Changes in Freshwater Mussel Populations in Bankhead National Forest from 1993 - 2002

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Executive summary

Streams in Bankhead National Forest, Alabama are classified as a critical conservation area for freshwater mussels, including the conservation of four federally listed species, and changes in the status of the fauna in these streams is of high conservation concern. We compared mussel abundance and species composition of mussels at five stream sites (Brown Creek, Brushy Creek, Flannagin Creek, Rush Creek, and Sipsey Fork) in the Forest based on surveys in 1993 and 2001-2002. Mussel abundance declined significantly in the Forest between surveys, most likely in response to an exceptionally severe drought in 2000. Even though small sample sizes in the 1993 survey hampered our ability to precisely estimate the magnitude of decline, our 80% confidence intervals extended as low as 30-70% or as high as 70-90% in all study streams. In general, all species declined at similar rates, and species relative abundance was similar at all sites in 1993 and 2001-2002. Species richness declined to varying extents at different stream sites, but for the five sites combined, all species found alive in 1993 were found alive in at least one stream in 2002. One species, the southern lilliput (*Toxolasma corvunvulus*), was found for the first time on the Forest in 2002.

The estimated magnitude of the decline coupled with isolation and fragmentation of mussel populations by Lewis Smith Reservoir and Brushy Lake portends at best a prolonged recovery period for many species and may result in extinction in the Forest of others. The situation calls for implementation of a sustained conservation strategy for mussels in Forest waters. Primary emphases of such a strategy are protection and maintenance of high quality stream habitat and careful monitoring to detect further

changes in the fauna over the next 5 to 10 years. Depending on recovery trajectories, stocking of hatchery cultivated juveniles may be necessary to maintain some species within the Forest.

Introduction

Bankhead National Forest (NF), Alabama, supports a globally important freshwater mussel fauna composed of at least 16 species, including two federally endangered and two federally threatened species. Mussel assemblages in the Forest represent the best and virtually only intact examples of the Black Warrior River system mussel fauna. The Black Warrior fauna is distinctive, highly endangered, and contains at least one endemic mussel species, the dark pigtoe (*Pleurobema furvum*). Bankhead NF supports all but one of the known populations of this species (McGregor and Pierson 1999). In addition, streams in Bankhead NF support several other species endemic to the Mobile Basin, including the largest known populations of the orange-nacre mucket (*Lampsilis perovalis*) and the triangular kidneyshell (*Ptychobranchus greeni*)(Haag 2004a, Haag 2004b)

Interest in the mussel fauna of Bankhead NF was heightened in the early 1990's with the listing under the Endangered Species Act of four species that occur in the Forest. The first comprehensive mussel survey of Bankhead NF was conducted in 1992 and provided information on the geographic distribution of mussels within the Forest (McGregor 1992). In 1993 the USDA Forest Service, Southern Research Station estimated mussel abundance and species composition at seven sites (Haag and Warren

1994, 1998). These two studies provide baseline information for evaluating temporal trends in the mussel resource of Bankhead NF.

In 2000, Bankhead NF experienced a severe drought. Streamflow declined to extremely low levels throughout the Forest and some streams dried completely, including streams that formerly supported important mussel populations. In 2001 and 2002, we resurveyed five sites that were surveyed in 1993 (Haag and Warren 1994) to assess mussel populations in the Forest following the drought. In this report, we compare pre- and post-drought mussel abundance and species composition at these sites and assess potential long-term impacts of the drought on mussel viability in Bankhead NF.

Methods

We estimated mussel abundance and species composition at five sites in Bankhead National Forest, Alabama: Brown Creek, Brushy Creek, Flannagin Creek, Rush Creek, and the Sipsey Fork, in 1993 and again in 2001 or 2002 (hereafter referred to as 2002, Table 1). We conducted all sampling from June to September. At each stream site, we established a permanent sample reach about 300 m in length. Within the sample reach, we sampled 2-5 habitat units (riffles, runs, or shallow pools) of 7-65 m in length. We did not sample sections of stream dominated by bedrock or deep, sluggish pools because these habitats typically yield low numbers of mussels in this region.

