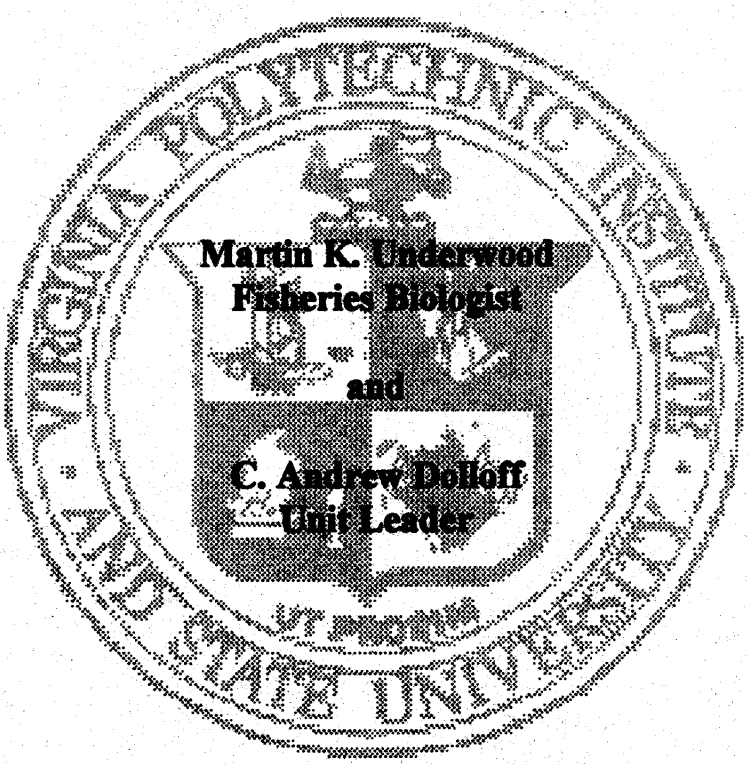
Basinwide Estimation of Habitat and Fish Populations in Five Shenandoah National Park Watersheds



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Introduction

The mountains of western Virginia are downwind of the major sulfur and nitrogen emitting regions of the nation (National Academy of Sciences, 1986). Shenandoah National Park (SNP), located in the northern region of the Blue Ridge Province, has the greatest loading of sulfate of any National Park in the United States (Webb et. al 1989). As a result stream water in some watersheds in SNP has exhibited a trend toward episodic and chronic acidification.

Numerous studies have demonstrated that acidification of streams can have a negative effect on all aquatic fauna. Because native brook trout (*Salvelinus fontinalis*) in the southeastern United States are largely confined to headwater streams in the Southern Appalachian Mountains (Neves and Pardue 1983), increased acidification poses a particular threat to the species existence in acid-sensitive watersheds.

Concern over the observed trends toward increasing acidification in SNP resulted in the initiation of a cooperative agreement between federal and academic researchers from SNP, the University of Virginia, and Virginia Polytechnic Institute and State University. This cooperative agreement, i.e. Fish In Sensitive Habitat (FISH), is part of a long term monitoring program designed to document trends in acidification and identify specific watersheds where acidification poses particular risks to species and species assemblages.

The purpose of this study was to characterize the habitat and populations of fish living in eight SNP watersheds affected to varying degrees by acidic deposition. Three basins with varying levels of acid neutralizing capacity (ANC); Paine Run-low, Staunton River-moderate, Piney River-high; were chosen for an intensive study, which was designed

and carried out as a masters thesis project that was completed in 1995. In summary, the responses (production, growth) of brook trout and blacknose dace (*Rhinichthys atratulus*) were linked to habitat and water chemistry (Newman 1995). The remaining five basins constituted the core for an extensive survey. ANC ranged from low (3 basins) to moderate (2 basins). Although there is a large body of water chemistry data for these five basins, habitat conditions and the status of fish populations were lacking. All five streams were inventoried for habitat characteristics, fish community composition, populations, densities, and distribution.

