2010 Duck River Quantitative Mussel Survey

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INTRODUCTION

The Duck River in south-central Tennessee remains one of the most biologically diverse rivers on the North American continent. Its watershed covers 3,127 square miles or approximately two million acres of the Interior Low Plateau Physiographic Province. Beginning in the Eastern Highland Rim subsection in Coffee County, the Duck River flows westward across the Central Basin for approximately 290 miles passing through six counties before joining Kentucky Reservoir on the Tennessee River in the Western Highland Rim subsection in Humphreys County. The Duck River is largely free-flowing for much of its length, except for the Tennessee Valley Authority (TVA) Normandy Dam near the headwaters. It is the longest river wholly contained within Tennessee's borders and drains 8% of Tennessee's land area.

The Upper Duck watershed, in particular, is characterized by sinkhole plains and year-round springs and limestone bluffs. The mineral-rich geology and eroding limestone base of the watershed add abundant calcium carbonate and nutrients to its water – primary drivers for the river's exceptional mussel fauna. Freshwater mussels filter the water for nutrients to construct their shells, in turn providing food for waterfowl, fish, and mammals. Mussels also provide habitat in the form of shelter and nesting sites for small fish, insects, and other aquatic organisms. Because they are sensitive to pollution, mussels serve as water quality indicators in this river, which also serves as the main water supply for 250,000 people.

The Duck River is a globally important repository of biological diversity with approximately 151 species of fish, 56 species of mussels, and 22 species of aquatic snails (Ahlstedt et al. 2004). Duck River contains more fish and mussel species than are found in all the rivers of Europe combined, and more per mile than any other river in North America (The Nature Conservancy 2011). However, as with most major rivers, it has experienced a host of anthropogenic perturbations including habitat loss due to landscape clearing and conversion, increased impervious surfaces, impoundment, agricultural runoff, phosphate mining, gravel dredging and municipal and industrial wastewater discharge. Historically, 75 mussel species occurred in the Duck River including 21 that are federally listed as endangered, 7 candidates, and numerous other imperiled species (Ahlstedt et al. 2004). Six mussel species of this extraordinary assemblage are presumed extinct.

Watters (2000) recognized freshwater mussels as being excellent indicators of water quality and habitat stability. Mussels provide a myriad of ecosystem services as nutrient cyclers, biodepositors, ecosystem engineers, and sediment bioturbators, thus enhancing habitat and food resources for the entire aquatic food web (Gutiérrez et al. 2003; Howard and Cuffey 2006; Vaughn et al. 2008; Spooner and Vaughn 2006, 2008; Vaughn 2010). Their total biomass may exceed that of any other aquatic group (Howard and Cuffey 2006). The important role that mussels play in aquatic ecosystems, therefore, cannot be overstated. Mussels are the most imperiled large group of animals worldwide due largely to altered river flows and pollution. The Duck River is one of the few nearly intact river systems remaining that provide a refuge for this fauna.

Periodic mussel population monitoring is necessary to collect data for use in historical trend analysis. The mussel population of the Duck River has been surveyed sporadically at inconsistent locations over the last century. However, beginning in 1979, TVA surveyed the upper river (above Columbia) and established 22 quantitative sites for future monitoring in association with the development of the Columbia Dam project (Ahlstedt 1991). TVA revisited some but not all of these sites and added others in 1988 (Jenkinson 1988) and ceased monitoring efforts before dismantling its defunct Columbia Dam project in 1999. These surveys provide a historical reference of the river's mussel population. Trend data indicates that populations of most mussel species have increased in recent years (Ahlstedt et al. 2004). Since 1991, reservoir release improvement measures implemented by TVA at Normandy Dam (Duck River Mile 248.6) have resulted in higher dissolved oxygen concentrations and minimum flow releases. Along with point source regulation and riparian habitat restoration activities, these management improvements are considered to be instrumental factors influencing the river's ongoing mussel population recovery (Ahlstedt et al. 2004).

The Duck River plays an important role in Tennessee and the southeastern United States regional mussel restoration plans (Plan for the Population Restoration and Conservation of Imperiled Freshwater Mollusks of the Cumberlandian Region and Tennessee Freshwater Mollusk Strategic Plan). The river is a source for both brood and translocation stock, as well as a recipient of extirpated mussel species via reintroductions. Currently 4 of 21 federally listed endangered mussel species known from the Duck remain extant (*Epioblasma ahlstedti*, Duck River darter snapper; *E. brevidens*, Cumberlandian combshell; *Lemiox rimosus*, birdwing pearlymussel; and *Quadrula intermedia*, Cumberland monkeyface). Globally, the Duck River contains the only known population of Duck River darter snapper (Jones and Neves 2010) and the largest populations by far of birdwing pearlymussel (Jones et al. 2009) and Cumberland monkeyface. The Cumberlandian combshell population is being annually augmented with individuals (adults and propagated juveniles) from the closest viable population located in the Clinch River in eastern Tennessee. Periodic quantitative mussel population sampling is necessary in order to monitor these endangered species populations and document the status of the river's mussel fauna. Therefore, the Tennessee Wildlife Resources Agency (TWRA) partnered with the United States Fish and Wildlife Service (USFWS) Tennessee Ecological Services Field Office and the Tennessee Chapter of The Nature Conservancy (TNC) to establish fixed quantative monitoring sites to periodically examine mussel population demographics in the Duck River.

METHODS

Quantitative sites were selected based on their proximity to previous quantitative survey sites, distribution within the watershed, extent of shoal habitat with depth less than one meter, and accessibility. Six sites were selected between Tarpley Bluff in Bedford County (DRM 207.3) and Littlelot in Hickman County (DRM 88.9). Specific sampling localities were recorded by latitude and longitude in decimal degrees using a hand held Global Positioning System (GPS) unit (Magellan Gold) with coordinates recorded on field sheets and verified with Google Earth software, along with a sketch of the site and dimensional measurements. Field notes also included the date, time, number of surveyors, reported flow from nearest U.S. Geological Survey (USGS) gage, and general habitat information. The sites were surveyed during low water levels between 7-15 September 2010, beginning at Tarpley Bluff and working downstream, completing one site per day. To assure adequate statistical power for future comparative trend analysis and provide a reasonable probability of detecting rare mussel species, sample size was set at 80, 0.25 meter (m^2) quadrats per site. Because the amount of suitable shoal habitat varied between sites, it was necessary to visually reconnoiter each site to determine the roughly even distribution of sample transects and quadrat spacing intervals prior to sample collection. Distance between transects (3-10 m) and quadrats (1-2 m) were expanded or contracted as necessary to distribute the 80 samples over the available habitat.

The upstream and downstream limits of each site were determined by visually inspecting substrate composition (e.g., an abrupt change from suitable gravel substrate to unsuitable bedrock or soft sediments), water depth, flow velocity, and presence or absence of mussels. Site dimensions were measured using a laser range finder (Bushnell Yardage Pro Compact 600). Total site area (m^2) was determined by multiplying mean river width, measured at 10 m intervals, by total length of the site. Small exposed gravel bars, islands, water greater than one meter deep, and bedrock not containing mussels but within the immediate shoal area were measured and removed from analysis. Sampling conditions were recorded for each site from respective USGS gage readings observed for the survey date (Table 1).

Data were collected by systematically placing quadrat samples along transect lines. Both quadrats and transects were evenly spaced throughout homogenous shoal areas. Transects were sampled perpendicular to flow beginning at the downstream end of the shoal and working in an upstream direction from a random start. The first and last quadrats were taken within one meter from each shore and the remainder extending across the shoal. Mussels were collected within the welded rebar quadrats by biologists trained to carefully hand sort through the substrate so as not to miss small individuals. All quadrats were excavated to approximately 15 centimeters (cm) in depth. Samples were placed in individual mesh bags and maintained in flowing river water until they were processed. Mussels were sorted by species and sex (where possible), enumerated, measured for length (nearest millimeter (mm)) using dial calipers, and returned to their approximate position of collection. Individual quadrat data for each site were entered into computer spreadsheets (Microsoft Excel) for statistical analyses in order to compute descriptive statistics for each species collected (e.g., mean density, standard deviation, standard error, precision, and 95% confidence intervals). Species' densities were calculated and population sizes at each site were estimated by multiplying mussel density (number/m^2) by total site area. Species' densities were compared to previous surveys when available; however, because different methods were used in previous surveys, these data are not directly comparable. Length frequency histograms and species' densities were graphed for the federally endangered mussel species at sites where 10 or more individuals per species were collected. Length frequency histograms were produced for the two most abundant species at sites where no endangered mussels were collected. Evidence of recent recruitment was subjectively defined as mussels less than three years old (by counting external growth rests) and/or by length (generally < 50 mm depending on species).

RESULTS

A total of 2,091 mussels representing 37 species were collected from the six sites, yielding a mean density of 17.43 mussels per m^2. The fluted kidneyshell (*Ptychobranchus subtentum*), a candidate for federal listing, became extirpated from the river over a half century ago. Reintroduced from Clinch River stock over the past five years, it was collected in quadrats at the Lillard's Mill site. Individuals of the Cumberlandian combshell, which had also been translocated from the Clinch River, were not collected quantitatively but were observed at the Lillard's Mill site. Results of the 2010 survey compare favorably with the most recent quantitative data collected from comparable sites on the Duck River in 2002 (Ahlstedt et al. 2004). Species richness was greater in 2010 at all four comparable sites (Tarpley Bluff from 6 in 2004 to 10 in 2010, Lillard's Mill 17 to 29, Venable Spring 16 to 25, and Hooper Island 19 to 23), while density was greater at two of four sites (Tarpley Bluff 2.2 m^2 in 2004 to 4.85 in 2010 and Lillard's Mill 36.6 to 37.4 m^2).

Tarpley Bluff

Tarpley Bluff, located at Duck River Mile (DRM) 207.3 in Bedford County and just downstream of Shelbyville, was the upstream most site sampled (Figure 1). The survey at Tarpley Bluff was completed in 4 hours on 7 September 2010 when the flow was low (167 cubic feet per second (ft^3/s)) and water was slightly turbid (Table 1). The 7 person survey crew was composed of 5 snorkelers and 2 sample processors. A GPS coordinate was recorded near the head of the island. Transects 1 - 8 were located in a gravel substrate dominated back chute, approximately 6 m wide by 60 m long along the left descending bank. Transects 9-12 were located across the head of the island, extending 20 m upstream and approximately 30-40 m wide, from the left descending bank to the channel margin where the gravel shoal transitioned to bedrock along the right descending bank. Collectively these shoal habitat areas totaled approximately 960 m^2.

During the present survey 10 species totaling 98 individuals were collected from 80 quadrats. Density at the site was 4.9 m^2, representing an increase in population density from 2002 of 123%, when Ahlstedt et al. (2004) sampled 20, 0.25 m^2 quadrats yielding only 11 mussels of six species for a density of 2.2 m^2 (Table 2). The spike (*Elliptio dilatata*) was the most abundant species (34 %), its density (1.65 m^2) had increased 725% since 2002 (0.2 m^2) (Figure 7, Table 2). The painted creekshell (*Villosa taeniata*) was the second most abundant mussel (20 %) and had increased 150% since 2002 (from 0.4 to 1.0 m^2) (Figure 8). The Tennessee pigtoe (*Fusconaia barnesiana*) (18 %), wavyrayed lampmussel (*Lampsilis fasciola*) (11%), and fluted shell (*Lasmigona costata*) (7%) rounded out the top five most abundant mussels. Recent recruitment was evident in the size class distribution of all these species. The length frequency

histogram of the spike produced a bell-shaped curve with a peak between the 35 to 40 mm size classes (Figure 7). The painted creekshell's histogram had peaks at both the 35 and 50 mm size classes (Figure 8). The total estimated population size occupying the site was 4,704 (95% CI, 4,424 – 4,984) (Table 3).

Lillard's Mill

The next site downstream was located at Lillard's Mill (DRM 179.2) in Marshall County, downstream of the mill dam (Figure 2). The site was completed in 6 hours on 8 September 2010, while the flow was low (172 ft^3/s) and water was clear (Table 1). The 11 person survey crew was composed of 6 snorkelers and 5 sample processors. GPS coordinates were recorded near the middle of the downstream island along the left descending channel. Transects 1-9 were spaced at 10 m intervals with quadrats 1-2 m apart and located in a gravel substrate dominated chute approximately 20 m wide by 100 m long along the left descending bank. Transects 10-12 were located in a narrow, swift channel 6 m wide beginning at the head of the island and extending 25 m downstream along the left descending bank. The remaining transects (13-17) were taken across the head of the island (~40 m wide) from an area covered with emergent aquatic macrophytes (e.g., water willow (*Justicia americana*) and curly pond weed (*Potamogeton sp.*)) and extending upstream approximately 30 m. Transects 15 and 16 crossed the right descending channel in an area 20 m by 20 m where the gravel shoal transitioned to bedrock along the right descending bank and extending down the right channel. Collectively these shoal areas totaled approximately 3,350 m^2 and represented approximately 15% of the available mussel habitat at this large complex site (Jones et al. 2009).