In 1993, we sampled a total of about 50 – 0.5 m^2 quadrats at each stream site, with the exception of Rush Creek, where we used 0.25 m^2 quadrats (Table 1). We placed quadrats by superimposing a grid consisting of 1-m^2 cells over each habitat unit and

selecting 25% of the cells using a random numbers table. We placed a quadrat in the center of each chosen cell, excavated substrate to a depth of about 15 cm, and identified, measured, and released all live mussels encountered.

In 2002, we sampled the same stream reaches but used transects instead of quadrats. In each habitat unit, we sampled one transect for every 5-m length of the unit. We determined the locations of each transect within the habitat unit by drawing a random number between 0 and the length of the unit in meters. The random number specified the distance from the downstream end of the unit to the location of the transect. We sampled transects by placing a 0.125-m^2 quadrat next to the shore at the starting point, searching the quadrat as previously described and then flipping the quadrat end-over-end, perpendicular to the stream channel, to the other shore. In this way, we sampled randomly selected cross-sections where each transect was 0.35 m wide times the width of the stream.

We examined changes in mussel abundance and assemblages between 1992 and 2002 using randomization procedures to avoid violating assumptions of parametric tests (Manly 1997). We expressed overall mussel abundance (all species combined) at each site for each survey and individual species abundance at each site for each survey as the mean number of individuals m^{-2}. We tested each site for differences in overall mussel abundance between surveys using a randomized, one-way analysis of variance (Manly 1997). We estimated the magnitude of declines in overall abundance for each site by calculating percent decline of the mean overall abundance between surveys. We used bootstrapped 95%, 90%, and 80% confidence limits around mean overall abundance estimates to construct confidence limits around estimated percent decline in the following

way. We calculated the percent decline between the lower confidence limit in 2002 and the upper limit in 1993 to obtain the upper bound estimate of percent decline, and calculated the percent decline between the upper limit in 2002 and the lower limit in 1993 to obtain the lower bound estimate of percent decline. To account for differences in mean abundance of individual species, we conducted a randomized, one-tailed, paired t-test (Sokal and Rohlf 1995, Manly 1997) for each site to test the hypothesis that species in 2002 were less abundant than species in 1993. We also calculated the mean difference between surveys in overall mussel abundance at each site and the difference for individual species abundance at each site. To detect shifts in abundance among species at a site, we used a randomized correlation (Pearson's coefficient) to test the hypothesis that individual species abundances in 1993 and 2002 were associated. All confidence intervals and *p*-values were derived from 10^4 randomizations.

We evaluated evidence of recent recruitment in study populations by using length of sampled individuals as a surrogate for age. For most species in this study, individuals < 30-40 mm in length are generally juveniles < 5 yr old (Haag and Staton 2003, Haag unpublished data). We constructed length-frequency distributions based on 10-mm size classes for the two most abundant species in 2002 (*Lampsilis perovalis* and *Villosa nebulosa*) and compared these with length-frequency distributions for those species in 1993. We tested these distributions for differences between the two surveys using a Kruskal-Wallis test with exact *p*-values (Mehta and Patel 2001). We did not construct length-frequency distributions for any other species because of low numbers of individuals found in 2002.

We made observations of physical conditions at all study sites at the nadir of the drought on November 3, 2000, about one week before the onset of fall rains. We obtained flow information on the Sipsey Fork from a U.S. Geological Survey recording gauge near Grayson, AL (USGS 02450250, http://waterdata.usgs.gov/al/nwis). We obtained geologic information from the Geologic Map of Alabama (Geological Survey of Alabama, Tuscaloosa, AL, http://:www.gsa.state.al.us/gsa/geomap.html).

Results

Mussel abundance in Bankhead National Forest declined precipitously between 1993 and 2002. Overall mussel abundance was significantly lower at all five sites in 2002 than in 1993 (Figure 1). Mean abundance declined 60-83% among all five sites and declined most steeply at Flannagin Creek (Table 2). Even though precision was low for all 1993 samples, 95% confidence intervals of mean overall abundance were non-overlapping for Brushy Creek, Flannagin Creek, and Sipsey Fork (Figure 1). Confidence intervals showed minimal overlap at Brown and Rush Creek. Among all sites, lower bounds of 80% and 90% confidence intervals around estimates of percentage decline ranged from 30-68% and 18-61% declines, respectively, and upper bounds extended as high as 90% at both confidence levels (Table 2).

