel populations. Data from SCUBA samples in Wheeler and Chickamauga Reservoirs plotted against data from brail samples obtained from corresponding areas during August and September 1957. (Line fitted by the formula Y = -0.001 ∤ 0.0036X.)

Of 18 species in SCUBA samples from Wheeler Reservoir, 11 occurred in brail samples; 17 species in SCUBA samples from Chickamauga, 16 occurred in brail samples (table 14). The data show the rate of exploitation was highly variable for the different species. This indicates that the brail method of fishing is selective, tending to catch certain species more frequently than others. The pigtoe appears to be especially vulnerable since the rate of depletion per drag for this species was higher than the average depletion rate for all other species combined on each test area.

Length frequency data acquired by SCUBA and brail samples provided a comparison between the size composition of the population and the size composition of the catch for two different areas (table 15). The length frequency distribution for the SCUBA samples in Wheeler Reservoir ranged from 15 to 104 mm.; the length range for the brail samples was 30 to 104 mm. Sizes less than 50 mm. made up 6 percent of the population and 1.8 percent of the catch. In Chickamauga Reservoir the length range was 30 to 119 mm., in both SCUBA and brail samples. Size frequencies less than 50 mm. in length comprised 1 percent of the SCUBA samples and 0.6 percent of brail samples. To test the homogeneity between SCUBA and brail samples at each location, the length data were analyzed by chi-square:

(Length data grouped at 10 mm. intervals)

Wheeler		Chickamauga	
SCUBA samples -	$X^2 = 15.04$	SCUBA samples -	$X^2 = 3.64$
brail samples -	$X^2 = 7.51$	brail samples -	$X^2 = 2.12$
Sum -	$X^2 = 22.55$	Sum -	$X^2 = 5.76$
6 d.f.; P	$= 0.005$	5 d.f.; P	$= 0.30$

The size frequency differential between SCUBA and brail samples in Wheeler Reservoir was highly significant, whereas the difference between SCUBA and brail samples from Chickamauga Reservoir was not significant. These tests indicate that the brail method of fishing tends to catch pigtoe mussels larger than 50 mm. in length more successfully than it does the smaller sizes. Since a greater number of the smaller sizes (less than 50 mm.) were available on the Wheeler beds, the size composition of the catch was not in agreement with that of the population. In contrast, the size composition of the catch in Chickamauga Reservoir was very similar to that of the population because of the lesser availability of small mussels on beds at this latter location (figure 6).

Habitat conditions.--Comparison of bottom characteristics at the 48 SCUBA sampling station in Wheeler Reservoir with the number of mussels taken at each station showed the following relation:

TABLE 14.

Comparison of Species Composition, Population Densities and Catch Per Drag in Two 5,000 Square Yard Test Areas Located in Wheeler and Chickamauga Reservoirs During August and September 1957.

Species Name	Wheeler 1/		Chickamauga 2/	
	Population Per Sq. Yd.	Catch Per Sq. Yd. Per Drag	Population Per Sq. Yd.	Catch Per Sq. Yd. Per Drag
Butterfly	0.25	0.0010	0.20	0.0003
Bullhead	----	------	0.05	0.0008
Elephant ear	0.30	0.0004	1.10	0.0070
Eggshell	0.10	0.0003	0.05	0.0005
Heelsplitter	0.05	------	0.05	------
Ladyfinger	0.05	0.0002	0.15	0.0007
Monkeyface	0.10	0.0001	1.90	0.0009
Mucket	----	------	0.10	0.0001
Pigtoe	2.50	0.0110	10.70	0.0389
Pimpleback	0.15	------	0.05	0.0001
Pistolgrip	----	------	0.05	0.0001
Pocketbook	----	------	0.10	0.0001
Three-horn	0.85	0.0019	0.35	0.0008
Three-ridge	0.45	0.0050	0.05	0.0008
Sandshell-black	----	------	0.05	0.0001
Maple leaf	0.05	0.0002	----	------
Kidney shell	0.05	------	----	------
Washboard	0.25	------	----	------
Wartyback-pink	0.65	0.0030	0.75	0.0025
Wartyback-white	0.80	0.0013	1.00	0.0024
Deertoe	0.05	------	----	------
Totals	6.70	0.0240	16.70	0.0560

1/ Mile 309.
2/ Mile 515.

TABLE 15

Length Frequency Distribution of the Sampled Population of Pigtoe Mussels (*Pleurobema cordatum*) from beds on Wheeler and Chickamauga Reservoirs in 1957. Length frequency Data from Brail Sampling on these Same Beds is Included for Comparison.