At Lillard's Mill, 29 mussel species totaling 748 individuals were collected from the 80 quadrats. Density was 37.4 m^2, representing an increase in population density from 2002 of 2.2%, when Ahlstedt et al. (2004) collected 20 quadrats that yielded 183 mussels of 17 species at a density of 36.6 m^2(Table 2). The spike was the most abundant species (25%) followed by two federally listed endangered species, the birdwing pearlymussel (16%) and the Duck River darter snapper (13%). The purple wartyback (*Cyclonaias tuberculata*) (11%) and painted creekshell (10%) rounded out the top five most abundant mussels at Lillard's Mill (Table 4). Recent recruitment was evident for nearly all species collected and length frequencies were graphed for the two endangered species that exceeded 10 individuals at this site. Birdwing pearlymussel density had increased from 2.50 m^2 in 1979 to 6.15 m^2 in 2010, with an abundance estimate of 20,603 (95% CI, 19,767 – 21,438) individuals within the 3,350 m^2 sample area (Figure 9, Table 4). Birdwing pearlymussel length frequency histograms produced bell-shaped curves with females peaking at the 35 mm size class (~age 5), and males peaking at 50 mm (~age 8). Being a long term brooder, the female curve drops off sharply due to their increased vulnerability to predation during their prolonged breeding display period (typically

October to May). Duck River darter snapper density increased from 0.40 m^2 in 1979 to 4.70 m^2 in 2010, with an abundance estimate of 15,745 (95% CI, 14,874 – 16,616) individuals within the 3,350 m^2 sample area. Both male and female length frequency histograms created bell-shaped curves with peaks at the 50 mm size class (~age 7) (Figure 12, Table 4). Also being a long term brooder, the female curve drops off sharply at approximately 60 mm length, potentially due to decreased fitness from reproductive stress and their increased vulnerability to predation while displaying for host darters (Jones et al. 2009). Total mussel population size for the area surveyed was estimated at 125,297 (95% CI, 124,860 – 125,720) (Table 4).

Venable Spring

Venable Spring was located at DRM 176.8 in Marshall County (Figure 3). The site was completed in 4 hours on 9 September 2010, while the flow was low (168 ft^3/s) and water was clear (Table 1). The 9 person survey crew was composed of 6 snorkelers and 3 sample processors. GPS coordinates were recorded near the upstream end of the site, at the tail of a point bar adjacent to the right descending bank. Transect 1 was located adjacent to the spring outflow and it extended out to a greater than 1 m deep run that was not sampled. Transects 2-8 were upstream 10 m apart in the widest portion of the site (~45 m), but also omitting the > 1 m deep area along the left channel bank. Transects 9-14 were located in the narrow area (15-25 m wide) between the point bar and the left descending bank. Gravel substrate dominated the site with some fine silt along the right descending bank. This large site was approximately 3,500 m^2; however, approximately 500 m^2 was omitted because it was too deep to sample, thus reducing the total area to 3,000 m^2.

Sampling at Venable Spring yielded 25 mussel species totaling 252 individuals. Mean density was 12.6 m^2 representing a 655% increase since TVA's 1979 survey that measured density at 1.67 m^2, but a decline of 35.7% since 2002 when Ahlstedt et al. (2004) collected 30 quadrats that yielded 147 mussels of 16 species for a density of 19.6 m^2 (Table 2). Two federally listed endangered species ranked first and second, the Duck River darter snapper was the most abundant (21%) followed by the birdwing pearlymussel (16%). The purple wartyback (8%), spike (8%), and painted creekshell (7%) rounded out the top five most abundant mussels (Table 5). A third federally listed endangered species, the Cumberland monkeyface, ranked 9th in abundance (4%) and had increased 189% (from 0.19 to 0.55 m^2) since 1988. Recent recruitment was evident for nearly all species collected and length frequency analyses were graphed for the three endangered species. Birdwing pearlymussel length frequency histograms produced bell-shaped curves with females peaking at the 30 mm size class (~age 4), and males peaking at 45 mm (~age 7) (Figure 10). Birdwing pearlymussel density increased 251% (from 0.57 m^2 in 1988 to 2.0 m^2 in 2010) and abundance occupying the 3,000 m^2 was estimated at 6,000 (95% CI, 5,041 – 6,959) individuals (Table 5). Duck River darter snapper abundance was

estimated to be 7,950 (95% CI, 7,017 – 8,883) and its density increased from 0 in 1988 to 2.65 m^2 in 2010 (Table 5, Figure 13). Its length frequency histograms created bell-shaped curves with males peaking at 35 mm (~age 4) and females at the 40 mm size class (~age 5) (Figure 13). The Cumberland monkeyface is a short term brooder and has a shell that is not highly dimorphic, therefore, males and females were grouped together (Figure 14). Cumberland monkeyface density, not measured in earlier surveys, was 0.5 m^2 with an estimated abundance of 1,500 (95% CI, -250 – 3,250) individuals residing in the survey area. Total mussel population size was estimated at 37,800 (95% CI, 37,284 – 38,315) (Table 5).

Hooper Island

The Hooper Island quantitative site was located at DRM 163.1 in Maury County, just upstream of Carpenters Bridge Road (Figure 4). It was completed in 4.5 hours on 13 September 2010, while the flow was low (160 ft^3/s) and water was clear (Table 1). The 9 person survey crew was composed of 6 snorkelers and 3 sample processors. GPS coordinates were recorded near the upstream end of the site at the head of the island. Forty quadrats were sampled from a gravel shoal approximately 40 m long by 16 m wide (640 m^2). Transects 1-5 were spaced 3 m apart, beginning in the left descending channel and extending upstream of the island head. Much of the main channel down the left side of the island was either bedrock or greater than 1 m deep, which precluded sampling. Therefore, a second set of 40 quadrats was sampled. Transects 6-12 were spaced 10 m apart downstream of the island tail from an area approximately 70 m long by 30 m wide (2,100 m^2). Gravel substrate dominated both the upstream and downstream sample areas of this complex site. Collectively, the two areas contained approximately 2,740 m^2.

The 80 quadrats collected from the two sample areas totaled 444 mussels of 23 species at a mean density of 22.2 m^2. This represents a 122% increase since TVA's 1979 survey found 14 species in 40 quadrats at a density of 10.0 m^2 but a decline by 9.0% since 2002 when Ahlstedt et al. (2004) collected 20 quadrats that yielded 122 mussels of 19 species at a density of 24.4 m^2 (Table 2). Muskrat predation was evident at the site with large middens found intermittently dispersed along the left descending bank that were dominated by the imperiled round hickorynut (*Obovaria subrotunda*). Two federally listed endangered species were ranked in the top five mussels collected. The birdwing pearlymussel (26%) was first and the Cumberland monkeyface ranked 4^{th} (7%); the other endangered mussel encountered at this site was the Duck River darter snapper which ranked 16^{th} (1%) (Table 6). The spike (19%), Cumberland moccasinshell (*Medionidus conradicus*) (9%), and Tennessee pigtoe (6%) rounded out the top five most abundant mussels at Hooper Island. Recent recruitment was evident for nearly all species collected and length frequency histograms were produced for two of the three endangered species. All three federally listed endangered species populations at this site

had increased significantly over previous surveys. Birdwing pearlymussel density increased from 0 in TVA's 1979 sample to 2.4 m^2 in 2002, and increased 143% to 5.85 m^2 in 2010 (Table 6, Figure 11). The estimated abundance for this species at the site was 16,029 (95% CI, 15,416 – 16,642) individuals. Birdwing pearlymussel length frequency analysis yielded bell-shaped curves with females peaking at 30 mm size class (~age 4), and males peaking at the 45 mm (~age 7) (Figure 11). The Cumberland monkeyface, not collected in 1979, increased 158% (from 0.6 to 1.55m^2) since 2002; estimated abundance was 4,247 (95% CI, 3,052 – 5,442) individuals (Table 6, Figure 11). The Cumberland monkeyface length frequency histogram, composed of 31 individuals, had peaks at both the 35 mm (~age 4) and 50 mm (~age 8) size classes (Figure 15). The Duck River darter snapper population also showed improvement after not being collected during quantitative sampling at this site in 1979 or 2002; five individuals were collected at a density of 0.25 m^2, resulting in an estimated abundance of 685 (95% CI, -1,655 – 3,025) individuals for this site. Total mussel population size occupying the 2,740 m^2 site was estimated at 60,828 (95% CI, 60,460 – 61,196) individuals.

Columbia Mill Dam

The site at Columbia Mill Dam was located at DRM 133.5 in Maury County, 0.37 miles downstream from the dam and TWRA boat ramp off Riverside Drive (Figure 5). The site was completed in 3.75 hours on 14 September 2010, while the flow was low (160 ft^3/s) and water was clear (Table 1). The 9 person survey crew was composed of 6 snorkelers and 3 sample processors. GPS coordinates were recorded near the middle of the site at the head of the island. Unconsolidated substrate and reduced vegetative cover (water willow) along the banks provided evidence that this site had been impacted by the May 2010 flood(personal observation), which saw a maximum flow of 45,900 ft^3/s as recorded at the Columbia USGS gage on 3 May 2010. Transects 1-5 were split by the island, and 15 quadrats spaced 1 m apart were taken from each side channel. Transects 6 and 7 were taken along the right channel near the head of the island. The right channel averaged 4 m wide by 25 m long (100 m^2) and the left channel averaged 6 m wide by 15 m long (90 m^2). Transects 8-14 were spaced at 5 m intervals with quadrats 3 m apart to cover the shoal that was approximately 44 m wide by 45 m long (1,980 m^2). Loose gravel was the predominate substrate with some large cobble near the pool at the upstream end of the site. The complex site, encompassing these three areas, totaled approximately 2,170 m^2.

Sampling produced 210 mussels of 19 species at a mean mussel density of 10.5 m^2 (Table 2). The Columbia Mill Dam site was not sampled quantitatively in previous studies by TVA or Ahlstedt et al. (2004). However, Ahlstedt et al. (2004) reported collecting 18 species totaling 204 individuals during a qualitative assessment at this site. No federally listed endangered species were collected at this site, although the birdwing pearlymussel has been

collected from muskrat middens in recent years (Hubbs, personal observation 2010). The purple wartyback (37%) was the most abundant mussel collected followed by the threeridge (*Amblema plicata*) (13%), pimpleback (*Q. pustulosa*) (12%), deertoe (*Truncilla truncata*) (7%), and pistolgrip (*Q. verrucosa*) (6%) (Table 7). Recent recruitment was evident for most species collected. Length frequency histograms generated for the purple wartyback and threeridge indicated bell shaped population curves with peaks in the 75-105 mm size classes (Figures 14 and 15). Total mussel population size was estimated at 22,790 (95% CI, 22,519 – 23,0600) individuals.

Littlelot

The site at Littlelot was located at DRM 88.9 in Hickman County, 20 m upstream from State Highway 230 Bridge (Figure 6). Survey work was completed in 4.75 hours on 15 September 2010, while the flow was low (120 ft^3/s) and water was clear (Table 1). The 10 person survey crew was composed of 6 snorkelers and 4 sample processors. GPS coordinates were recorded at the downstream end of the site on the left descending bank, 20 m upstream from the bridge. The May 2010 flood also appeared to affect this site, as evidenced by abundant recently unconsolidated gravel and cobble substrate (personal observation). Vegetative cover (water willow) was present along the right bank and cattle accessed the river along the site's left side. The sample area was 70 m long by 40 m wide on a shoal formed at the end of a pool before it entered a run. However, due to depth >1 m, a 70 by 15 m area mid-river was not sampled. Therefore, the total sample area was only 1,750 m^2. Transects 1-13 were spaced 5 m apart with samples at 2 m intervals extending out from each bank toward the unsampled deep area mid-river. Loose gravel was the predominate substrate with some large cobble near the tail of the pool at the upstream end of the site.

Sampling produced 340 mussels of 17 species at a mean density of 17 m^2 (Table 2). This site was not sampled quantitatively in previous studies by TVA or Ahlstedt et al. (2004). However, Ahlstedt et al. (2004) reported collecting 16 species totaling 104 individuals during a qualitative assessment at this site. No federally listed endangered species were collected at this site. The purple wartyback (34%) was the most abundant mussel collected (Table 7) followed by the pimpleback (12%), ebonyshell (*Fusconaia ebena*) (9%), deertoe (9%), and pistolgrip (7%). Recent recruitment was evident for most species collected. Length frequency histograms were generated for the purple wartyback and pimpleback. The purple wartyback histogram formed a bell-shaped curve with a peak in the 90-95 mm size classes (Figure 16). The pimpleback histogram also produced a bell-shaped curve and peaked at the 65 mm size class. Total site mussel population size was estimated at 29,750 (95% CI, 29,353 – 30,147) individuals.