Declines occurred for all mussel species, but patterns of relative abundance among species at a site changed little between surveys. Mean abundance across species was significantly lower in 2002 than in 1993 at all sites (paired t-test, Table 3), and the average differences between species abundances in 2002 and 1993 were negative at all

sites. Individual species abundances between surveys were correlated significantly at all sites (r = 0.63 – 0.98, p< 0.0028 - 0.049) except Brown Creek (r = 0.92, p< 0.15), where power to detect association likely was low. For all species-site combinations, only 4 of 40 populations showed positive changes in abundance between surveys, but of these, the magnitude of increase was substantial only for *Villosa nebulosa* at Sipsey Fork (Table 3). At this site, *V. nebulosa* shifted from one of the least abundant species in 1993 to the most abundant species in 2002 (Table 3).

Species richness declined to a variable extent among streams from 1993 to 2002 (Table 3). Richness was unchanged at Brown Creek and Brushy Creek and was similar at the Sipsey Fork (1993: 13 species; 2002: 12 species). The steepest declines in richness occurred at Rush Creek (1993: 8 species; 2002: 6 species) and Flannagin Creek (1993: 7 species; 2002: 4 species). All species found in 1993 occurred at least one stream site in 2002 with the exception of *Potamilus purpuratus*, which was represented only as a single weathered shell in 1993 but was not found in 2002. A single individual of *Toxolasma corvunculus* (southern lilliput), was found in 2002 but this species was not found in 1993.

Evidence of recent recruitment was rare but was observed for several species. Individuals <30 mm in length were found for *Medionidus acutissimus, Strophitus subvexus, Villosa nebulosa*, and *V. vibex*. Individuals < 40 mm in length were found for *Lampsilis perovalis* and *V. lienosa*. Recent recruitment was not evident for any other species. The length-frequency distribution for *L. perovalis* for all sites combined did not differ between 1993 and 2002 (χ^2 = 0.0004, p<0.99; Figure 2), but differed significantly for *V. nebulosa* (χ^2 = 9.40, p<0.002; Figure 2).

Discussion

The sharp decline in mussel abundance between 1993 and 2002 is likely due to a severe drought that occurred in the region in 2000. During the summer and fall of 2000, this drought produced the longest period of sustained low flows ever observed in the 37-year period of record for the Sipsey Fork gauging station (1966-2003, Figure 3). Mean monthly discharges far below normal began in May 2000 and continued until November. October and September flows represented the two lowest mean monthly discharges ever recorded at the site for any month, and the August discharge was the fourth lowest value.

The drought affected streams in Bankhead National Forest in different ways depending on the geologic formation occupied by the stream channel. Four of the study streams (Brown, Brushy, Rush, Sipsey) flow through Parkwood Formation shales and sandstones which apparently have good water retention qualities. These four streams were extremely low by the end of the drought and wide expanses of stream margin and riffle areas were exposed in many places. However, many riffles retained water within the interstices of gravels and cobbles, all pools remained watered, and at least some flow was evident in all streams. In contrast, Flannagin Creek flows through porous, fractured Bangor Limestone, which includes karst features. As a combined result of the drought and underlying geology, Flannagin Creek was dewatered almost completely, and only isolated, small pools and moist areas remained in the streambed. Of the stream reach that we examined, 73% (428 out of 584 m) was completely dry from bank to bank, and digging in the substrate in these areas produced no water or observable moisture at depths

of at least 15 cm. Wet sections of the channel consisted of small, isolated pools from 4-42 m long (mean = 13 m) and generally only 1-2 meters wide

Two observations support the drought as a causal factor for the decline of mussels in Bankhead National Forest. First, the observation that the mussel fauna of Flannagin Creek declined most sharply in abundance and richness is consistent with the observation that water levels in this stream were affected most severely by the drought. Second, few other factors are likely to have resulted in such steep declines in only 8-9 years throughout this large geographic area. We visited most of the study streams periodically between 1994 and 1999 (Haag and Warren 1997, Haag and Warren 2000). Although we did not estimate abundance during these visits, mussels remained common and easy to find throughout this time period, further suggesting that the decline occurred rapidly and sometime after 1999. The watersheds of all five streams are almost entirely within USDA Forest Service ownership. Although forest management and other activities (e.g., horseback riding, timber harvest, temporary road construction) undoubtedly occurred at various locations in the Forest between surveys, it is unlikely that such activities adversely affected mussels over such a large area to the extent we observed.