Length groups (mm)	Wheeler Population Samples Number	Wheeler Population Samples Percent	Wheeler Catch Samples Number	Wheeler Catch Samples Percent	Chickamauga Population Samples Number	Chickamauga Population Samples Percent	Chickamauga Catch Samples Number	Chickamauga Catch Samples Percent
15-19	1	0.3	...	...	...	...	...	...
20-24	2	0.6	...	...	...	...	...	...
25-29	2	0.6	...	...	...	...	...	...
30-34	2	0.6	1	0.2	...	...	...	...
35-39	5	1.6	1	0.2	...	...	...	...
40-44	3	1.0	3	0.6	1	0.5	1	0.3
45-49	4	1.3	4	0.8	1	0.5	1	0.3
50-54	8	2.6	14	2.6	1	0.5	1	0.3
55-59	10	3.2	29	5.5	1	0.5	3	0.8
60-64	18	5.8	24	4.5	2	1.0	3	0.8
65-69	32	10.2	49	9.2	12	5.7	14	3.9
70-74	85	27.2	117	22.1	19	9.0	39	10.8
75-79	52	16.6	130	24.5	21	9.9	54	14.9
80-84	40	12.8	80	15.1	50	23.6	85	23.5
85-89	22	7.0	48	9.1	44	20.8	77	21.3
90-94	20	6.4	20	3.8	26	12.3	47	12.0
95-99	5	1.6	9	1.7	16	7.5	17	4.7
100-104	2	0.6	1	0.2	9	4.2	12	3.3
105-109	...	...	...	...	6	2.8	4	1.1
110-114	...	...	...	...	2	0.9	3	0.8
115-119	...	...	...	...	1	0.5	1	0.3
Totals	313	100.0	530	100.0	212	100.0	362	100.0
Mean length	70.7 mm.		72.6 mm.		82.4 mm.		81.3 mm.	
Standard deviation	12.9		10.2		11.4		9.9	
Standard error	0.80		0.44		0.78		0.52	

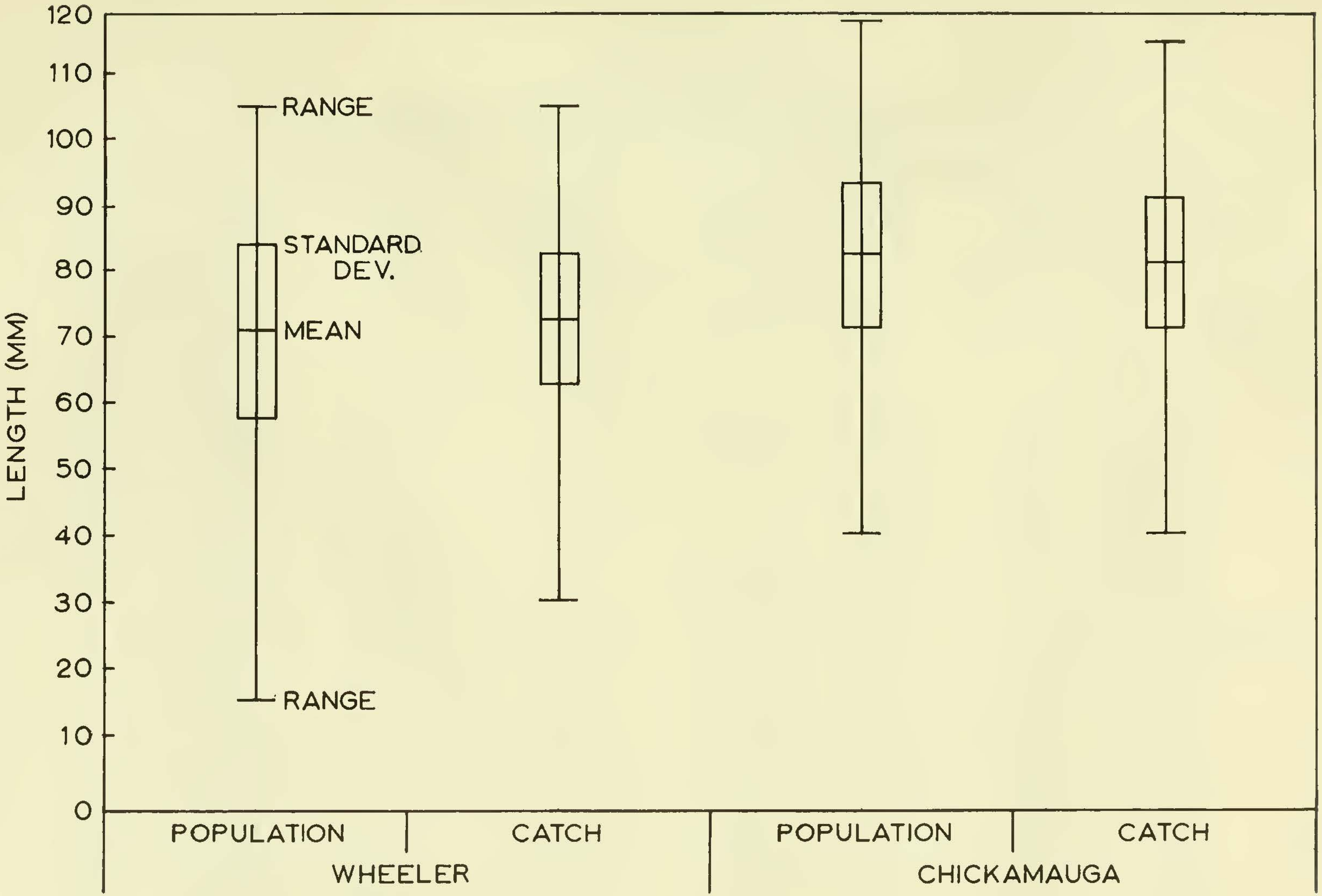

Figure 6.--Comparison of the length frequency distribution of pigtoe mussels collected by bottom samples and brail samples on Wheeler and Chickamauga Reservoirs in August 1957.