DISCUSSION

Many species depend on an intact, healthy, environment as well as the services provided by other species to ensure survival (e.g., mussels depend on their host fish for dispersal of their offspring). In order for an ecosystem to remain healthy and to better withstand and recover from forces such as climate change, more intense flooding, and continuing habitat loss, a variety of factors must be in place. Connection of the river channel to its floodplain, sufficient flows to meet ecological needs, and intact riparian habitat all combine to make the system more resilient. A diverse suite of species each performs their essential ecological function to support the ecosystem as a whole, and work together to ensure the natural sustainability of all life forms. Literally teaming with aquatic life, the Duck River and its watershed is a globally important repository of biological diversity.

Healthy rivers and streams have incalculable economic value to the human community. Complex ecosystems like the Duck River watershed provide many natural services important to society including protection of water supplies, waste assimilation, soil formation and protection, nutrient storage and recycling, pollution breakdown and absorption, contribution to climate stability, ecosystem maintenance, and recovery from catastrophic events. The Duck River watershed provides biological resources in the form of food, medicinal products and pharmaceutical drugs, wood products, and breeding stocks and population reservoirs for both common and rare species. The Duck River also provides important social benefits such as research, education and biological monitoring, recreation, tourism, and cultural values.

The improvement of the mussel resources in the Duck River as noted by Ahlstedt et al. (2004) and further documented by this survey is an extraordinary accomplishment. The importance of the increases seen in the populations of two endangered mussel species, Duck River darter snapper and Cumberland monkeyface, cannot be over stated, as they have literally been brought back from the brink of extinction. The Duck River population of a third endangered species, the birdwing pearlymussel, remains the largest extant population throughout its current range. In addition, probably the best population globally of both the candidate slabside pearlymussel and imperiled round hickorynut and one of the better populations rangewide of the candidate rabbitsfoot are found in the Duck River (Butler, unpublished data). The improved status of all these imperiled species was enhanced by TVA's Reservoir Release Improvement program initiated at Normandy Dam, improvements to sewage treatment and public water supply facilities, and the cooperation of resource conservation agencies and NGO organizations that have worked to improve water quality and riparian habitat in the watershed (Ahsltedt et al. 2004; Jones et al. 2009).

However, ongoing conservation efforts are critical to abate a number of threats to this remarkable system and mussel restoration efforts to effectively expand the range of current populations. Long-term success will require the work and commitment of a variety of state and federal agencies as well as local stakeholders. Over 500 miles of streams are listed as impaired or not meeting designated uses within the Duck River watershed (Tennessee Department of Environment and Conservation. Year 2010 303(d) list). The watershed is largely agricultural, with substantial row crops, beef production, and the largest poultry producing county in Tennessee (Bedford County) in its upper reaches. Six low-head mill dams still exist in the Duck River main stem, acting as physical barriers to host fish and limiting the expansion of some mussel populations. Over time, the growing urban and suburban populations will put increased pressure on the river in terms of water supply demands and changing land use. Society should continue to work to enhance and protect the river for the well-being and enjoyment of Tennesseans, today and for future generations.

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TABLES

Table 1. Total area (m^2) sampled at Duck River quantitative sites.

Site	Duck River Mile	Shoal Habitat Surveyed (m^2)	USGS gage and observed flow (ft^3/s)	Gage Height (elevation, ft)
Tarpley Bluff	207.3	960	Shelbyville, 167	2.72
Lillard's Mill Dam	179.2	3,350	Milltown, 172	10.94
Venable Spring	176.8	3,000	Milltown, 168	10.93
Hooper Island	163.1	2,740	Columbia, 160	1.38
Columbia Mill Dam	133.5	2,170	Columbia, 160	1.38
Littlelot	88.9	1,750	Columbia, 120	1.37

Table 2. Mussel density and species richness measured at comparable Duck River sites, 1979 to 2010.

Survey	TVA 1979			TVA 1988			Ahlstedt et al. 2004			This Study		
Site	# m^2	# of Quadrats	# Species	# m^2	# of Quadrats	# Species	# m^2	# of Quadrats	# Species	# m^2	# of Quadrats	# Species
Tarpley Bluff	NS			NS			2.2	20	6	4.85	80	10
Lillard's Mill Dam	17.8	40	19	26.8	40	16	36.6	20	17	37.4	80	29
Venable Spring	1.67	12	4	7.81	21	11	19.6	30	16	12.65	80	25
Hooper Island	10.0	40	14	NS			24.4	20	19	22.2	80	23
Columbia Mill Dam	NS			NS			NS			10.5	80	19
Littlelot	NS			NS			NS			17	80	17

NS = Not sampled

Table 3. Tarpley Bluff site summary statistics of 80, 0.25 m^2 quadrat samples.

Total	Mean Density per m^2	Standard Deviation	Standard Error	CV of SE (Precision)	Lower 95% CI	Upper 95% CI	Total Population per site (960 m^2)	Lower 95% CI	Upper 95% CI	Species
1	0.05	0.1118034	0.01250038	0.2500076	0.025499255	0.074500745	48	24.47928496	71.52071504	*Actinonaias pectorosa*
3	0.15	0.1911822	0.021375469	0.142503129	0.10810408	0.19189592	144	103.7799168	184.2200832	*Cyclonaias tuberculata*
33	1.65	0.75797448	0.0847467	0.051361636	1.483896468	1.816103532	1584	1424.54061	1743.45939	*Elliptio dilatata*
18	0.9	0.44933143	0.050238308	0.055820343	0.801532916	0.998467084	864	769.4715989	958.5284011	*Fusconaia barnesiana*
1	0.05	0.1118034	0.01250038	0.2500076	0.025499255	0.074500745	48	24.47928496	71.52071504	*Lampsilis cardium*
11	0.55	0.38132846	0.042635114	0.077518389	0.466435177	0.633564823	528	447.77777	608.22223	*Lampsilis fasciola*
7	0.35	0.32583874	0.036430986	0.104088533	0.278595267	0.421404733	336	267.451456	404.548544	*Lasmigona costata*
3	0.15	0.1911822	0.021375469	0.142503129	0.10810408	0.19189592	144	103.7799168	184.2200832	*Strophitus undulatus*
1	0.05	0.1118034	0.01250038	0.2500076	0.025499255	0.074500745	48	24.47928496	71.52071504	*Villosa iris*
20	1	0.49041445	0.054831669	0.054831669	0.892529929	1.107470071	960	856.8287319	1063.171268	*Villosa taeniata*
98	**4.9**	**1.33098422**	**0.148813083**	**0.030370017**	**4.608326357**	**5.191673643**	**4704**	**4423.993302**	**4984.006698**	**Population**
	Species richness = 10									

Table 3 continued. Tarpley Bluff.

	Species	Population	Relative Abundance	Rank
1	*Elliptio dilatata*	1584	34%	1
2	*Villosa taeniata*	960	20%	2
3	*Fusconaia barnesiana*	864	18%	3
4	*Lampsilis fasciola*	528	11%	4
5	*Lasmigona costata*	336	7%	5
6	*Cyclonaias tuberculata*	144	3%	6
7	*Strophitus undulatus*	144	3%	6
8	*Actinonaias pectorosa*	48	1%	8
9	*Lampsilis cardium*	48	1%	8
10	*Villosa iris*	48	1%	8
	Total	**4704**		

Table 4. Lillard's Mill site summary statistics of 80, 0.25 m^2 quadrat samples.

Total	Mean Density per m^2	Standard Deviation	Standard Error	CV of SE (Precision)	Lower 95% CI	Upper 95% CI	Total Population per Site (3350 m^2)	Lower 95% CI	Upper 95% CI	Species
40	2	2.77420304	0.310174759	0.155087379	1.392057472	2.607942528	6700	5681.696266	7718.303734	*Amblema plicata*
86	4.3	5.27808941	0.590126276	0.137238669	3.143352499	5.456647501	14405	13503.8909	15306.1091	*Cyclonaias tuberculata*
184	9.2	7.62142217	0.852126808	0.092622479	7.529831456	10.87016854	30820	30211.8408	31428.1592	*Elliptio dilatata*
94	4.7	5.5766239	0.623504462	0.132660524	3.477931255	5.922068745	15745	14873.951	16616.049	*Epioblasma ahlstedti*
16	0.8	1.61009474	0.180019537	0.225024421	0.447161708	1.152838292	2680	1202.489652	4157.510348	*Fusconaia barnesiana*
5	0.25	0.9743547	0.108939479	0.435757918	0.03647862	0.46352138	838	-2023.68649	3698.686487	*Lampsilis cardium*
6	0.3	1.06021254	0.118538969	0.395129898	0.06766362	0.53233638	1005	-1589.42291	3599.422908	*Lampsilis fasciola*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	168	-6398.69962	6733.699616	*Lampsilis ovata*
3	0.15	0.76472879	0.085501878	0.570012517	-0.01758368	0.31758368	503	-3240.20219	4245.202187	*Lampsilis teres*
22	1.1	2.54379364	0.284413421	0.258557656	0.542549695	1.657450305	3685	1987.310433	5382.689567	*Lasmigona costata*
123	6.15	6.99927664	0.782566708	0.127246619	4.616169253	7.683830747	20603	19766.9987	21438.0013	*Lemiox rimosus*
9	0.45	1.27189682	0.142206711	0.316014912	0.171274847	0.728725153	1508	-567.453915	3582.453915	*Lexingtonia dolabelloides*
3	0.15	0.76472879	0.085501878	0.570012517	-0.01758368	0.31758368	503	-3240.20219	4245.202187	*Leptodea fragilis*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	168	-6398.69962	6733.699616	*Medionidus conradicus*
4	0.2	0.87728003	0.098085871	0.490429356	0.007751693	0.392248307	670	-2550.15915	3890.159149	*Megalonaias nervosa*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	168	-6398.69962	6733.699616	*Obliquaria reflexa*
2	0.1	0.6284399	0.070263853	0.702638529	-0.037717152	0.237717152	335	-4278.52458	4948.524584	*Obovaria subrotunda*
2	0.1	0.6284399	0.070263853	0.702638529	-0.037717152	0.237717152	335	-4278.52458	4948.524584	*Pleurobema oviforme*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	168	-6398.69962	6733.699616	*Pleurobema rubrum*
6	0.3	1.65659404	0.185218474	0.617394915	-0.06302821	0.66302821	1005	-3048.81501	5058.81501	*Ptychobranchus subtentum*
5	0.25	0.9743547	0.108939479	0.435757918	0.03647862	0.46352138	838	-2023.68649	3698.686487	*Quadrula c. cylindrica*
2	0.1	0.6284399	0.070263853	0.702638529	-0.037717152	0.237717152	335	-4278.52458	4948.524584	*Quadrula intermedia*
23	1.15	2.39778379	0.268088527	0.233120458	0.624546487	1.675453513	3853	2321.83107	5383.16893	*Quadrula pustulosa*
17	0.85	1.7653486	0.197377975	0.232209382	0.46313917	1.23686083	2848	1322.813199	4372.186801	*Quadrula verrucosa*
10	0.5	1.33122196	0.148839664	0.297679328	0.208274258	0.791725742	1675	-279.562471	3629.562471	*Truncilla truncata*
2	0.1	0.6284399	0.070263853	0.702638529	-0.037717152	0.237717152	335	-4278.52458	4948.524584	*Toxolasma lividus*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	168	-6398.69962	6733.699616	*Utterbackia imbecillis*
78	3.9	5.36184363	0.599490567	0.15371553	2.724998489	5.075001511	13065	12055.70383	14074.29617	*Villosa taeniata*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	168	-6398.69962	6733.699616	*Villosa vanuxemensis*
748	**37.4**	**21.9190686**	**2.450700875**	**0.065526761**	**32.59662628**	**42.20337372**	**125290**	**124859.7513**	**125720.2487**	**Population**
	Species richness = 29									

Table 4 continued. Lillard's Mill.