Another potential factor involved in widespread mussel declines in Bankhead National Forest is habitat fragmentation and population isolation caused by Lewis Smith Reservoir and, to a lesser extent, Brushy Lake. The major watersheds in the Forest that support important mussel populations, Brushy Creek and Sipsey Fork, are isolated from each other and from downstream mussel populations by Lewis Smith Reservoir. The Brushy Creek watershed is further fragmented by Brushy Lake, which isolates mussel populations in upper Brushy Creek and Owl Creek from populations elsewhere in the

watershed. Fragmentation and isolation decreases total population size and can render populations vulnerable to extinction through a combination of loss of genetic variability, chance fluctuations in reproduction and survivorship, and chance environmental disturbance, such as droughts (Gilpin and Soule 1986).

In Bankhead NF, populations of mussel species characteristic of large streams such as *Elliptio arca, Lampsilis ornata, Potamilus purpuratus, Quadrula asperata*, and *Tritogonia verrucosa* are at particularly high risk of local extinction. These species are represented only by small populations that are restricted to the lower reaches of the Sipsey Fork and Brushy Creek and are isolated from sources of immigrants from other populations in the Mobile Basin. Based on the collection of a single, weathered shell of *Potamilus purpuratus* in the Sipsey Fork in 1993, but the absence of live individuals in 1993 or 2002, this large stream species is apparently now extinct in the Forest. Although common elsewhere in the Mobile Basin, its extinction in the Forest is probably due to habitat fragmentation and population isolation. These factors will likely result in continued erosion of mussel diversity in the Forest over time.

Despite the long-term threat to diversity posed by habitat isolation and population fragmentation, these factors are not likely responsible for the rapid decline in mussel abundance in Bankhead NF between 1993 and 2002. Because most mussel species in the Forest can live at least 15-30 yr (Haag and Staton 2003), declines due to isolation and fragmentation will likely be manifested over longer time periods. Further, declines due to these factors would be expected to differ in severity and rapidity between small, localized populations of large-river species and relatively larger and more contiguous populations of headwater mussel species such as *Lampsilis perovalis*, *Strophitus*

subvexus, and *Villosa* spp. In contrast, recent mussel declines in the Forest were swift and occurred similarly across all species.

Isolation and fragmentation will retard recovery of at least some species from the 2000 drought and future natural disturbances. Populations of headwater mussel species that occupy many kilometers of contiguous habitat within Bankhead NF may recover fully from the 2000 drought and may be viable into the foreseeable future because of their relatively broad distribution and large population size. Although our ability to assess strength of recent recruitment was limited, we found evidence of recent recruitment for all headwater species. In contrast, small populations of large-stream mussel species and small, isolated populations of headwater species (e.g., above Brushy Lake) may not recover easily from severe reductions in population size caused by the drought.

An encouraging observation for the future of the Bankhead NF mussel fauna is that all species present prior to the drought were also found alive in 2002. Thus, the species pool exists for a potential full recovery of those species present in sufficient numbers to reproduce. In addition, *Toxolasma corvunculus* was not previously known from Bankhead NF. Our collection in 2002 represents an addition to the known fauna of the Forest and is also the first time this species has been found alive anywhere in over 25 years (J.D. Williams, U.S. Geological Survey. Gainesville, FL, personal communication).

The decline of the mussel fauna in Bankhead NF is of high conservation concern. These streams are a critical conservation area for freshwater mussels (Master 1998, Smith et al. 2002), including the conservation of four federally listed species. Our results indicate this important mussel fauna underwent a severe, rapid decline. Even though

sample sizes in the 1993 survey hampered our ability to produce highly precise estimates of the magnitude of the decline, our 80% confidence intervals extended as low as 30-70% but as high as 70-90% in all study streams. Estimated declines even as low as 30% coupled with isolation and fragmentation of the populations by Lewis Smith Reservoir and Brushy Lake portend at best a prolonged recovery. The situation calls for a sustained, adaptive conservation strategy.