Bottom type	Percent of total area	Percent of all mussels	Number of species
Rubble--gravel--sand	75.0	97.4	18
Mud-gravel	6.0	1.0	2
Marl	19.0	1.6	4

The importance of the rubble--gravel--sand bottom type is demonstrated; practically all of the mussels occurred here. This type of bottom best meets the requirements for most species. The mud-gravel type was not extensive, found only on lateral areas close to shore. The marl formation, extending across the stream to form an irregular pattern at various locations, provides an impenetrable bottom unsuitable for mussels. The few that were found here had embedded in isolated soil pockets where the marl strata was broken or depressed.

The deposition of silt on mussel beds ranged as high as 1 1/4 inches in depth on lateral areas close to shore where the current was slow. Silt was about 1/2 inch deep on central areas in the stream channel. Silt deposits were especially deep on bottoms behind large boulders or sunken logs where the stream flow was impeded. A relatively large number of dead shells, of different species and sizes, were found under layers of silt 1 inch or deeper at several stations. These shells were embedded in a normal position with the valves closed; the shells showed little sign of erosion, indicating that mortality had occurred within recent months.

As previously reported, juvenile deertoe mussels, a noncommercial species, were the most abundant of the small size classes found on the areas sampled. According to Ellis (1931) the deertoe is a mud-loving species capable of surviving on bottoms that most other species cannot tolerate.

Bottom conditions on the limited area sampled in Chickamauga Reservoir were similar to conditions in Wheeler Reservoir except for the absence of the marl type formation. The depth and extent of silt layering on the beds was approximately the same as described for the Wheeler beds.

Age and growth of the pigtoe.--Age determinations of samples from Wheeler and Chickamauga beds showed that only a few specimens less than 1 year old were available for study from Wheeler and none less than 6 years old from the study area in Chickamauga Reservoir. The calculated annual growth rate for the first 5-year period on the Wheeler beds was 7.0 millimeters. The annual growth increment for the second 5-year period averaged 3.7 mm. on Wheeler and 2.8 mm. on Chickamauga (table 16). Growth was slower and more variable on both reservoirs after the tenth year. Although older specimens were present, age was indeterminate beyond 25 years. The

TABLE 16.

Age and Growth of the Pigtoe (Pleurobema cordatum) in Wheeler and Chickamauga Reservoirs. Lengths Measured in Millimeters.

Wheeler				Chickamauga			
Year of life	Length range	Mean length	Annual increment	Year of life	Length range	Mean length	Annual increment
1	5-11	7.8	...	...	...	...	...
2	11-15	13.0	5.2	...	...	...	...
3	17-30	22.6	9.6	...	...	...	...
4	21-36	30.5	7.9	...	...	...	...
5	30-38	35.2	4.7	...	...	...	...
6	36-44	39.2	4.0	6	40-42	40.7	...
7	38-48	43.1	3.9	7	40-48	44.0	3.3
8	46-54	49.3	6.2	8	42-50	47.0	3.0
9	50-54	52.0	2.7	9	50-54	52.3	5.3
10	52-58	54.3	2.3	10	52-56	54.0	1.7
11	52-59	54.6	0.3	11	54-58	56.5	2.5
12	56-60	57.4	2.8	12	56-62	59.5	3.0
13	60-61	60.5	3.1	13	56-66	60.0	0.5
14	60-65	62.8	2.3	14	58-68	61.5	1.5
15	60-67	63.9	1.1	15	62-68	64.7	3.2
16	64-67	65.6	1.7	16	64-70	66.8	2.1
17	64-70	66.8	1.2	17	64-76	69.2	2.4
18	68-72	68.7	1.9	18	68-78	73.3	4.1
19	70-74	72.1	3.4	19	70-80	75.4	2.1
20	74-76	75.2	3.1	20	72-82	75.9	0.5
21	74-77	75.6	0.4	21	72-83	76.8	0.9
22	76-78	77.0	1.4	22	78-84	81.0	4.2
23	78-82	79.5	2.5	23	78-86	82.2	1.2
24	80-84	82.4	2.9	24	84-88	85.0	2.8
25	84-88	84.5	2.1	25	84-89	87.0	2.0

eroded surface of these older shells precluded the use of the annular ring method for age determination. The difference in growth rates between the two reservoirs during a past span of 19 years, ages 6 through 25, was tested for significance by chi-square:

	Wheeler	Chickamauga
Total growth increment (19 years)	45.3 mm.	46.3 mm.
Mean annual growth	2.38 mm.	2.44 mm.
Chi-square	6.04	6.03
Sum of pooled chi-squares =	12.07;d.f.=19;P=0.8	

Apparently, growth conditions were approximately the same in both reservoirs since the difference in growth rates was not significant.

The age compositions of the stocks of pigtoe mussels on beds in Wheeler and Chickamauga Reservoirs were determined by converting length frequency data from SCUBA samples (table 15) to corresponding age frequencies. Adjustments were made to the data to compensate for variations in growth for the different sizes. To facilitate comparison, age frequencies were grouped for successive 3-year intervals (table 17, figure 7).