	Species	Population	Relative Abundance	Rank
1	*Elliptio dilatata*	30820	25%	1
2	*Lemiox rimosus*	20603	16%	2
3	*Epioblasma ahlstedti*	15745	13%	3
4	*Cyclonaias tuberculata*	14405	11%	4
5	*Villosa taeniata*	13065	10%	5
6	*Amblema plicata*	6700	5%	6
7	*Quadrula pustulosa*	3853	3%	7
8	*Lasmigona costata*	3685	3%	8
9	*Quadrula verrucosa*	2848	2%	9
10	*Fusconaia barnesiana*	2680	2%	10
11	*Truncilla truncata*	1675	1%	11
12	*Lexingtonia dolabelloides*	1508	1%	12
13	*Lampsilis fasciola*	1005	1%	13
14	*Ptychobranchus subtentum*	1005	1%	13
15	*Lampsilis cardium*	838	1%	15
16	*Quadrula c. cylindrica*	838	1%	15
17	*Megalonaias nervosa*	670	1%	17
18	*Lampsilis teres*	503	0.4%	18
19	*Leptodea fragilis*	503	0.4%	18
20	*Obovaria subrotunda*	335	0.3%	20
21	*Pleurobema oviforme*	335	0.3%	20
22	*Quadrula intermedia*	335	0.3%	20
23	*Toxolasma lividus*	335	0.3%	20
24	*Lampsilis ovata*	168	0.1%	24
25	*Medionidus conradicus*	168	0.1%	24
26	*Obliquaria reflexa*	168	0.1%	24
27	*Pleurobema rubrum*	168	0.1%	24
28	*Utterbackia imbecillis*	168	0.1%	24
29	*Villosa vanuxemensis*	168	0.1%	24
	Total	**125297**		

Table 5. Venable Spring site summary statistics of 80, 0.25 m^2 quadrat samples.

Total	Mean Density per m^2	Standard Deviation	Standard Error	CV of SE (Precision)	Lower 95% CI	Upper 95% CI	Total Population per Site (3000 m^2)	Lower 95% CI	Upper 95% CI	Species
5	0.25	0.9743547	0.108939479	0.435757918	0.03647862	0.46352138	750	-1812.25656	3312.256555	*Amblema plicata*
21	1.05	2.27200909	0.254026061	0.241929582	0.55210892	1.54789108	3150	1727.454057	4572.545943	*Cyclonaias tuberculata*
19	0.95	2.03699953	0.227750395	0.239737258	0.503609226	1.396390774	2850	1440.344925	4259.655075	*Elliptio dilatata*
53	2.65	3.76223742	0.420643718	0.158733479	1.825538312	3.474461688	7950	7016.647146	8883.352854	*Epioblasma ahlstedti*
8	0.4	1.50610572	0.168392857	0.420982144	0.069949999	0.730050001	1200	-1275.375	3675.375004	*Fusconaia barnesiana*
2	0.1	0.6284399	0.070263853	0.702638529	-0.037717152	0.237717152	300	-3831.51455	4431.514553	*Lampsilis cardium*
4	0.2	0.87728003	0.098085871	0.490429356	0.007751693	0.392248307	600	-2283.72461	3483.724611	*Lampsilis fasciola*
3	0.15	0.76472879	0.085501878	0.570012517	-0.01758368	0.31758368	450	-2901.6736	3801.6736	*Lampsilis ovata*
12	0.6	1.43729704	0.16069958	0.267832633	0.285028824	0.914971176	1800	225.1441185	3374.855882	*Lasmigona costata*
40	2	2.91656118	0.326091366	0.163045683	1.360860922	2.639139078	6000	5041.291383	6958.708617	*Lemiox rimosus*
8	0.4	1.20757105	0.135014653	0.337536632	0.135371281	0.664628719	1200	-784.715393	3184.715393	*Lexingtonia dolabelloides*
3	0.15	0.76472879	0.085501878	0.570012517	-0.01758368	0.31758368	450	-2901.6736	3801.6736	*Leptodea fragilis*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	150	-5730.17876	6030.17876	*Megalonaias nervosa*
16	0.8	2.32977426	0.2604846	0.32560575	0.289450185	1.310549815	2400	485.4381922	4314.561808	*Obovaria subrotunda*
2	0.1	0.6284399	0.070263853	0.702638529	-0.037717152	0.237717152	300	-3831.51455	4431.514553	*Pleurobema oviforme*
3	0.15	0.76472879	0.085501878	0.570012517	-0.01758368	0.31758368	450	-2901.6736	3801.6736	*Pleurobema rubrum*
14	0.7	1.65659404	0.185218474	0.264597821	0.33697179	1.06302821	2100	544.1648149	3655.835185	*Quadrula c. cylindrica*
10	0.5	1.33122196	0.148839664	0.297679328	0.208274258	0.791725742	1500	-250.354451	3250.354451	*Quadrula intermedia*
3	0.15	0.76472879	0.085501878	0.570012517	-0.01758368	0.31758368	450	-2901.6736	3801.6736	*Quadrula pustulosa*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	150	-5730.17876	6030.17876	*Strophitus undulatus*
3	0.15	0.76472879	0.085501878	0.570012517	-0.01758368	0.31758368	450	-2901.6736	3801.6736	*Truncilla truncata*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	150	-5730.17876	6030.17876	*Toxolasma lividus*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	150	-5730.17876	6030.17876	*Utterbackia imbecillis*
18	0.9	1.90668378	0.213180208	0.236866898	0.482166792	1.317833208	2700	1307.222641	4092.777359	*Villosa taeniata*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	150	-5730.17876	6030.17876	*Villosa vanuxemensis*
252	**12.6**	**9.88234585**	**1.104913445**	**0.087691543**	**10.43436965**	**14.76563035**	**37800**	**37284.37373**	**38315.62627**	**Population**
	Species richness = 25									

Table 5 Continued. Venable Spring.

	Species	Population	Relative Abundance	Rank
1	*Epioblasma ahlstedti*	7950	21%	1
2	*Lemiox rimosus*	6000	16%	2
3	*Cyclonaias tuberculata*	3150	8%	3
4	*Elliptio dilatata*	2850	8%	4
5	*Villosa taeniata*	2700	7%	5
6	*Obovaria subrotunda*	2400	6%	6
7	*Quadrula c. cylindrica*	2100	6%	7
8	*Lasmigona costata*	1800	5%	8
9	*Quadrula intermedia*	1500	4%	9
10	*Fusconaia barnesiana*	1200	3%	10
11	*Lexingtonia dolabelloides*	1200	3%	10
12	*Amblema plicata*	750	2%	12
13	*Lampsilis fasciola*	600	2%	13
14	*Lampsilis ovata*	450	1%	14
15	*Leptodea fragilis*	450	1%	14
16	*Pleurobema rubrum*	450	1%	14
17	*Quadrula pustulosa*	450	1%	14
18	*Truncilla truncata*	450	1%	14
19	*Lampsilis cardium*	300	1%	19
20	*Pleurobema oviforme*	300	1%	19
21	*Megalonaias nervosa*	150	0.4%	21
22	*Strophitus undulatus*	150	0.4%	21
23	*Toxolasma lividus*	150	0.4%	21
24	*Utterbackia imbecillis*	150	0.4%	21
25	*Villosa vanuxemensis*	150	0.4%	21
	Total	**37800**		

Table 6. Hooper Island site summary statistics of 80, 0.25 m^{-2} quadrat samples.

Total	Mean Density per m^2	Standard Deviation	Standard Error	CV of SE (Precision)	Lower 95% CI	Upper 95% CI	Total Population Per Site (2740 m^2)	Lower 95% CI	Upper 95% CI	Species
5	0.25	0.9743547	0.108939479	0.435757918	0.03647862	0.46352138	685	-1655.1943	3025.19432	*Amblema plicata*
20	1	2.2501758	0.251584951	0.251584951	0.506893496	1.493106504	2740	1388.88818	4091.11182	*Cyclonaias tuberculata*
83	4.15	4.82372827	0.539325612	0.129957979	3.092921801	5.207078199	11371	10673.0737	12068.9263	*Elliptio dilatata*
5	0.25	0.9743547	0.108939479	0.435757918	0.03647862	0.46352138	685	-1655.1943	3025.19432	*Epioblasma ahlstedti*
28	1.4	2.55372649	0.285523981	0.203945701	0.840372996	1.959627004	3836	2740.73001	4931.26999	*Fusconaia barnesiana*
11	0.55	1.38618866	0.154985315	0.281791481	0.246228783	0.853771217	1507	-6.3329714	3020.33297	*Lampsilis fasciola*
2	0.1	0.89442719	0.10000304	1.000030401	-0.096005959	0.296005959	274	-5096.5633	5644.56327	*Lampsilis ovata*
12	0.6	1.69586243	0.189608947	0.316014912	0.228366463	0.971633537	1644	-53.126485	3341.12649	*Lasmigona costata*
117	5.85	5.96848262	0.66731693	0.11407127	4.542058817	7.157941183	16029	15416.3917	16641.6083	*Lemiox rimosus*
6	0.3	1.23657346	0.138257319	0.46085773	0.029015655	0.570984345	822	-1652.9904	3296.99035	*Lexingtonia dolabelloides*
3	0.15	0.99492383	0.111239247	0.74159498	-0.068028924	0.368028924	411	-3571.6617	4393.66168	*Leptodea fragilis*
39	1.95	3.48559422	0.389713129	0.199852887	1.186162268	2.713837732	5343	4269.71006	6416.28994	*Medionidus conradicus*
2	0.1	0.6284399	0.070263853	0.702638529	-0.037717152	0.237717152	274	-3499.45	4047.44996	*Megalonaias nervosa*
27	1.35	2.46031798	0.275080275	0.203763167	0.810842661	1.889157339	3699	2604.71029	4793.28971	*Obovaria subrotunda*
8	0.4	1.20757105	0.135014653	0.337536632	0.135371281	0.664628719	1096	-716.70673	2908.70673	*Pleurobema oviforme*
17	0.85	1.87657107	0.209813402	0.246839297	0.438765731	1.261234269	2329	1003.37424	3654.62576	*Pleurobema rubrum*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	137	-5233.5633	5507.56327	*Ptychobranchus fasciolaris*
3	0.15	0.76472879	0.085501878	0.570012517	-0.01758368	0.31758368	411	-2650.1952	3472.19522	*Quadrula c. cylindrica*
31	1.55	3.08487531	0.344910031	0.2225226	0.87397634	2.22602366	4247	3051.96463	5442.03537	*Quadrula intermedia*
9	0.45	1.4222464	0.159016815	0.353370701	0.138327042	0.761672958	1233	-664.74201	3130.74201	*Quadrula pustulosa*
7	0.35	1.30335497	0.145723946	0.41635413	0.064381067	0.635618933	959	-1276.9882	3194.98822	*Quadrula verrucosa*
7	0.35	1.13739654	0.127168665	0.363339042	0.100749417	0.599250583	959	-992.27599	2910.27599	*Villosa taeniata*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	137	-5233.5633	5507.56327	*Villosa vanuxemensis*
444	**22.2**	**13.5892735**	**1.519373156**	**0.068440232**	**19.22202861**	**25.17797139**	**60828**	**60460.4486**	**61195.5514**	**Population**
	Species richness = 23									

Table 6 Continued. Hooper Island.

	Species	Population	Relative Abundance	Rank
1	*Lemiox rimosus*	16029	26%	1
2	*Elliptio dilatata*	11371	19%	2
3	*Medionidus conradicus*	5343	9%	3
4	*Quadrula intermedia*	4247	7%	4
5	*Fusconaia barnesiana*	3836	6%	5
6	*Obovaria subrotunda*	3699	6%	6
7	*Cyclonaias tuberculata*	2740	5%	7
8	*Pleurobema rubrum*	2329	4%	8
9	*Lasmigona costata*	1644	3%	9
10	*Lampsilis fasciola*	1507	2%	10
11	*Quadrula pustulosa*	1233	2%	11
12	*Pleurobema oviforme*	1096	2%	12
13	*Quadrula verrucosa*	959	2%	13
14	*Villosa taeniata*	959	2%	13
15	*Lexingtonia dolabelloides*	822	1%	15
16	*Amblema plicata*	685	1%	16
17	*Epioblasma ahlstedti*	685	1%	16
18	*Leptodea fragilis*	411	1%	18
19	*Quadrula c. cylindrica*	411	1%	18
20	*Lampsilis ovata*	274	0.5%	20
21	*Megalonaias nervosa*	274	0.5%	20
22	*Ptychobranchus fasciolaris*	137	0.2%	22
23	*Villosa vanuxemensis*	137	0.2%	22
	TOTAL	**60828**		

Table 7. Columbia Mill Dam site summary statistics of 80, 0.25 m^2 quadrat samples.