The conservation strategy should include two primary elements: protection and maintenance of habitat quality and careful monitoring of the recovery trajectory of the fauna. Any activity potentially adversely affecting streams in the Forest should be reviewed carefully and if necessary curtailed to provide optimal conditions for natural recovery of the fauna. A re-assessment of the fauna will be necessary in <10 years to determine the degree of recovery from the drought. If recovery is not observed at that time, population supplementation using hatchery cultivated juveniles may be necessary. Species will need individual evaluation to determine need for and desirability of supplemental stocking. Priority for supplemental stocking should be based on range-wide status of each species, availability of local or other suitable brood stock, and feasibility of producing juveniles. Critically endangered or threatened species or those in imminent danger of extirpation from the Forest should receive highest priority. Any supplemental stockings should be preceded with a thorough evaluation of genetic composition of brood stock and juveniles slated for stocking. Further, it should be acknowledged that the long-term efficacy of supplemental stocking to produce self-sustaining viable populations of some species, especially large river species, is uncertain given continued low habitat availability and population isolation caused by reservoirs. It

is also emphasized that the most desirable outcome is natural recovery of populations without supplemental stocking. However if natural recovery is not realized, supplemental stocking may be a viable option to maintain some mussel species within the Forest.

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Table 1. Freshwater mussel sampling sites in Bankhead National Forest, Alabama.

Stream	Locality	Latitude Longitude	Year	Area sampled (m^2)
Brown Creek	trail 223H crossing, 9.1 km ENE Grayson, Lawrence Co., AL	34° 18' 20"N 87° 14' 09"W	1993 2002	25.0 34.1
Brushy Creek	FS road 254, 6.5 km NE Grayson, Lawrence Co., AL	34° 19' 51"N 87° 17' 09"W	1993 2001	26.0 40.6
Flannagin Creek	FS road 208 crossing, 9.1 km NW Grayson, Lawrence Co., AL	34° 20' 20"N 87° 23' 18"W	1993 2001	25.5 47.4
Rush Creek	FS road 245 crossing, 10.4 km NW Addison, Winston Co., AL	34° 16' 26"N 87° 15' 06"W	1993 2001	12.5 33.6
Sipsey Fork	mouth of Hurricane Creek, 5.2 km SW Grayson, Winston Co., AL	34° 15' 11"N, 87° 22' 02"W	1993 2002	25.0 43.6

Table 2. Estimated percent decline and confidence intervals of overall mussel abundance between 1993 and 2002 in Bankhead National Forest, Alabama.

Stream	estimated % decline	Confidence interval 80 %	90%	95%
Brown Creek	79	38-92	18-94	0-95[1]
Brushy Creek	79	68-92	40-93	27-95
Flannagin Creek	83	68-92	61-93	55-94
Rush Creek	64	30-81	18-85	0-87
Sipsey Fork	60	39-75	30-78	23-80

[1]lower bound extends to a possible increase of 13%

Table 3. Changes in mussel abundance by species at 5 sites in Bankhead National Forest, AL between 1993 and 2002. Species that were found alive at a site but not encountered in quantitative sampling are denoted by having an abundance value less than species that were represented in quantitative sampling by only one individual. Difference is estimated abundance in 1993 subtracted from the abundance in 2002. *t* is the test statistic for a one-tailed randomized paired t-test (H_a: $\mu_{2002} < \mu_{1993}$; * = $p<0.05$, ** = $p<0.01$).

		Estimated abundance (number · m^{-2})		
Stream	Species	1993	2002	Difference
Brown Creek	*Lampsilis perovalis*	0.96	0.21	-0.76
	Medionidus acutissimus	0.28	0.03	-0.25
	Strophitus subvexus	0.28	0.03	-0.25
	Villosa lienosa	0.08	0.06	-0.21
	Villosa vibex	0.04	0.03	-0.01
	Mean			-0.26
	t			-1.907*
Brushy Creek	*Lampsilis perovalis*	0.62	0.12	-0.49
	Medionidus acutissimus	0.27	0.05	-0.22
	Strophitus subvexus	0.12	0.03	-0.09
	Villosa lienosa	0.04	0.03	-0.01
	Villosa nebulosa	<0.04	0	--
	Villosa vibex	0.12	0.03	-0.09
	Mean			-0.18
	t			-2.108*
Flannagin Creek	*Lampsilis perovalis*	0.55	0.11	-0.44
	Lampsilis straminea	<0.04	0	--
	Medionidus acutissimus	0.16	0	-0.16
	Pleurobema furvum	0.12	0	-0.12
	Villosa lienosa	1.22	0.17	-1.05
	Villosa nebulosa	2.24	0.38	-1.86
	Villosa vibex	0.04	0.06	0.02
	Mean			-0.60
	t			-1.969*