The dominant strength on the Wheeler beds was composed of survivors which originated during the years of 1937 through 1939. Almost 90 percent of the population was older than 12 years. Only about 4 percent of the present population was younger than 5 years.

The age structure of the population in the Chickamauga study area showed that the dominant strength was represented by the year classes of 1934 through 1936. Over 95 percent were older than 12 years. No specimens less than 6 years old were found on these beds.

Reproduction of the pigtoe.--During 1957, the first females containing fertilized eggs were collected on April 6; the first females with immature glochidia were taken on April 24. Mature glochidia, ready for release, were first found in samples on May 6. The presence of sexual development as the season progressed is shown in figure 8. The pattern of the curve shows three distinct points which correspond to peaks in the development of glochidia. These modes, based on the percentage frequency for mature glochidia in proportion to the total number in each sample, occurred on May 15, June 17, and August 20. The periods during which the percentages of mature glochidia declined, following the dates of each modal point, represent spawning periods. Three definite spawning periods occurred within the following dates: May 15 to June 6, June 17 to July 10, August 20 to October 4.

Females with fertilized eggs were first observed on April 6 when the water temperature was 61°F.; females with mature glochidia were first observed 1 month later when the temperature was 70°F. From this observation, it appears that about a month is required, with rising temperature, to advance from ovoposition to full development of the glochidia. This agrees with findings by Howard (1921) who reported that the fertilization

TABLE 17.

Age Composition of Pigtoe Stocks on Beds Sampled in Wheeler and Chickamauga Reservoirs in 1957. Ages Combined for Three-Year Periods.

Age Groups	Year Classes	Population Samples: Wheeler Number	Wheeler Percent	Chickamauga Number	Chickamauga Percent
0 - 2	1957-1955	1	0.3	0	0.0
3 - 5	1954-1952	10	3.3	0	0.0
6 - 8	1951-1949	13	4.2	3	1.5
9 - 11	1948-1946	14	4.5	3	1.5
12-14	1945-1943	35	11.2	11	5.0
15-17	1942-1940	67	21.2	23	10.5
18-20	1939-1937	107	32.5	33	15.6
21-23	1936-1934	46	14.8	73	34.8
24-26	1933-1931	21	6.8	31	14.6
27-29	1930-1928	4	1.2	22	10.4
30-32	1927-1925	0	0.0	13	6.1
		313	100.0	212	100.0