We used a combination of visual estimates and more precise measurements to estimate habitat and fish populations for all five watersheds (Dolloff et al. 1993). We inventoried stream habitat parameters, estimated total available habitat, and estimated fish populations by sampling habitats from the SNP boundary to the upper extent habitable by fish.

In this the first of two reports we present the results of the extensive habitat and fish population surveys. In a later report we will combine information obtained from the habitat and fish population surveys in the intensively sampled basins with surveys in these five basins to produce an analysis of status and trends for fish populations in SNP watersheds.

Methods

Habitat survey

We used the basinwide visual estimation technique (BVET) to collect a large amount of data associated with individual habitat units. Habitat and fish populations in

each basin were surveyed by the same two person crew during the summer of 1994 (June - August). All main branches were surveyed starting at the SNP boundary or at a confluence with another stream. Tributaries were surveyed only if they had sufficient water to support fish, which was determined by the field crew. Surveys were concluded when, in the opinion of the crew leader, the habitat became unable to support fish, i.e. no water. In practice, this occurred when the stream emerged from underground or simply "went dry."

Data collected included habitat unit type, length, mean wetted channel width, mean bankfull channel width, maximum and mean depth, substrate composition (dominant and subdominant), and number of pieces of large woody debris (LWD) in different size categories. Habitat types were limited to pools and riffles following descriptions by Bisson et. al (1982). Bankfull area was estimated to provide basinwide estimation of channel capacity during periods of high flow. Substrate was assigned to one of nine size classes (Appendix 1a), the dominant-covering the major percentage of the bottom of a selected habitat, and subdominant-covering the second highest percentage of the bottom, were identified and recorded in each habitat unit. The number of LWD pieces in each of seven size classes (Appendix 1b) were recorded along with other significant features that were suspected to influence fish populations (e.g. landslides, tributary junctions, bridge and trail crossings, and major changes in riparian vegetation).

Fish population survey

We determined the sampling fraction (relative proportions of habitat units by habitat type) before each sampling period according to a stratified random design based on the size and location of habitat units in the drainage and their perceived importance to fish.

Each habitat unit was numbered in sequence beginning at the downstream end of each sampled reach, and random numbers were chosen as the starting points for selection of units for measurement. A typical sequence included every 5th (20%) pool and every 10th (10%) riffle. In smaller reaches every 3rd (33%) pool and every 5th (20%) riffle was sampled to make sure we had enough paired samples.

Fish populations were censused by divers equipped with face mask, snorkel, and writing slate. Divers carefully entered each selected habitat unit and recorded the species, numbers, and relative size (i.e. age 0+, 1+, and 2+ for brook trout) of all fish observed. After completing the observations at a habitat unit, the recorder attached an identifying flag in a conspicuous location to be referenced during the next phase of population sampling.

After the underwater observations were completed in the sub basin, the sampling crew selected a fraction (approximately 10%) of the total number of units snorkeled in which to conduct a multiple-pass removal census (Zippen 1958) with a backpack electroshocker (700V AC) and dip nets . All fish were identified, measured for fork length (mm) and total length (mm), and weighed (0.1 g) before being returned to their approximate location of capture. Electrofishing was essential for two reasons: (1) to verify identifications and counts made by divers; and, (2) to obtain accurate measurements of length and weight.

Total lengths of fish were used to calculate length frequencies for blacknose dace and brook trout . Population estimates for each species (including age 0+ brook trout) were calculated, and diver counts of fish number per unit of habitat area (density) were averaged for similar habitat types in each reach to obtain reach estimates of density.

Habitat area used for calculating densities was truncated at limits of distribution. The distribution for each species encompasses habitat from where individuals of a certain species were first observed to where they were last seen by a diver in each reach.

Data were entered into a standard spreadsheet and compiled immediately after the surveys were completed. Results were summarized using Quattro Pro, Sigma Plot, Harvard Graphics, Presentations, Microfish, and PC-SAS.