Total	Mean Density per m^2	Standard Deviation	Standard Error	CV of SE (Precision)	Lower 95% CI	Upper 95% CI	Total Population per Site (2170 m^2)	Lower 95% CI	Upper 95% CI	Species
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	109	-4144.829303	4361.829303	*Actinonaias ligamentina*
28	1.4	2.12042508	0.23707794	0.169341385	0.93532724	1.86467276	3038	2317.757223	3758.242777	*Amblema plicata*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	109	-4144.829303	4361.829303	*Ellipsaria lineolata*
77	3.85	4.86553365	0.54399974	0.141298633	2.783760514	4.916239486	8355	7753.528654	8955.471346	*Cyclonaias tuberculata*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	109	-4144.829303	4361.829303	*Elliptio crassidens*
3	0.15	0.76472879	0.08550188	0.570012517	-0.01758368	0.31758368	326	-2098.877237	2749.877237	*Elliptio dilatata*
2	0.1	0.6284399	0.07026385	0.702638529	-0.037717152	0.237717152	217	-2771.462194	3205.462194	*Fusconaia ebena*
3	0.15	0.76472879	0.08550188	0.570012517	-0.01758368	0.31758368	326	-2098.877237	2749.877237	*Lampsilis fasciola*
9	0.45	1.27189682	0.14220671	0.316014912	0.171274847	0.728725153	977	-367.5746253	2320.574625	*Lasmigona costata*
3	0.15	0.76472879	0.08550188	0.570012517	-0.01758368	0.31758368	326	-2098.877237	2749.877237	*Lexingtonia dolabelloides*
10	0.5	1.33122196	0.14883966	0.297679328	0.208274258	0.791725742	1085	-181.0897199	2351.08972	*Leptodea fragilis*
4	0.2	0.87728003	0.09808587	0.490429356	0.007751693	0.392248307	434	-1651.894135	2519.894135	*Megalonaias nervosa*
7	0.35	1.13739654	0.12716866	0.363339042	0.100749417	0.599250583	760	-785.8536155	2304.853616	*Obliquaria reflexa*
2	0.1	0.6284399	0.07026385	0.702638529	-0.037717152	0.237717152	217	-2771.462194	3205.462194	*Ptychobranchus fasciolaris*
6	0.3	1.23657346	0.13825732	0.46085773	0.029015655	0.570984345	651	-1309.120097	2611.120097	*Quadrula quadrula*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	109	-4144.829303	4361.829303	*Quadrula c. cylindrica*
26	1.3	2.18394603	0.24418001	0.187830779	0.821407176	1.778592824	2821	2022.118133	3619.881867	*Quadrula pustulosa*
12	0.6	1.43729704	0.16069958	0.267832633	0.285028824	0.914971176	1302	162.8542457	2441.145754	*Quadrula verrucosa*
14	0.7	1.52945759	0.17100376	0.244291079	0.36483264	1.03516736	1519	479.981184	2558.018816	*Truncilla truncata*
210	**10.5**	**5.98309856**	**0.66895109**	**0.063709628**	**9.188855862**	**11.81114414**	**22790**	**22519.03021**	**23060.96979**	**Population**
	Species richness = 19									

Table 7 Continued. Columbia Mill Dam.

	Species	Population	Relative Abundance	Rank
1	*Cyclonaias tuberculata*	8355	37%	1
2	*Amblema plicata*	3038	13%	2
3	*Quadrula pustulosa*	2821	12%	3
4	*Truncilla truncata*	1519	7%	4
5	*Quadrula verrucosa*	1302	6%	5
6	*Leptodea fragilis*	1085	5%	6
7	*Lasmigona costata*	977	4%	7
8	*Obliquaria reflexa*	760	3%	8
9	*Quadrula quadrula*	651	3%	9
10	*Megalonaias nervosa*	434	2%	10
11	*Elliptio dilatata*	326	1%	11
12	*Lampsilis fasciola*	326	1%	11
13	*Lexingtonia dolabelloides*	326	1%	11
14	*Fusconaia ebena*	217	1%	14
15	*Ptychobranchus fasciolaris*	217	1%	14
16	*Actinonaias ligamentina*	109	0%	16
17	*Ellipsaria lineolata*	109	0%	16
18	*Elliptio crassidens*	109	0%	16
19	*Quadrula c. cylindrica*	109	0%	16
	Total	**22790**		

Table 8. Littlelot site summary statistics of 80, 0.25 m^2 quadrat samples.

Total	Mean Density per m^2	Standard Deviation	Standard Error	CV of SE (Precision)	Lower 95% CI	Upper 95% CI	Total Population per Site (2170 m^2)	Lower 95% CI	Upper 95% CI	Species
2	0.1	0.6284399	0.070263853	0.702638529	-0.037717152	0.237717152	175	-2235.050156	2585.050156	*Arcidens confragosa*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	88	-3342.604277	3517.604277	*Ellipsaria lineolata*
114	5.7	7.4160278	0.829162321	0.145467074	4.07484185	7.32515815	9975	9476.047936	10473.95206	*Cyclonaias tuberculata*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	88	-3342.604277	3517.604277	*Elliptio crassidens*
31	1.55	2.81001824	0.314179142	0.20269622	0.934208882	2.165791118	2713	2017.251964	3407.748036	*Fusconaia ebena*
5	0.25	0.9743547	0.108939479	0.435757918	0.03647862	0.46352138	438	-1057.149657	1932.149657	*Lampsilis cardium*
10	0.5	1.33122196	0.148839664	0.297679328	0.208274258	0.791725742	875	-146.0400967	1896.040097	*Lampsilis fasciola*
6	0.3	1.06021254	0.118538969	0.395129898	0.06766362	0.53233638	525	-830.295549	1880.295549	*Lampsilis ovata*
21	1.05	2.44379866	0.273233303	0.260222193	0.514462726	1.585537274	1838	944.937877	2730.062123	*Lasmigona costata*
10	0.5	1.84184827	0.205931158	0.411862315	0.096374931	0.903625069	875	-537.6877412	2287.687741	*Leptodea fragilis*
17	0.85	1.87657107	0.209813402	0.246839297	0.438765731	1.261234269	1488	640.8412112	2334.158789	*Megalonaias nervosa*
8	0.4	1.20757105	0.135014653	0.337536632	0.135371281	0.664628719	700	-457.7506462	1857.750646	*Obliquaria reflexa*
16	0.8	1.73131983	0.193573326	0.241966658	0.420596281	1.179403719	1400	570.0543636	2229.945636	*Potamilus alatus*
42	2.1	3.36625097	0.376369741	0.179223686	1.362315307	2.837684693	3675	3060.262756	4289.737244	*Quadrula pustulosa*
25	1.25	2.81721651	0.314983957	0.251987165	0.632631445	1.867368555	2188	1323.184023	3051.815977	*Quadrula verrucosa*
1	0.05	0.4472136	0.05000152	1.000030401	-0.048002979	0.148002979	88	-3342.604277	3517.604277	*Strophitus undulatus*
30	1.5	2.65291814	0.296614283	0.197742855	0.918636006	2.081363994	2625	1946.742007	3303.257993	*Truncilla truncata*
340	**17**	**17.5974682**	**1.967516567**	**0.115736269**	**13.14366753**	**20.85633247**	**29750**	**29353.0246**	**30146.9754**	**Population**
	Species richness = 17									

Table 8 Continued. Littlelot.

	Species	Population	Relative Abundance	Rank
1	*Cyclonaias tuberculata*	9975	34%	1
2	*Quadrula pustulosa*	3675	12%	2
3	*Fusconaia ebena*	2713	9%	3
4	*Truncilla truncata*	2625	9%	4
5	*Quadrula verrucosa*	2188	7%	5
6	*Lasmigona costata*	1838	6%	6
7	*Megalonaias nervosa*	1488	5%	7
8	*Potamilus alatus*	1400	5%	8
9	*Lampsilis fasciola*	875	3%	9
10	*Leptodea fragilis*	875	3%	9
11	*Obliquaria reflexa*	700	2%	11
12	*Lampsilis ovata*	525	2%	12
13	*Lampsilis cardium*	438	1.47%	13
14	*Arcidens confragosa*	175	0.59%	14
15	*Ellipsaria lineolata*	88	0.3%	15
16	*Elliptio crassidens*	88	0.3%	15
17	*Strophitus undulatus*	88	0.3%	15
	TOTAL	**29754**		

FIGURES

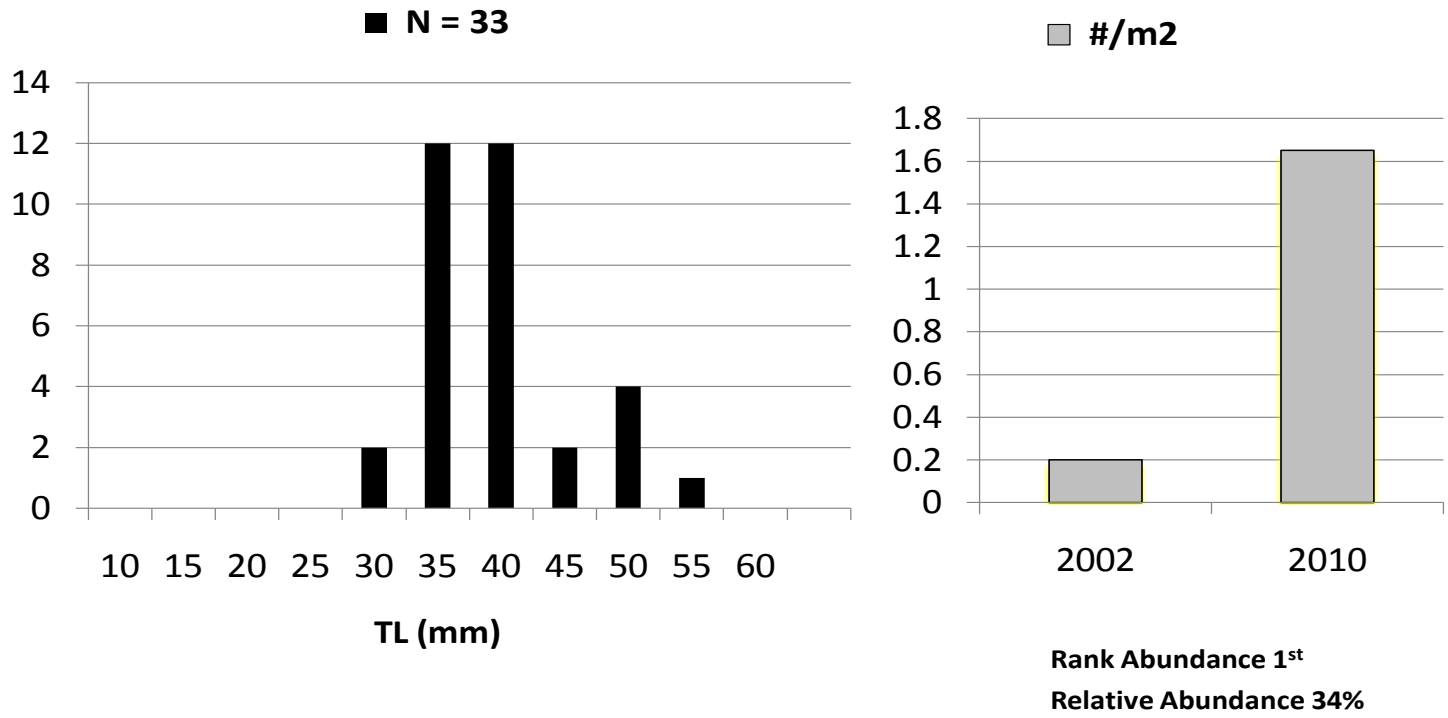


Figure 7. Spike, 2010 Tarpley Bluff length frequency and density.