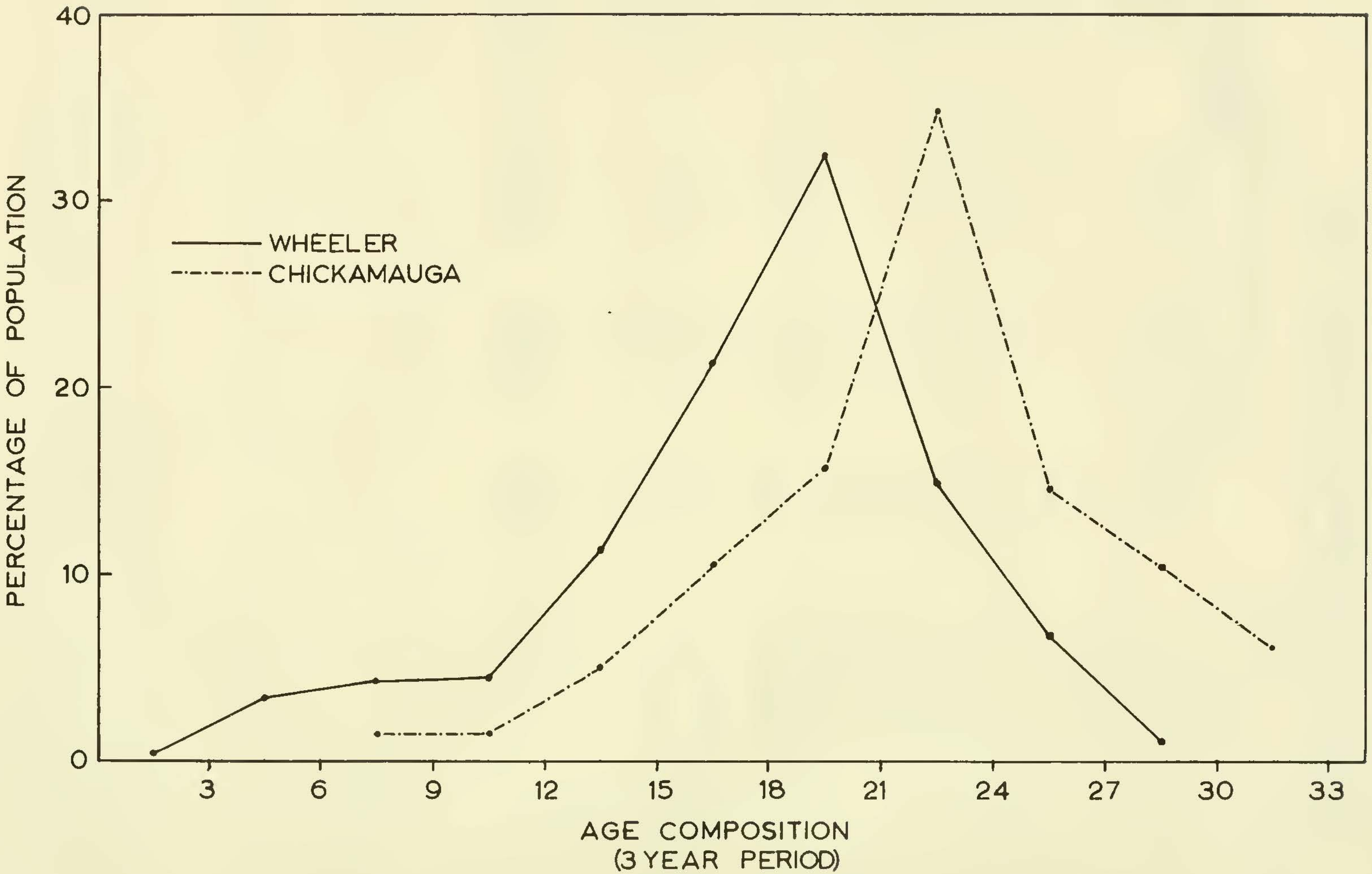

Figure 7.--Comparison of the age composition of pigtoe stocks on beds in Wheeler and Chickamauga Reservoirs in 1957. Age classes are combined for successive 3-year periods.

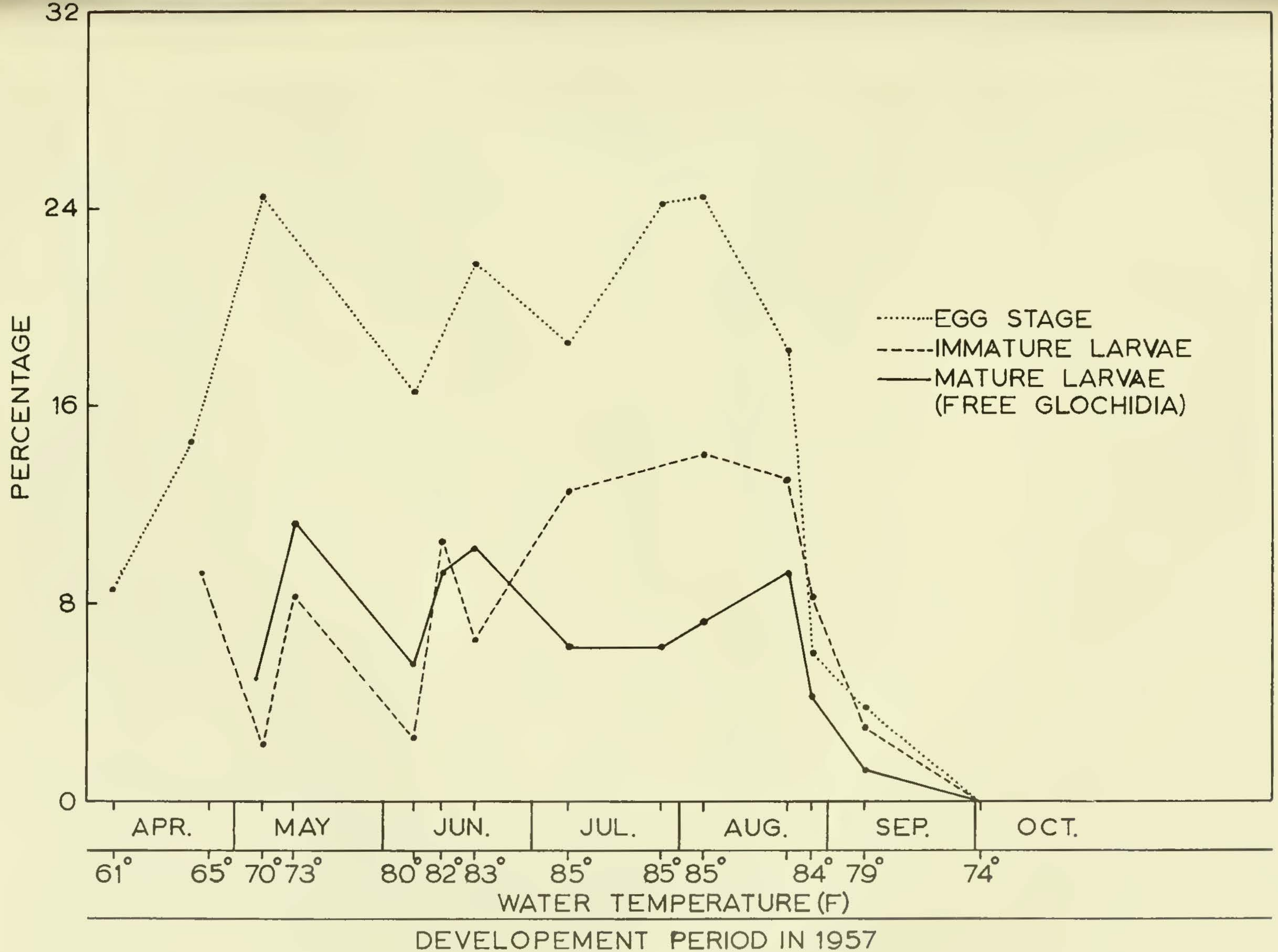

Figure 8.--Sexual development chart showing the stages of development of gravid pigtoe mussels in Wheeler Reservoir by time periods in 1957. Percentages are based on the number in each stage in relation to the total number examined for each sample period. (Each sample consisted of 100 specimens.)

of eggs of *Pleurobema* sp. occurred in early spring and the release of glochidia by the parent female in the summer and early fall. The occurrence of three spawning periods is probably explained by the fact that many of the gravid females examined had marsupia containing all three stages of development. Thus, these females probably spawned intermittently until all fertilized eggs had matured and were emitted.