Study Sites

All five watersheds lie within the SNP boundary (Figure 1), and eventually flow into the Atlantic Ocean via either the Shenandoah (Potomac) or Rappahanock River. They are presented in this report in the order that they were surveyed: Brokenback Run, White Oak Run, Shaver Hollow, Twomile Run, and Meadow Run.

Brokenback Run (moderate ANC) is a second-order stream located in the Central District of SNP in the Old Rag Mountain vicinity, and is considered moderately sensitive to episodic acidification. Brokenback Run flows east from an elevation of 840 meters over mostly granitic bedrock to its confluence with the Hughes River just outside the park boundary. First-order tributary Weakley Hollow flows into Brokenback Run approximately 1.8 kilometers upstream of the Park boundary from an elevation of 510 meters. This is the only watershed of the extensive survey that occurs in the Upper Rappahanock River System.

White Oak Run (low ANC) is a second-order stream located in the South District of SNP, and is considered highly sensitive to chronic acidification. White Oak Run flows west from an elevation of 730 meters over silica-clastic bedrock to its confluence with

Madison Run inside the park boundary. From an elevation of 700 meters, Luck Hollow is a first-order stream that drains into White Oak Run approximately 1.3 kilometers upstream of its confluence with Madison Run.

Moderately sensitive Shaver Hollow (moderate ANC) flows west from an elevation of 700 meters. First order Shaver Hollow flows over mostly granitic bedrock through the Central District of SNP to its confluence with another tributary from which is formed the North Fork of Dry Run.

Twomile Run (low ANC) is a second-order stream located in the South District of SNP, and is considered highly sensitive to episodic acidification. Twomile Run flows west from an elevation of 670 meters over mostly silica-clastic bedrock, to its eventual confluence with the Shenandoah River outside the park boundary. An unnamed first order tributary flows into Twomile Run approximately 1.4 kilometers from the downstream boundary of SNP.

Meadow Run (low ANC) is a second order stream that is located in the South District of SNP, and is also considered highly sensitive to episodic acidification. Meadow Run flows west from an elevation of 730 meters over silica-clastic bedrock to where it goes subterranean approximately 2 kilometers before it reaches the South River. Three first-order tributaries of Meadow Run were included in the survey. Wildcat Hollow, the largest tributary, flows into Meadow Run 1.5 kilometers upstream from the SNP boundary. An unnamed tributary flows into the main branch approximately 300 meters above Wildcat Hollow. Cold Spring Hollow, a spring-fed tributary, drains into Meadow Run approximately 2.9 kilometers upstream from the Park boundary. Both Wildcat Hollow and the unnamed tributary begin at elevations of 730 meters, and Cold Spring Hollow starts at an elevation

of 670 meters.

Results

Since abnormally high flows or other conditions didn't occur after the initial inventory of habitat features in each basin , physical habitat conditions were assumed constant for the duration of each survey.

Brokenback Run

We surveyed habitat in over 6 kilometers of Brokenback Run including the main branch and one tributary, Weakley Hollow. In total there were 354 pools and 323 riffles. Total habitat area for the main branch ranged from 5,181 m^2 for pools to 6,566 m^2 for riffles (Table 1). Total habitat area in Weakley Hollow for riffles was twice the amount in pools (Table 1). The bankfull area for the main branch was the highest for all five watersheds (Table 2).

Brokenback Run had the highest mean maximum and mean average depth for all five basins in both riffles and pools (Figures 2A, 2B). Among the tributaries from the various basins Weakley Hollow had the highest mean maximum and mean average depth for riffles and was second highest for pools (Figure 3A, 3B).

Considerable variability of substrate class dominance occurred in the main branch, with all classes represented except clay. Substrate classes that occurred more frequently were bedrock, cobble, and boulder in ascending order as shown in figure 2C. In Weakley Hollow, the most frequent dominant substrates were boulder, sand, and silt (Figure 3C).

The LWD in the active channel of the main branch and the tributary mostly consisted of two smallest size classes (Figure 2D and 3D). However, a significant amount of root wads (size class 7) were present in the main branch.