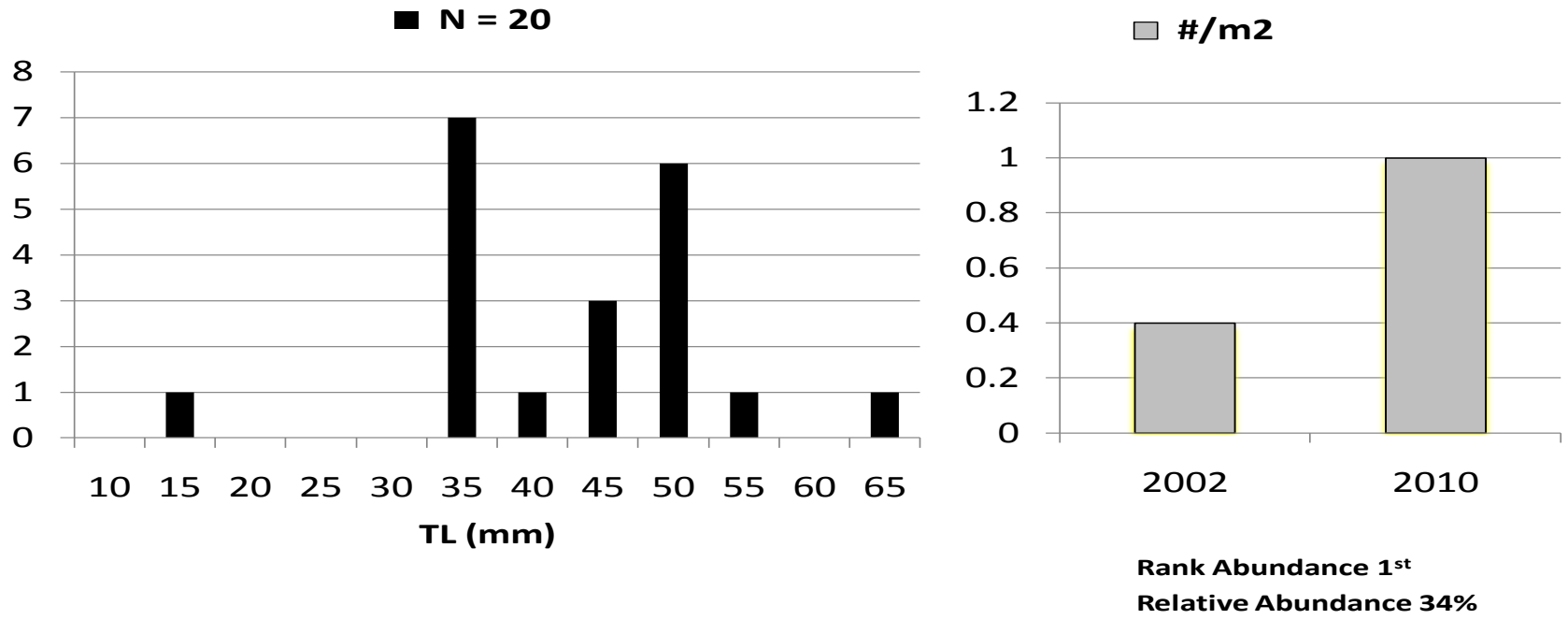
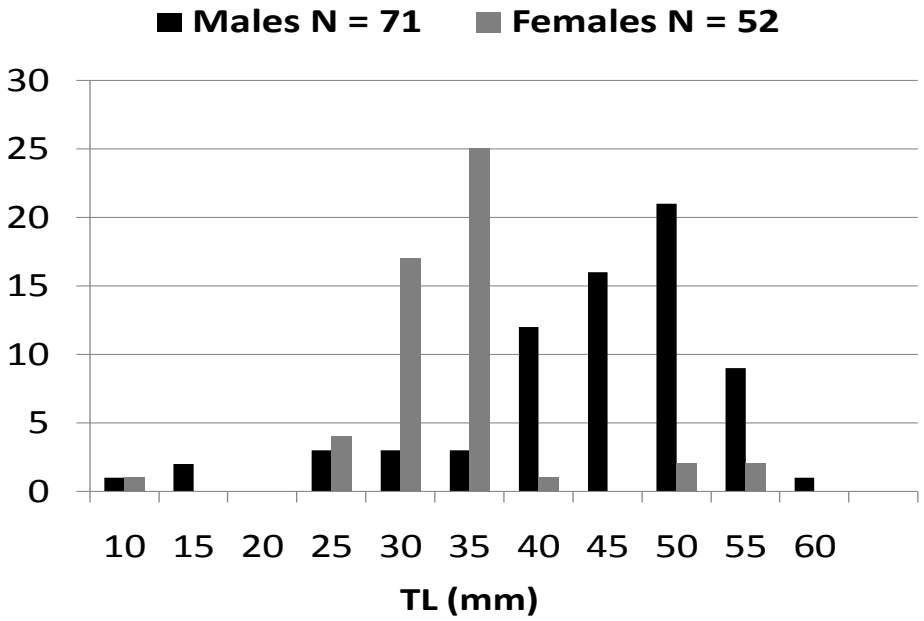


Figure 8. Painted creekshell, 2010 Tarpley Bluff length frequency and density.



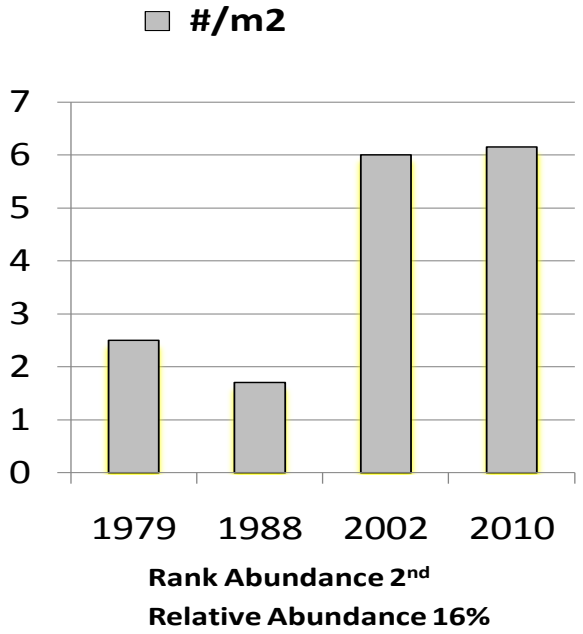


Figure 9. Birdwing pearlymussel, 2010 Lillard's Mill length frequency and density.

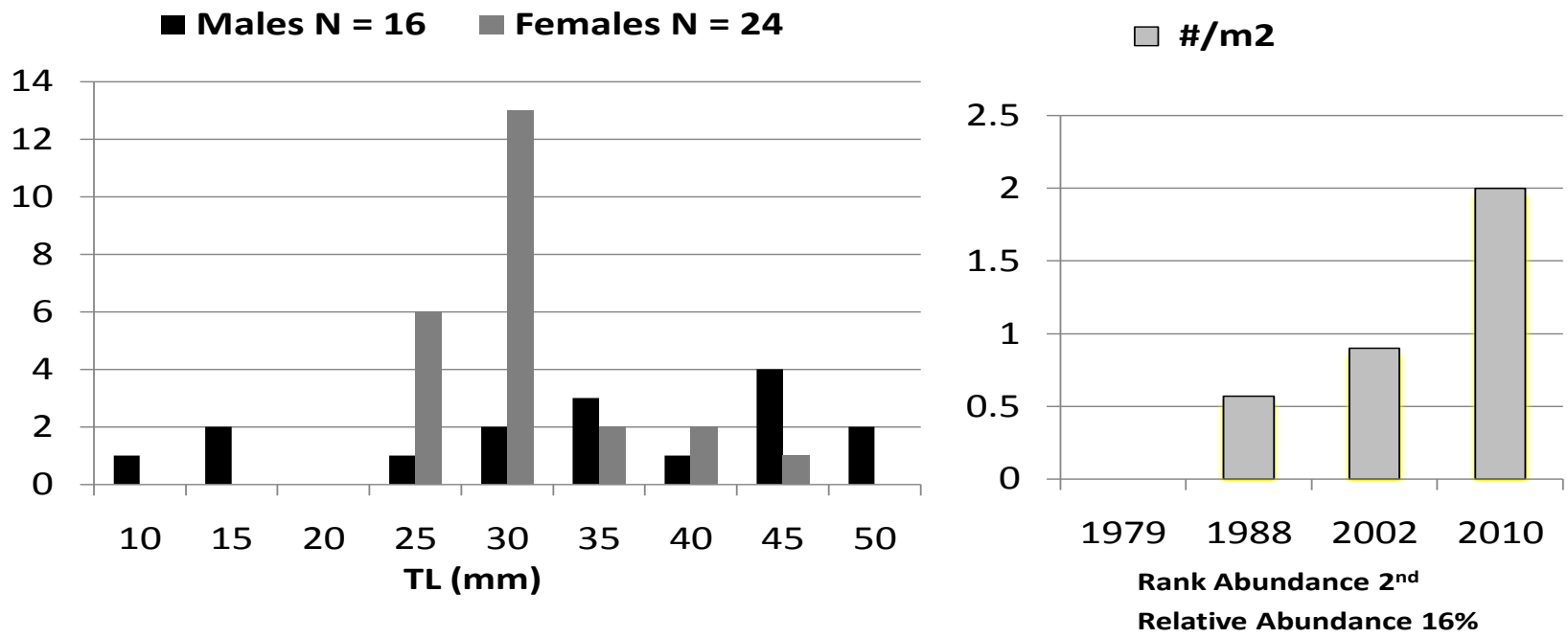
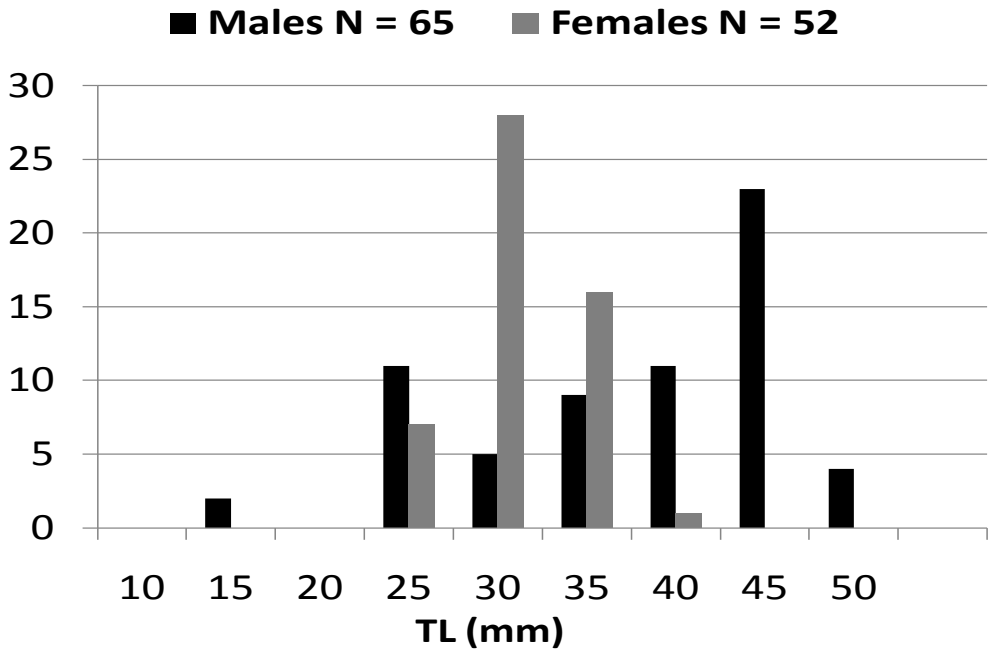


Figure 10. Birdwing pearlymussel, 2010 Venable Spring length frequency and density.



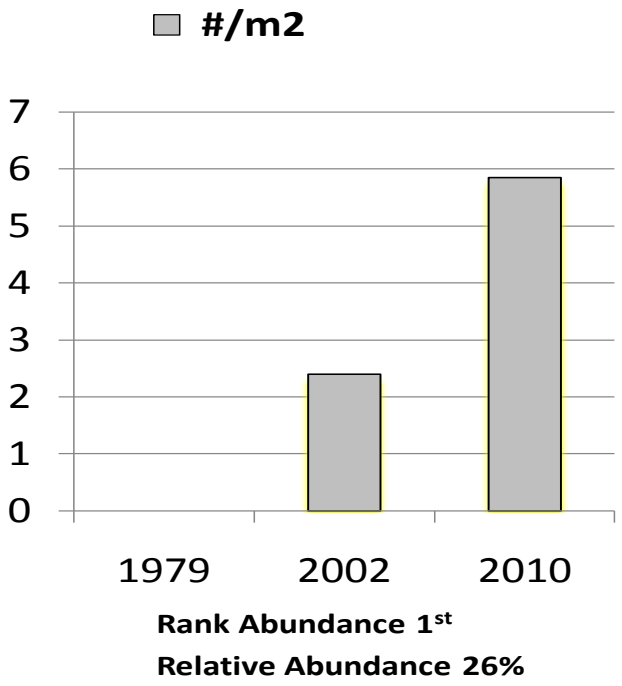


Figure 11. Birdwing pearlymussel, 2010 Hooper Island length frequency and density.