Rush Creek	*Lampsilis perovalis*	0.80	0.24	-0.56
	Lampsilis straminea	0.08	0.03	-0.05
	Medionidus acutissimus	0.08	0.03	-0.05
	Pleurobema furvum	0.08	0	-0.08
	Strophitus subvexus	0.56	0.15	-0.41
	Villosa lienosa	0.08	0.09	0.01
	Villosa nebulosa	0.08	0.03	-0.05
	Villosa vibex	0.16	0.12	-0.04
	Mean			-0.16
	t			-2.142**
Sipsey Fork	*Elliptio arca*	0.16	<0.02	-0.14
	Elliptio arctata	<0.04	0.02	--
	Lampsilis ornata	0.04	<0.02	-0.04
	Lampsilis perovalis	0.28	0.09	-0.19
	Lampsilis straminea	<0.04	0	--
	Pleurobema furvum	0.48	0.18	-0.30
	Potamilus purpuratus	WD	0	--
	Ptychobranchus greeni	0.88	0.18	-0.70
	Quadrula asperata	0.04	0.05	0.01
	Strophitus subvexus	0.04	0.02	-0.02
	Toxolasma corvunculus	0	0.02	0.02
	Tritogonia verrucosa	0.28	0.07	-0.21
	Villosa lienosa	0	0.02	0.02
	Villosa nebulosa	<0.04	0.23	0.21
	Villosa vibex	<0.04	0	--
	Mean			-0.12
	t			-2.031*

Figure 1. Total abundance (all species) of freshwater mussels at five sites in Bankhead National Forest in 1993 and 2002.