Three fish species were found in the Brokenback Run basin: brook trout (*Salvelinus fontinalis*), blacknose dace (*Rhinichthys atratulus*), and American eel (*Anguilla rostrata*). We were not able to calculate population estimates for American eels because none were seen by divers and only two individual American eels were found in our electrofishing survey. Brook trout were the only salmonid found in Brokenback Run even though the state of Virginia currently stocks rainbow trout (*Oncorhynchus mykiss*) less than one mile downstream in the Hughes River. Adult and young of the year brook trout were present throughout both the main branch and the tributary (Figures 4A and 5).

Analysis of length frequency data from Brokenback Run showed that all three year classes of brook trout are present with age 1+ fish being the most prevalent. Age 0+ brook trout were not represented as well as in some of the other streams surveyed (Figure 4B). Population estimates for both adult and young of the year brook trout were calculated along with 95% confidence intervals. Numbers of adults in the main branch ranged from 602 in riffles to 941 in pools (Tables 3 and 4). Densities of young of the year brook trout were lower than adult densities in the main branch (Figure 4C). Population estimates for adult brook trout were significantly higher than young of the year estimates in Weakley Hollow(Tables 5 and 6).

We found that blacknose dace in Brokenback Run differed in markings and coloration from blacknose dace in the other four basins. Jenkins and Burkhead 1994, also noted this difference in streams of the upper Rappahanock drainage. The bi-modal

distribution of blacknose dace (e.g., two year classes) (Figure 4D) was expected; dace spawn from spring through summer and typically live two years. When we surveyed Brokenback Run, in the first week of June, the nuptial males were brightly colored, indicating they were in spawning condition.

Blacknose dace population estimates ranged from 180 in riffles to 333 in pools for the main branch (Tables 3 and 4). Because blacknose dace were not seen by divers or captured by electrofishing above 1960 meters (Figure 4A) densities were calculated for only the section from the SNP boundary upstream to 1960 meters (Figure 4C). There is no obvious explanation for this absence. Blacknose dace were not present in Weakley Hollow which flows into the main branch well within their main branch distribution.

White Oak Run

We surveyed habitat in over 5 kilometers of White Oak Run including one major tributary, Luck Hollow. The stream bed of White Oak Run was mostly dry from the confluence of White Oak Run and Madison Run upstream approximately 500 meters. Only a few large bedrock pools contained water in the lower section. Lower Luck Hollow also was dewatered for about 700 meters. But as in White Oak Run the habitat improved upstream. Near the top of White Oak Run we encountered a large waterfall (at least 8 meters tall) above which the habitat consisted of a long shallow riffle (less than 5 centimeters in depth) that went underground after approximately 350 meters. In total there were 205 pools and 184 riffles in White Oak Run. Estimated area for the main branch ranged from 2,300 m^2 for pools to 2,522 m^2 for riffles, and estimated areas in Luck Hollow for both habitat types were very low because of the amount of dewatered area

(Table 1). Bankfull estimates for White Oak Run and Luck Hollow are 14,008 m^2 and 4,793 m^2 respectively (Table 2).

Because of the dry conditions in White Oak Run the mean maximum and mean average depths for the main branch and Luck Hollow were relatively low compared to the other four basins (Figures 6A,B; 7A,B).

Substrate classes consisted of small gravel, large gravel, cobble, boulder, and bedrock in both the main branch and Luck Hollow. (Figures 6C and 7C). Most of the LWD was size class 1 in White Oak Run and Luck Hollow (Figures 6D and 7D).

Diversity of fish species in White Oak Run was higher than three other streams surveyed. Brook trout and blacknose dace were present along with fantail darters (*Etheostoma flabellare*), which were only present in White Oak Run.

Brook trout extend up to approximately 200 meters below the waterfall which is at 3100 meters (Figure 8A). We did not sample above the waterfall but assumed fish were not present because of the height of the waterfall and the lack of habitable water above it. Brook trout were observed by divers in Luck Hollow, but in very low numbers.