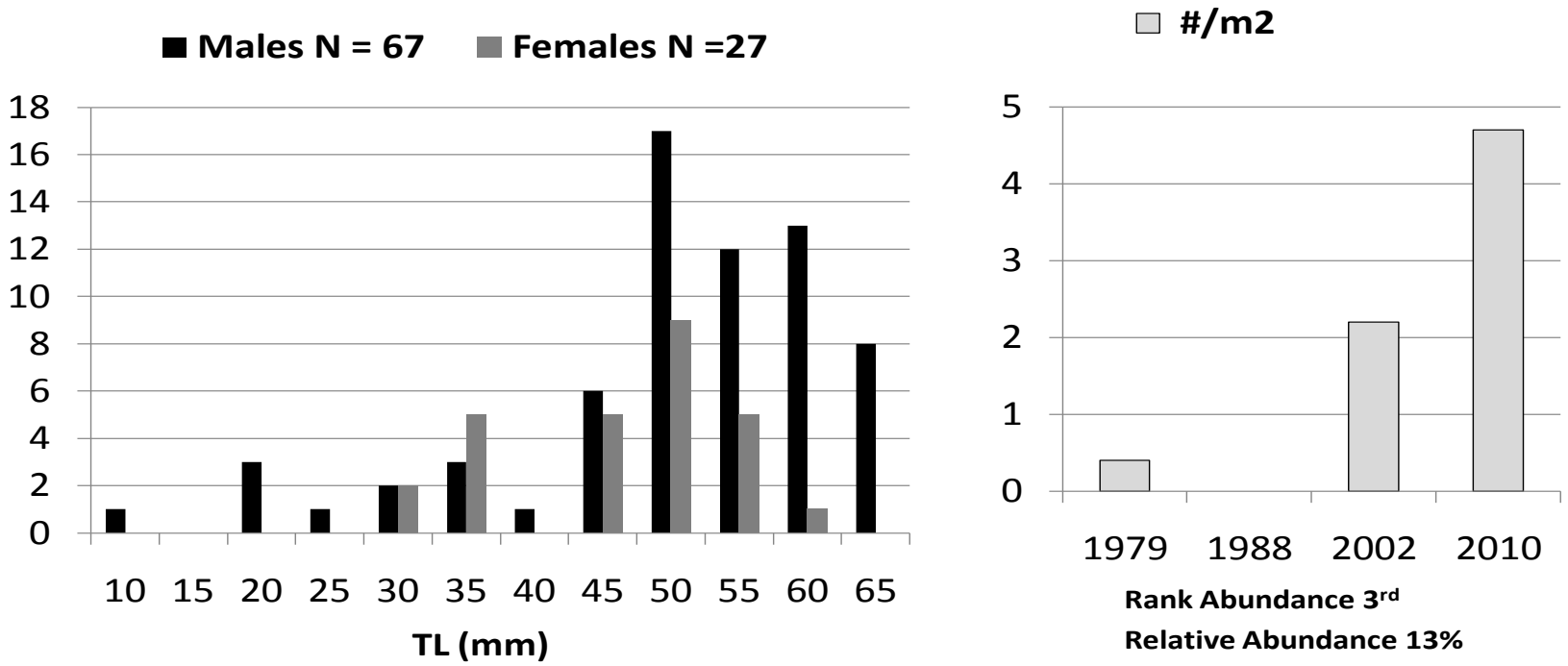


Figure 12. Duck River darter snapper, 2010 Lillard's Mill length frequency and density.

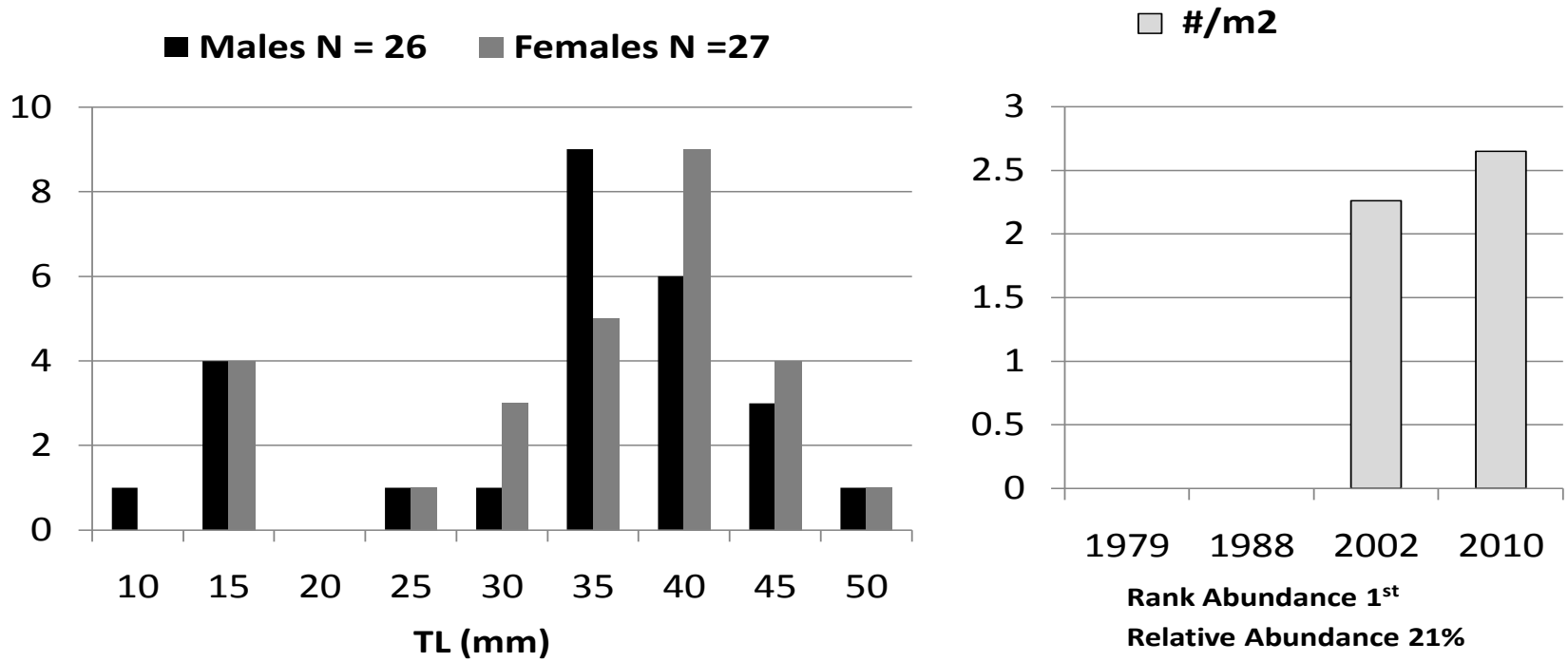


Figure 13. Duck River darter snapper, 2010 Venable Spring length frequency and density.

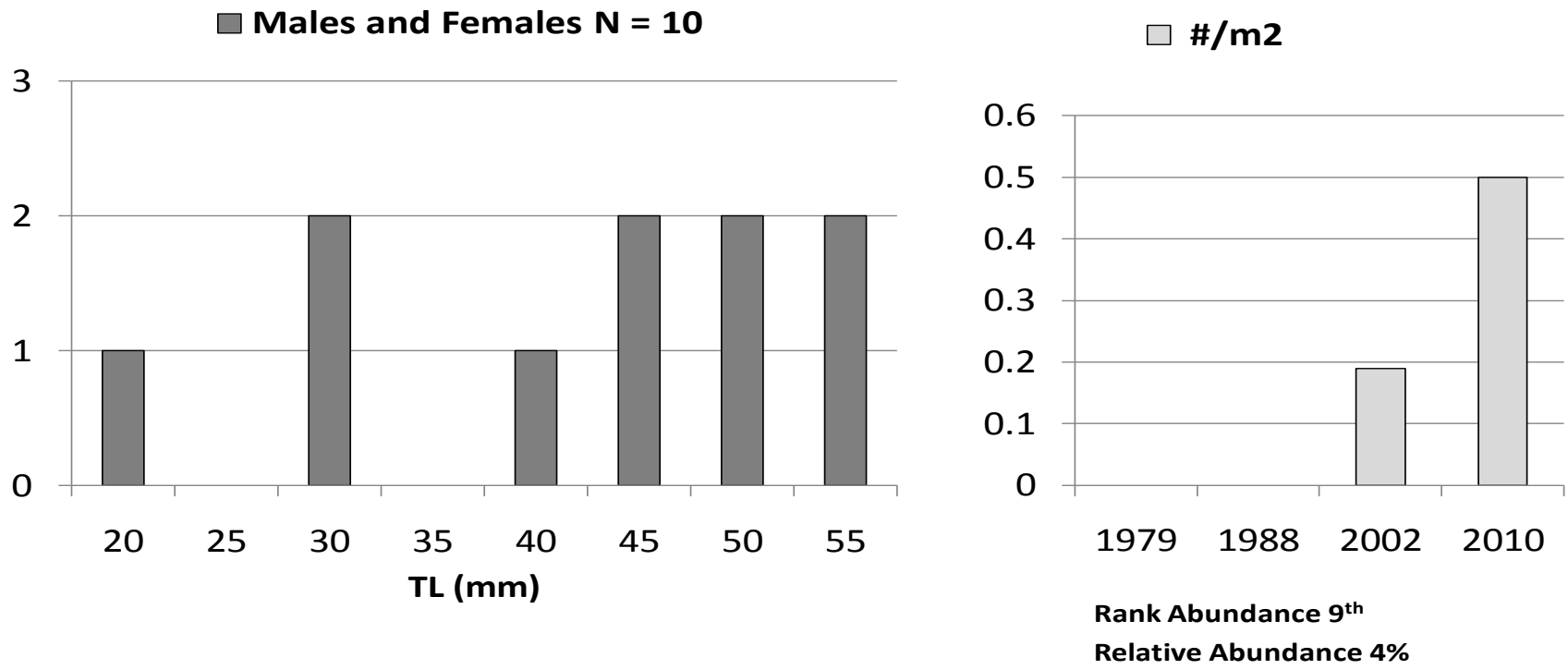
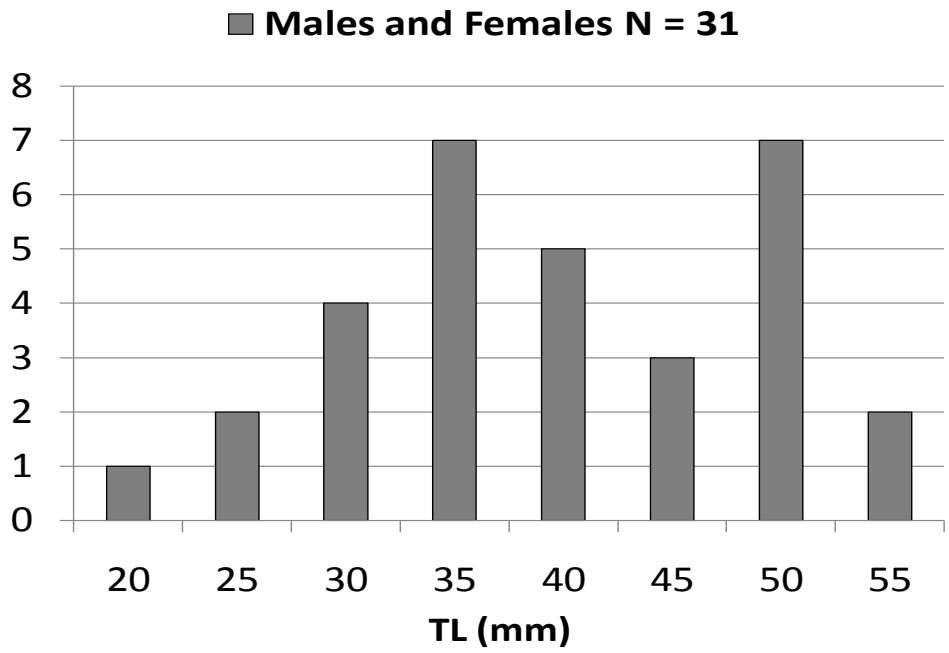


Figure 14. Cumberland monkeyface, 2010 Venable Spring length frequency and density.



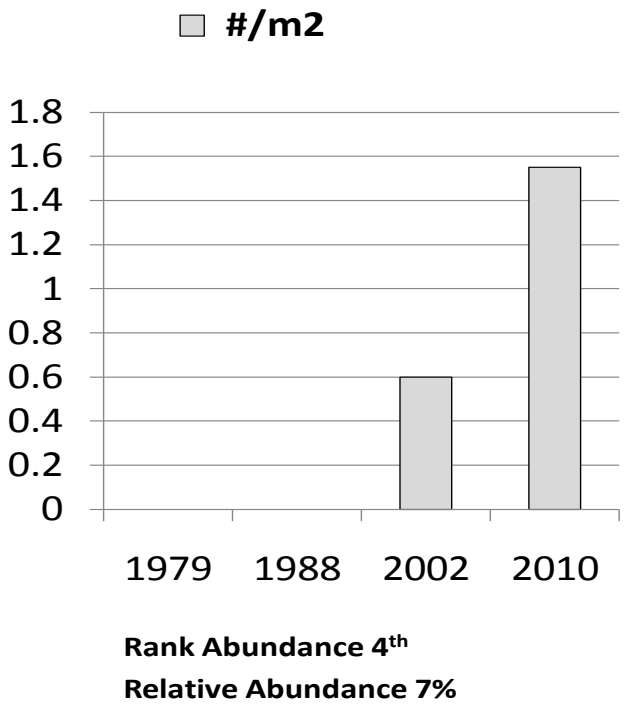


Figure 15. Cumberland monkeyface, 2010 Hooper Island length frequency and density.