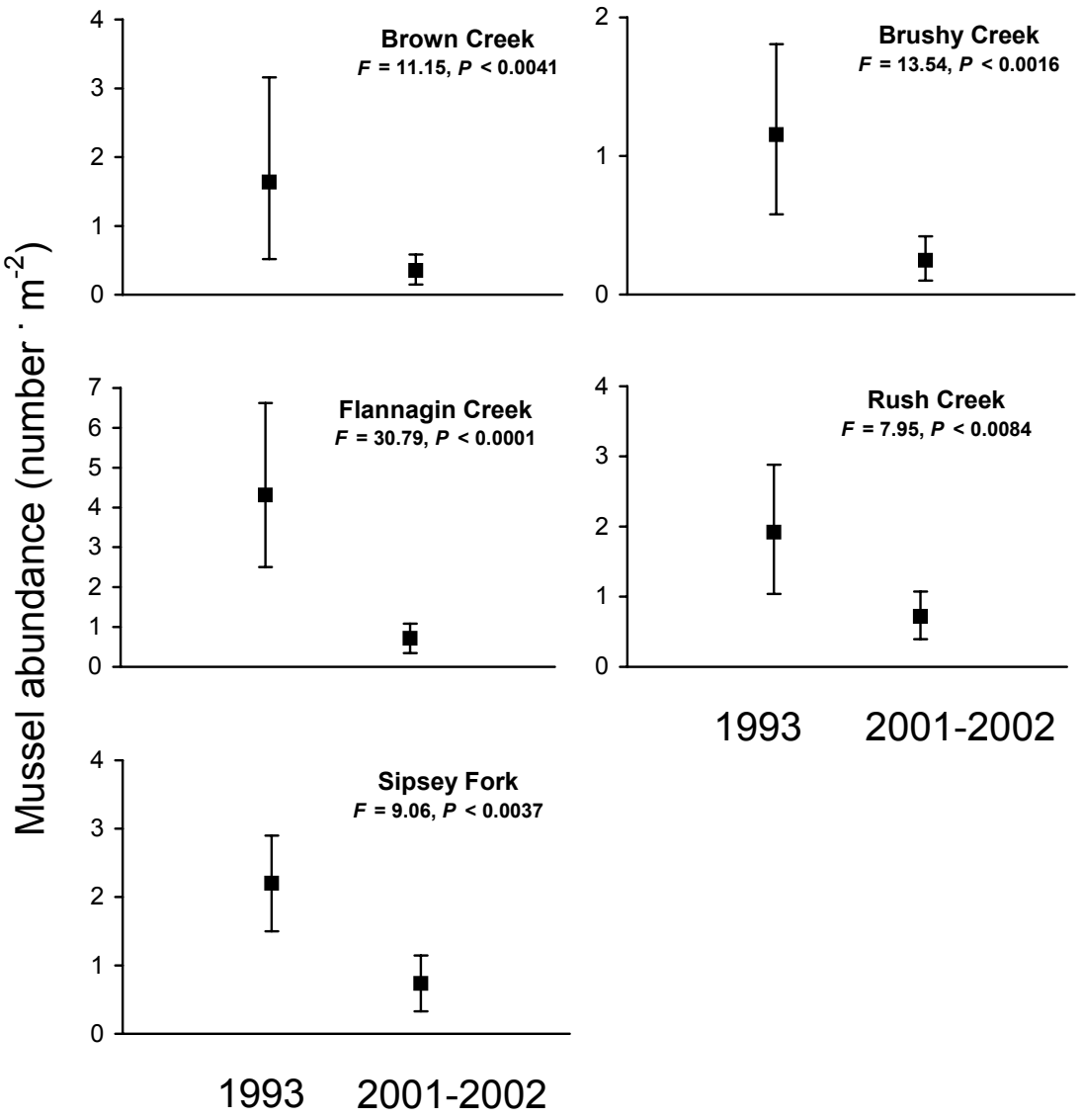

Figure 2. Length-frequency distributions of *Lampsilis perovalis* and *Villosa nebulosa* in Bankhead National Forest in 1993 and 2002.