The youngest gravid female examined was 6 years old and measured 42 mm. in length. Some of the oldest reproductively active females were estimated to be 25 years old and were 90 mm. in length. Pigtoe glochidia were examined while in the preparasitic stage. Surber (1915) described the shape as semicircular with a straight hinge-line. He reported the dimensions as 0.160 mm. (length) by 0.175 (depth). Our findings agree with those of Surber except dimensions were slightly smaller--the length was 0.156 mm. and the depth 0.163 mm.

Gills from 283 fish collected from Wheeler Reservoir during the summer months of 1956 were examined to find evidence of parasitism by pigtoe glochidia. The results this first year were negative. In 1957, 330 fish of 16 species were examined for gill infections. Of these, one encystment was found on each of three species of fish, a fresh-water drum *Aplodinotus grunniens*, channel catfish *Ictalurus punctatus*, and bluegill *Lepomis macrochirus*. These three encystments could not be identified conclusively as pigtoe glochidia because of the difficulty of extracting the organisms intact from the cysts and taking exact measurements. In all, 27 fish, represented by the previously mentioned species, were parasitized by other kinds of glochidia. Most of these were on the fresh-water drum, which was heavily parasitized by glochidia of the deertoe *Truncilla donaciformis*.

COMPARISON OF RESULTS

Analyses of catch records and data from brail sampling show a considerable decline in the status of the commercial fishery on Wheeler Reservoir between 1956 and 1957. The commercial catch of pigtoe mussels in 1957 was 49 percent less than that in 1956. Despite an increase in the selling price of shells, from an average of $2.50 per boxload in 1956 to $3.50 per boxload in 1957, fishing effort declined 24 percent in 1957, probably because of a significant reduction in the catch per unit of effort. A drop of 33 percent in catch per unit of effort reduced fisherman earnings below a profitable level (table 5).

A positive linear regression existed between catch per unit of effort and the density of the population in areas sampled with crowfoot brail and SCUBA gear in two reservoirs. The density of pigtoe mussels on beds in Chickamauga Reservoir was 4 times as great as the density on beds in Wheeler Reservoir and the brail catch per unit of effort on the more abundant population was 4 times as great as that for the sparse population. This relation remained fairly constant, although catch per unit of effort on a given area varied seasonally.

While annual fluctuations in catch per unit of effort denote changes in the size of the population, seasonal variation seems to be caused by changes in the behavior of the mussels which affect their catchability. Intensive brail dragging over the beds in the early part of the season may have a disturbing influence and reduce catch success during the latter part of the season. As previously described, the seasonal catch success (see table 6) for both 1956 and 1957 was highest in April, declined sharply in May, increased slightly in June, and gradually declined as the season advanced. The trend in fishing effort followed a similar pattern. Unfavorable weather prevented fishing during March of 1956 and restricted the amount of fishing done in March of 1957. Weather was not a serious factor, however, during the remaining months of either year.

Certain species are harvested at a higher rate in proportion to their relative abundance than are other species in the population. The pigtoe appears to be especially vulnerable, since the rate of harvest for this species in test areas was higher than the average rate for all other species combined. The crowfoot brail appears to be biased in catching certain sizes of pigtoe mussels. The brail tends to catch size groups larger than 50 mm. in length with a higher frequency rate in proportion to relative abundance than it does the smaller size groups. This indicates the smaller and therefore younger stocks, being less vulnerable, are offered some natural protection from fishing pressure.

A valid statistical comparison between the two methods used to estimate the size of the pigtoe population in Wheeler Reservoir is not possible because of the different procedures used. A simple comparison, however, shows that the estimate by SCUBA sampling is about 70 percent as high as that for the tag and recovery method. It was impossible to achieve strict accuracy by either method because of the variables involved, foremost of which was the non-uniform distribution of the mussels on the beds. The actual count method by SCUBA sampling is presumed to provide the most reliable estimate.

Using the number estimated by SCUBA sampling, population of pigtoe mussels at the end of the 1957 harvest season was 20,564,000 in the productive area of Wheeler Reservoir. Since catch records provided an estimate of 6,024,000 harvested during the previous 2 years, the estimated number available at the start of the 1956 harvest season was 26,590,000, if natural mortality is disregarded. These figures indicate that 23 percent of the population was exploited during the two years. When calculated for each year, the harvest rates were 14 percent in 1956 and 9 percent in 1957.