Length frequency analysis for brook trout showed that age 0+, and age 1+ fish were well represented in White Oak Run, but age 2+ fish were not (Figure 8B). Adult brook trout population estimates and densities were higher than in any of the other four basins (Tables 7 and 8 ; Figure 8C).

The distribution of blacknose dace in the main branch extended nearly as far as the brook trout (Figure 8A). Blacknose dace were not observed in Luck Hollow.

Analysis of length frequency data showed that both year classes of blacknose dace were well represented (Figure 8D). Blacknose dace population estimates and densities

were one of highest (Twomile Run had the highest) in the five basins (Tables 7 and 8 ; Figure 8C).

Fantail darters apparently were confined to about 1300 meters in the lower reaches of White Oak Run. Fantail darters were neither seen by divers or captured by electrofishing above Luck Hollow (Figure 8A). Fantail darter densities were higher in riffles than in pools (Figure 8C).

Shaver Hollow

We surveyed over 1.6 kilometers of stream habitat in Shaver Hollow. We surveyed a total of 90 pools and 76 riffles from the SNP boundary up to where the stream went completely dry and split into two forks. The stream had moderate flows up to the one kilometer mark, after which there were sections of dry stream bed broken up by stagnant pools. There were also two steep cascades, one at 780 meters and the other at 912 meters. Total habitat area ranged from 709 m^2 for pools and 878 m^2 for riffles (Table 1). The bankfull habitat area estimate for Shaver Hollow was 6,948 m^2 (Table 2).

The mean maximum and mean average depths for Shaver Hollow are shown in Figures 9A and 9B for both pools and riffles. Dominant substrate was primarily cobble, boulder, and bedrock (Figure 9C). Once again, the smallest size class of LWD was most common; however there were significant numbers of the larger diameter size pieces (size classes 5 and 6) (Figure 9D).

We found only two species of fish in Shaver Hollow; brook trout and blacknose dace. No fish were found in any of the sample units above the waterfall located at 780 meters (Figure 10A).

Length frequency analysis shows that all three year classes of brook trout were present in Shaver Hollow (Figure 10B), with age 1+ fish comprising the bulk of the population. However, Shaver Hollow showed a strong representation of age 2+ fish compared to the other four basins. In addition, four of eight brook trout caught in pool 54 (pool below waterfall) were greater than 225 mm TL. One of those fish was 271 mm TL and weighed over 200 grams. Population estimates for adult brook trout in Shaver Hollow were significantly higher in pools than in riffles, and population estimates for young of the year fish were very low (Tables 9 and 10). Densities for both cohorts of brook trout in Shaver Hollow are similar to the population estimates (Figure 10C). Densities for both fish species were calculated using only the habitat area below the waterfall at 780 meters.

Both year classes of blacknose dace were present in Shaver Hollow (Figure 10D). Population estimates for blacknose dace in Shaver Hollow range from 309 fish in pools to 49 fish in riffles (Tables 9 and 10). Densities for Shaver Hollow ranged from 91 fish per 100 m^2 in pools to 12 fish per 100 m^2 in riffles (Figure 10C).

Twomile Run

We surveyed a total of 222 pools and 181 riffles in over 5 kilometers of the main branch, one unnamed tributary, and the upper right fork of Twomile Run. Total area in Twomile Run was 3,472 m^2 for pools an 3,799 m^2 for riffles (Table 1). Estimated areas in the right fork and the unnamed tributary were very low because of low water level (Table 1). Bankfull area for the main branch of Twomile Run was 19,483 m^2, while the bankfull areas for the right fork and the tributary were 1,470 m^2 and 1,229 m^2 respectively (Table 2). The mean maximum and mean average depths for the main branch were similar to

depths found in White Oak Run (Figure 11A and 11B) .

Dominant substrates in the main branch of Twomile Run consisted mostly of small gravel and larger size classes with bedrock and cobble the most frequently observed (Figure 11C). Most of the LWD found in Twomile Run was less than 10 cm in diameter (size classes 1 and 4) (Figure 11D).