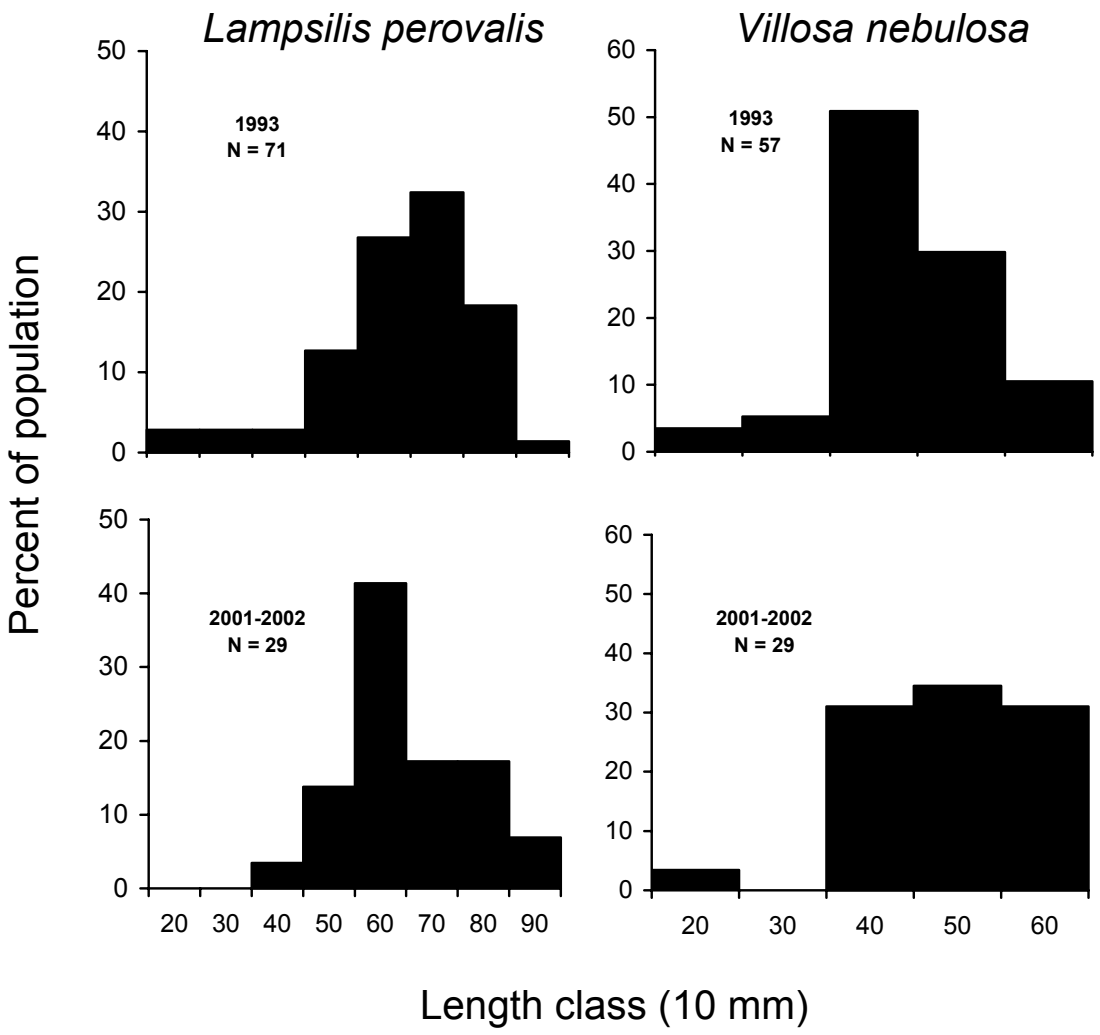
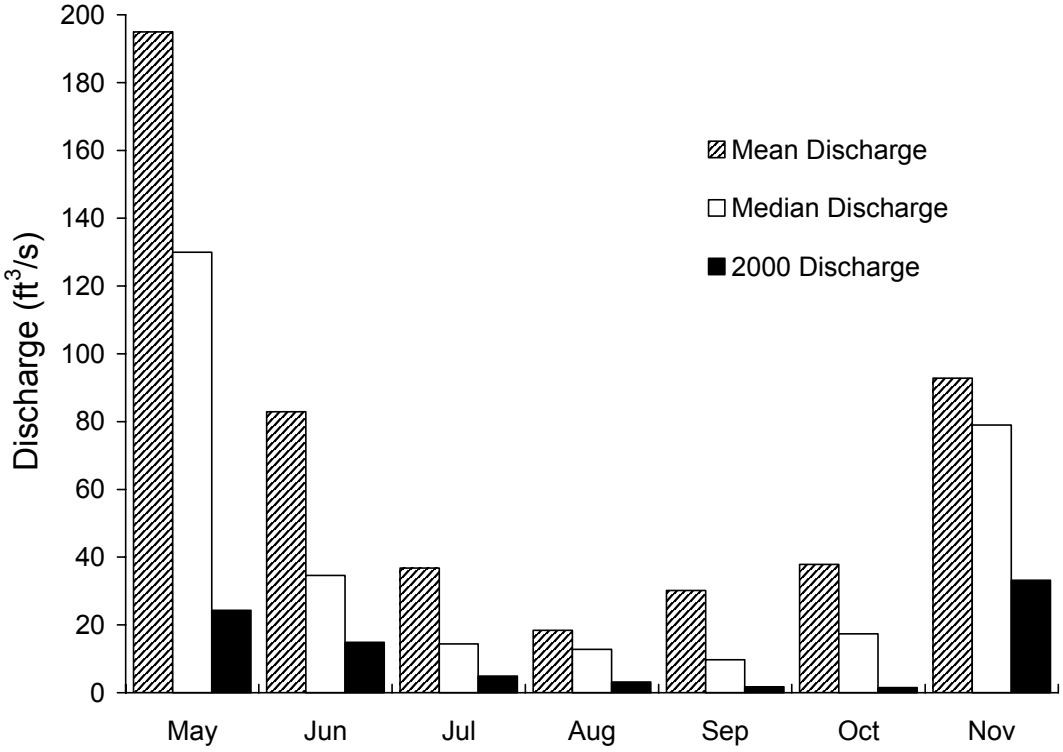
Figure 3. Mean and median monthly discharge for the Sipsey Fork near Grayson, Alabama (U.S. Geological Survey gauge 02450250) from 1966-2003 compared with 2000 discharge.