It is obvious that with the high rate of mortality attributed to commercial fishing, an equally high rate of replacement is needed for the population to maintain the same relative abundance, disregarding natural mortality. The significant decline in catch per unit of effort between 1956 and 1957 indicated a declining abundance, substantiated by the age structure of the available population in Wheeler Reservoir (see figure 9). Over 90 percent of the population was older than 12 years and almost 20 years had elapsed since the dominant year class originated. Recruitment to the population between 1956 and 1957 was less than 1 percent as compared to the 23 percent loss by commercial exploitation. Since the beds on Wheeler Reservoir had been exposed to commercial fishing for the past 12 years, it was suspected that harvest operations might have a harmful effect on the survival of young mussels and therefore limit recruitment. Further studies on Chickamauga Reservoir failed to justify this hypothesis. The age structure of this relatively unexploited population showed that over 95 percent of the population was older than 12 years. These old-age stocks were dominated by the year classes of 1934-36. While protected from fishing, there has been no recruitment to the Chickamauga population during the past 6-year period as evidenced by the failure to find any mussels younger than the 1951 year class.

Age and growth studies of the pigtoe mussel showed that between 8 and 9 years is required to produce a desirable market size shell of 50 mm. in length. This also is approximately the age at which they reach an optimum catchable size. The slow growth rate does not permit a rapid restoration of catchable stocks to the fishery even if reproduction should be successful at least once within the next few years. Since growth rates were similar in Wheeler and Chickamauga Reservoirs, there is no evidence that favors one location over the other so far as growth is concerned.

Examination of the condition of gill marsupia in gravid female pigtoes in 1957 indicated glochidia production to be satisfactory for the population in Wheeler Reservoir. Release of glochidia by parent females occurred during three distinct periods between May 15 and October 4. However, since the parasitic phase in the life-cycle of the pigtoe is unknown at present, the fate of the glochidia produced could not be determined. Despite the fact that gills from 613 fish of 17 different species were examined during the summer months of 1956 and 1957, the identity of the host-fish presumed necessary for complete development of the pigtoe glochidia could not be determined. Because of this complex life-cycle, the availability and habits of a host-fish could have a great influence on the future status of the pigtoe stocks. To account for the natural abundance and present distribution of the pigtoe in the Tennessee River, an excellent relation of coexistence between the glochidia and its host-fish must have prevailed in past years. Presumably, the success of this relation has declined because of a change in the availability of the host-fish or poor survival of the glochidial stage in the present environment.

That the silt deposits on recently examined bottoms in Wheeler and Chickamauga Reservoir may be having a detrimental effect on the mussels present, is indicated by the finding of large numbers of properly oriented dead shells, young as well as old individuals, under heavy deposits of silt. Very few live young mussels, with the exception of the