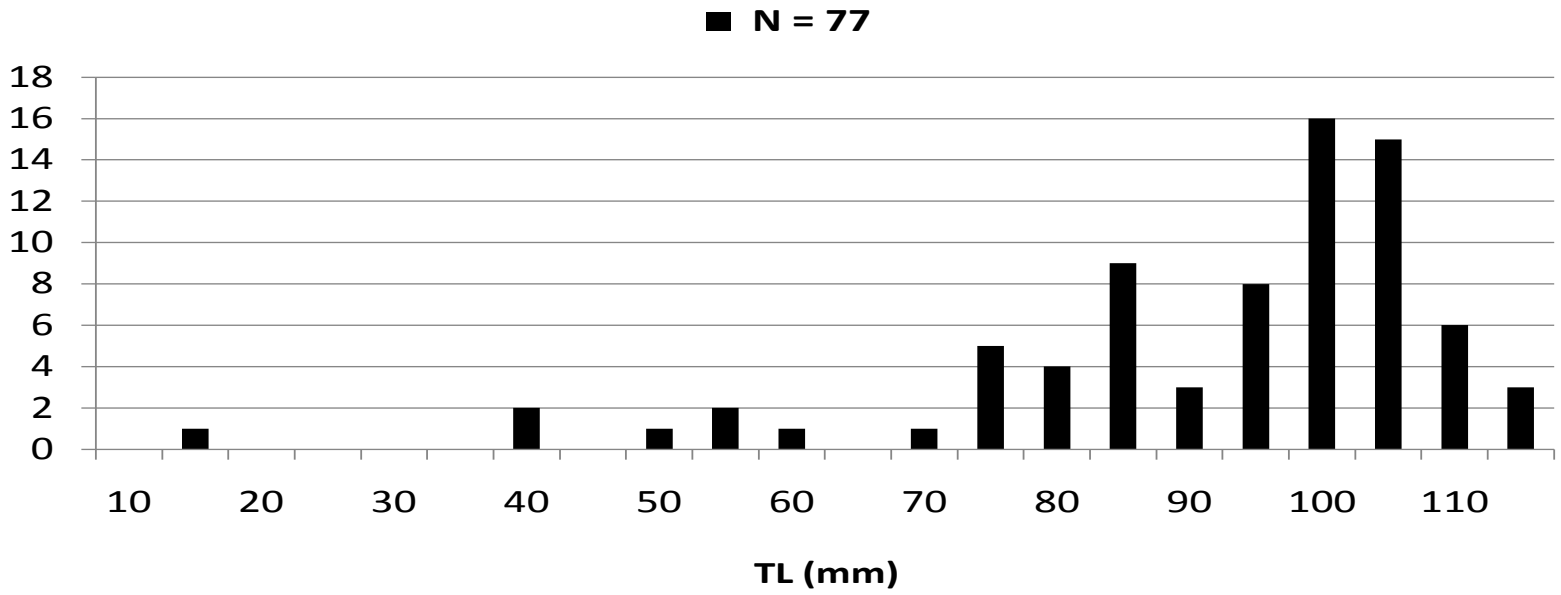


Figure 16. Purple wartyback, 2010 Columbia Mill Dam length frequency.

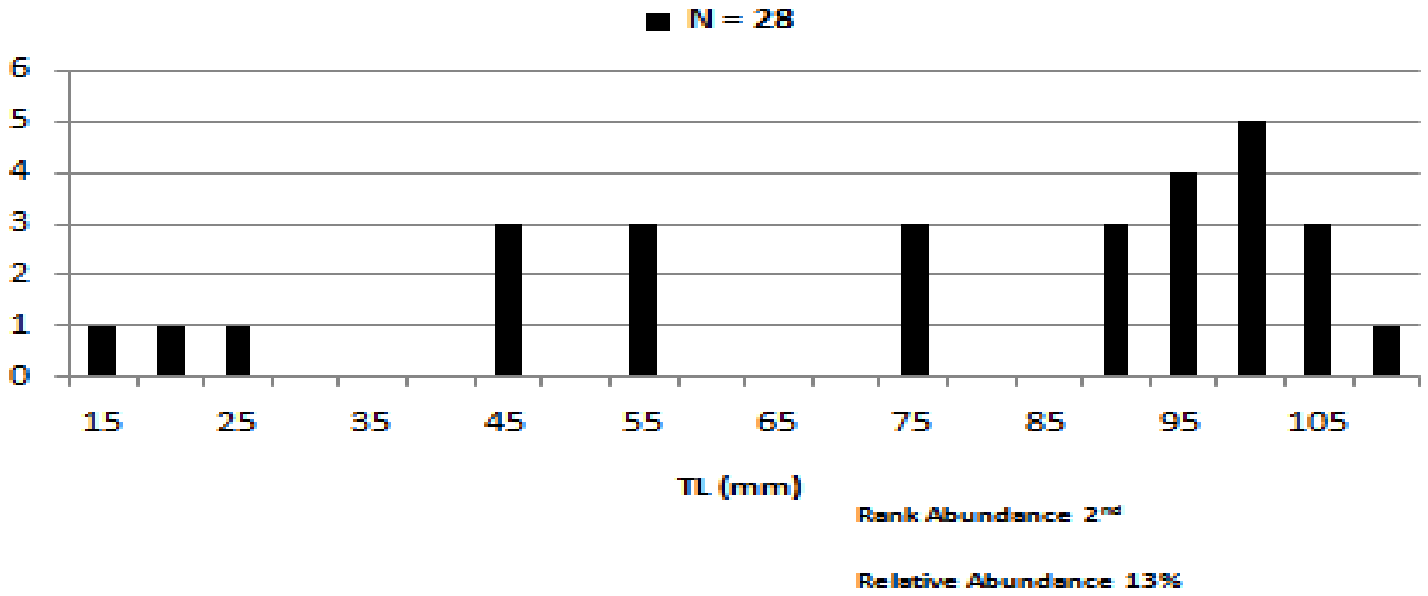


Figure 17. Threeridge, 2010 Columbia Mill Dam length frequency.

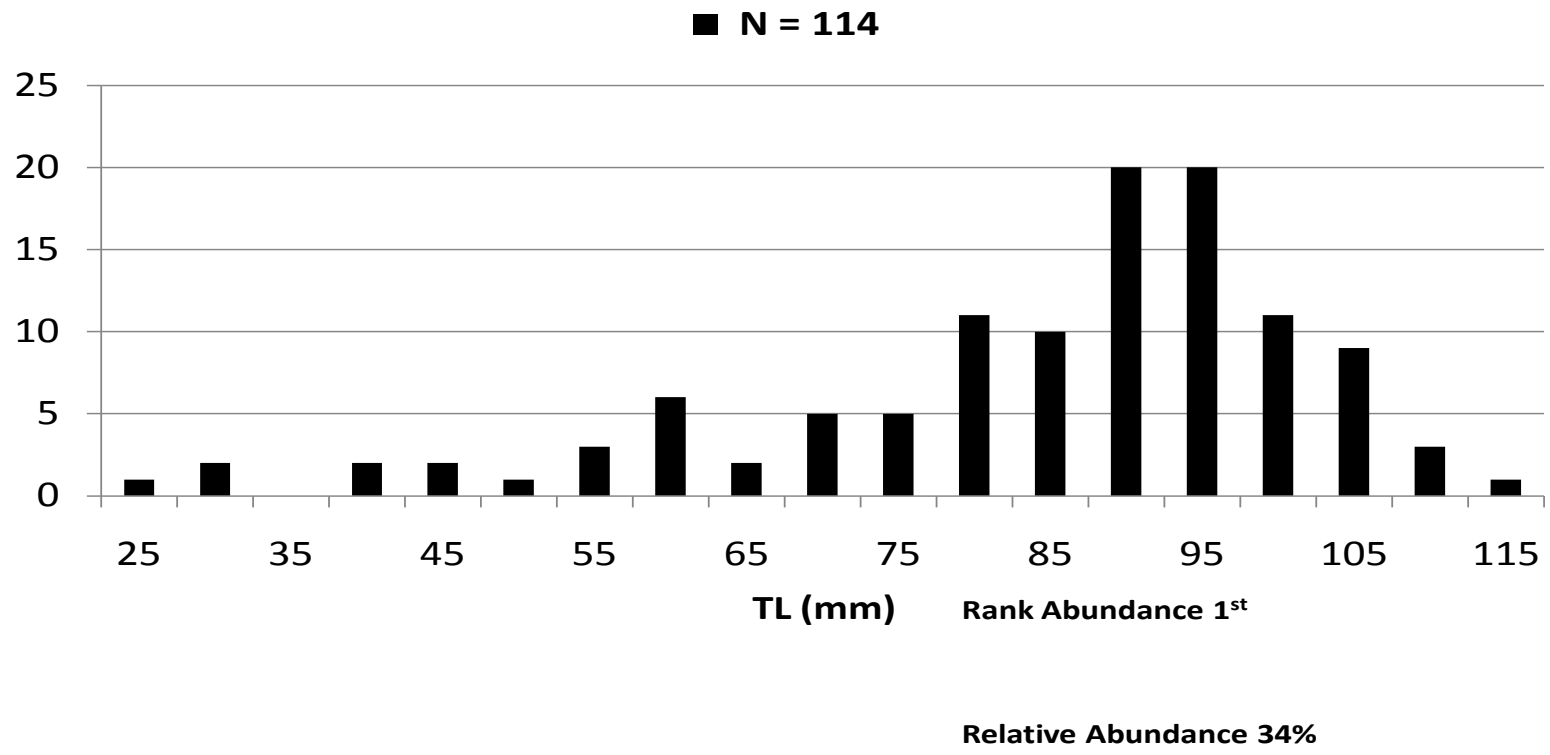


Figure 18. Purple wartyback, 2010 Littlelot length frequency.

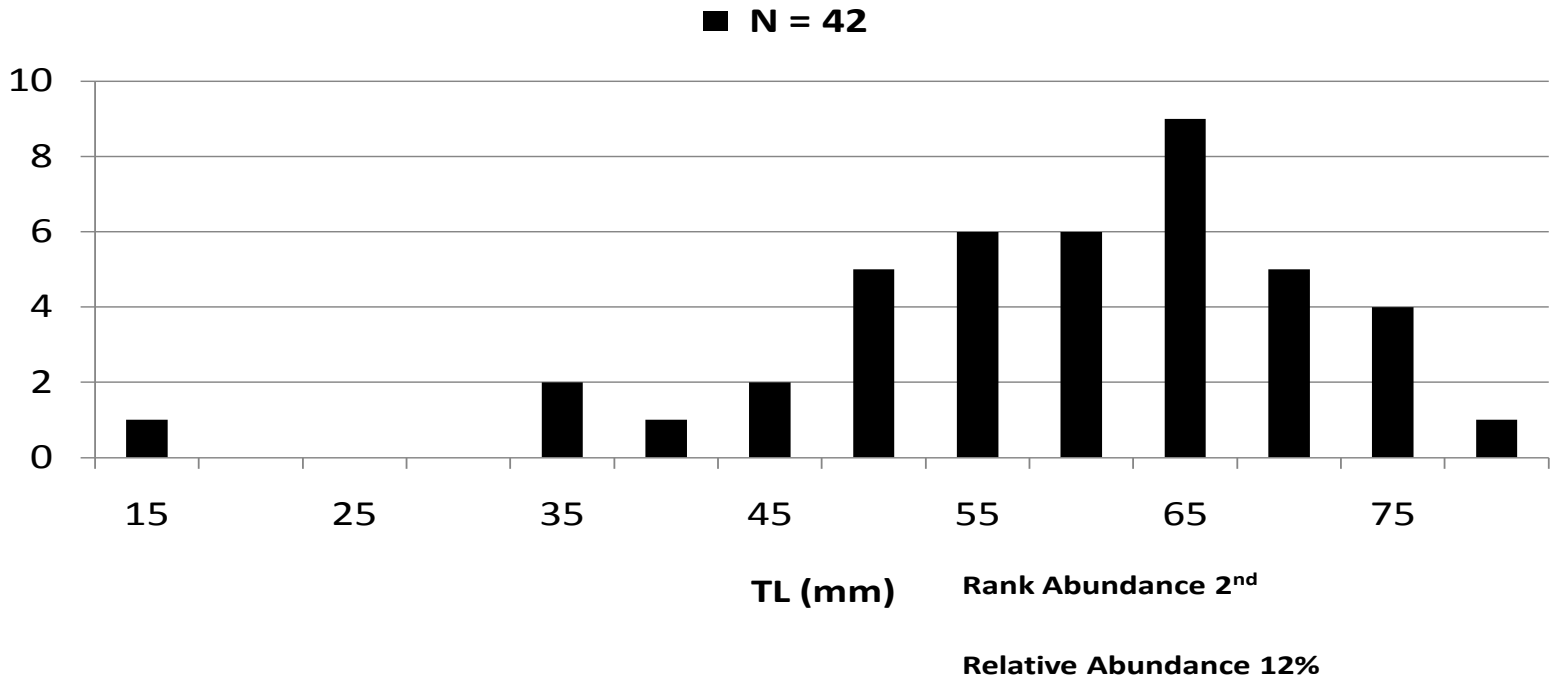


Figure 19. Pimpleback, 2010 Littlelot length frequency.