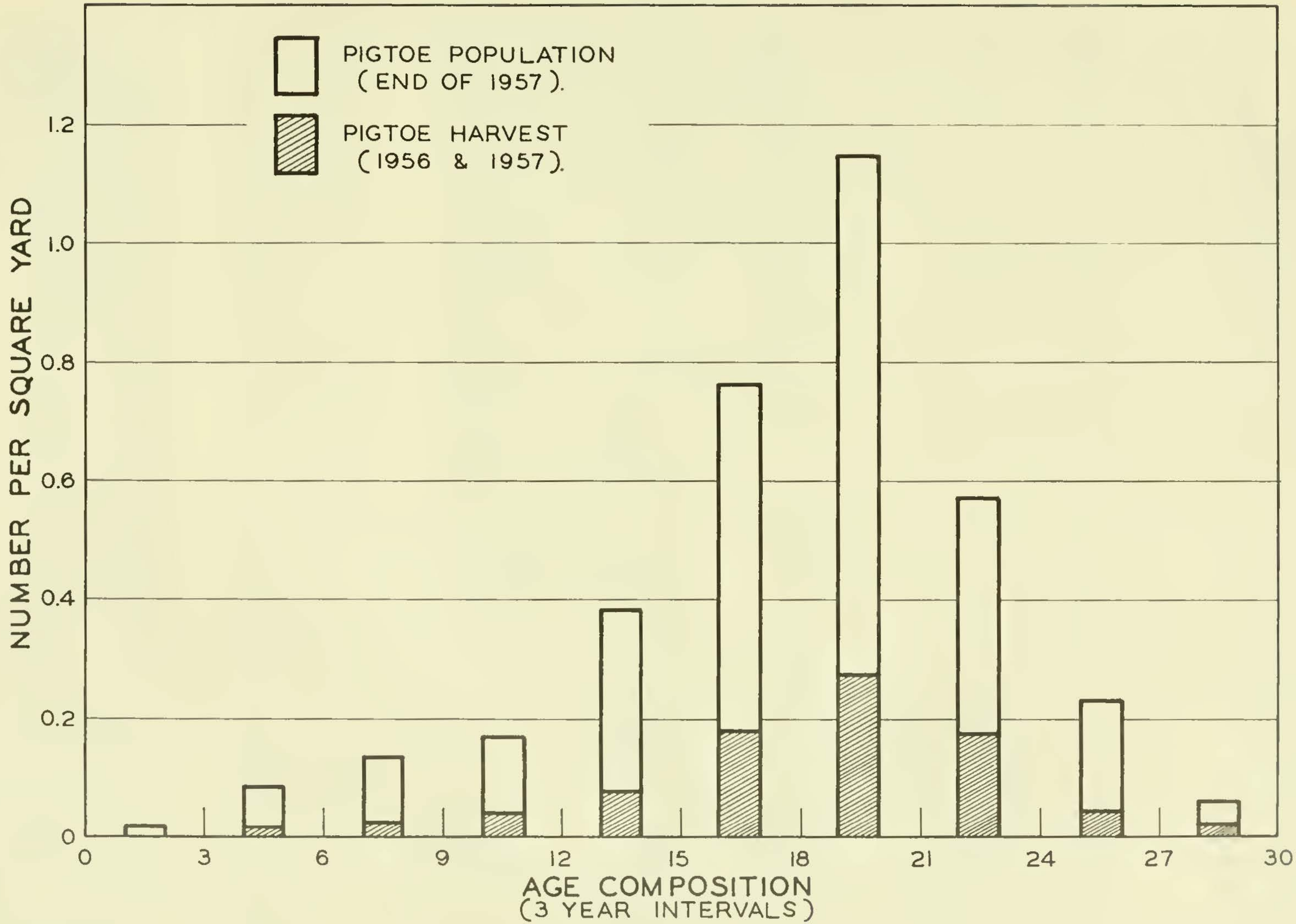

Figure 9.--Comparison of the age structure, population density and mortality from commercial fishing for the pigtoe stocks in Wheeler Reservoir (mile 308-316).

deertoe, a mud-loving species, were found in SCUBA samples. Silt deposition has long been regarded as a destructive factor on mussel beds. Ellis (1936) reported that lethal limits of silt coverage on experimental beds of mussels varied from 1/4 inch for the least resistent species to 1 inch for some of the most resistent species. Death was attributed to gradual smothering as the silt accumulated over the mussels.

Siltation in the reservoirs of the Tennessee River was intensified after impoundment of the stream was completed during the years 1936 to 1944. On the basis of the age structure of the population of pigtoe mussels in Wheeler Reservoir, the dominant year classes of 1936-39 were produced during the years before the reservoir system was completed. On Chickamauga Reservoir, over 90 percent of the pigtoe population was preimpoundment stock. This indicates that success of population expansion and the change from a stream to a reservoir type habitat are related. As the present age structures show, recruitment to the populations by subsequent year classes has steadily declined during the elapsed span of years since habitat conditions changed.

As previously stated, the results from these studies apply to specific areas in the Tennessee River. Because of physical limitations, it was impossible to carry out a comprehensive study program on all parts of the river simultaneously, which would be necessary to determine annual variations in population structure. Further research is needed to understand the complete life-history of the pigtoe mussel. This is important since the economic level of the commercial fishery is primarily dependent on the abundance of this species.

CONCLUSIONS

The pigtoe mussel Pleurobema cordatum is the most abundant commercial species taken by the mussel fishery on all parts of the Tennessee River. On Wheeler Reservoir, the pigtoe comprised over 80 percent of the commercial catch in 1956 and 1957.

The commercial fishery on Wheeler Reservoir declined between 1956 and 1957 as evidenced by the significant reduction in total catch, catch per unit of effort, and fishing effort during the latter year. This decline was attributed to the high rate of exploitation during 1956, and presumably earlier years, which reduced the size of the population available for the fishery in 1957.

Catch per unit of effort by the crowfoot brail varies in direct proportion to the size of the available population for a given area. Catch rates also vary on a seasonal basis for a given area, being highest in April and declining as the season progresses. The brail method of fishing is selective for certain species and sizes of mussels in a population. Pigtoe mussels over 50 mm. in length are especially vulnerable to fishing by the brail method.

Overharvesting of stocks of pigtoe mussels in Wheeler Reservoir in 1956 and 1957 resulted from the high rate of exploitation by commercial fishing (23 percent both years) as compared to the low rate of natural replacement (less than 1 percent). Major support to the fishery is derived from stocks which are over 15 years old; some members appear to be over 25 years old.

The limiting factors in natural replacement appear to be related to the complex life history of the pigtoe mussel and changes in the environment after the river was impounded. Although the pigtoe produced glochidia in 1957, their survival is uncertain because of apparent failure to find the proper host-fish for the parasitic stage of development. Extensive silt deposits on bottom areas, accumulated since the river was impounded, appear to have created an unfavorable habitat for the survival of young mussels. Only juvenile sizes of the deertoe *Truncilla donaciformis*, a silt-tolerant species, were found in appreciable numbers on bottom areas sampled.

The slow growth of the pigtoe is not conducive to a rapid restoration of the resource for commercial purposes even if a dominant year class succeeded in expanding the size of the population in the near future. Approximately 8 to 9 years must elapse before an adequate marketable size of 50 mm. in length is reached.

Findings described in this report do not indicate the need for imposing specific regulations on the commercial harvesting of mussels, which would conserve or increase the resource in future years. There is a possibility that more knowledge of the life-cycle of the pigtoe mussel might lead to some means for increasing its abundance. However, if a poor environment is the chief limiting factor, there is slight hope of restoring depleted populations to a former level and the trend may continue to be that of a vanishing resource.

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