The fish assemblage in Twomile Run consisted of brook trout and blacknose dace. Most of the fish were found in the main branch, with very few fish in the tributary and the right fork. Brook trout and blacknose dace were observed in the first 100 meters of the tributary, and one brook trout was seen during the habitat survey in the lower part of the right fork.

Adult brook trout were found throughout the watershed, and brook trout young of the year were only found from the park boundary up to the confluence of the tributary and the main branch (Figure 12A).

All three year classes of brook trout were present in Twomile Run (Figure 12B). Age 0+ fish were well represented considering that they were only found in the lower sections. Age 1+ fish are not very numerous in Twomile Run and only one individual found in the electrofishing survey represents the age 2+ fish.

The population estimate for adult brook trout in pools was 675 fish (Table 11). No adult brook trout were present in riffles. Population estimates for young of the year brook trout in the main branch were 329 fish in pools and 139 fish in riffles (Table 11 and 12).

Densities for brook trout were 20 fish per 100 m^2 for adults in pools, 22 fish per 100 m^2 for young of the year in pools, and 9 per 100 m^2 for young of the year in riffles (Figure 12C). Densities for age 0+ brook trout were calculated using area up to only where they

were observed and captured.

Blacknose dace in Twomile Run extend further upstream than the brook trout (Figure 12A). Two age classes of blacknose dace were present in Twomile Run (Figure 12D). Population estimates and densities for blacknose dace in pools were the highest of all five main branches surveyed (Table 11, Figure 12C).

Meadow Run

We surveyed habitat in nearly 9 kilometers of Meadow Run, including the main branch, right fork, Cold Spring Hollow, an unnamed tributary, and Wildcat Hollow. Major habitat summaries were done only for the main branch, Wildcat Hollow, and the unnamed tributary because the remainder were not habitable by fish at the time of the survey. A total of 459 pools and 406 riffles were surveyed. The majority of the estimated area consisted of riffle habitat in Meadow Run (Table 1). Bankfull area estimates for Meadow Run ranged from 715 m^2 in the right fork to 25,219 m^2 in the main branch (Table 2).

The mean maximum and mean average depths for the main branch were relatively high compared to the other watersheds even though it was sampled in August (Figures 13A and 13B). Water depths in the unnamed tributary (Figures 14A and 14B), and Wildcat Hollow (Figures 15A and 16B) were comparable to depths in the main branch.

Dominant substrate consisted primarily of small gravel, large gravel, cobble, and boulder in the main branch of Meadow Run, with smaller amounts of silt, bedrock, and organic matter (Figure 13C). Substrate dominance in the unnamed tributary and Wildcat Hollow was similar, with both exhibiting silt and organic matter as a dominant substrate more frequently than the main branch (Figures 14C and 15C).

LWD, as in all the other basins, was made up of mostly the smaller diameter pieces (e.g. size classes 1 and 4) (Figure 13D). This was also the case in the unnamed tributary and Wildcat Hollow (Figures 14D and 15D). We found a stream structure in a riffle immediately below the confluence of Cold Spring Hollow and Meadow Run at 2,831 meters. The structure consisted of five or six railroad ties laid perpendicular to the stream channel approximately a meter apart. The ties were fixed into the predominately bedrock substrate with steel reinforcing stock and looked like they had been in place for many years.

Brook trout were common throughout the basin while blacknose dace were very rare. Brook trout young of the year and adults were widely and abundantly distributed in both the main branch and Wildcat Hollow (Figures 16A and 17A). No fish were seen by divers in Cold Spring Hollow or the right fork. However, a large adult brook trout was seen in a pool on the right fork during the habitat survey.

All three age classes of brook trout were present in Meadow Run (Figure 16B). Age 0+ fish accounted for approximately 80% of the brook trout in Meadow Run. Meadow Run had more young of the year brook trout than any of the four other basins (Tables 13 and 14). Density of brook trout in pools of the main branch ranged from 16 fish per 100 m^2 for adults to 35 fish per 100 m^2 for young of the year (Figure 16C).

We captured 36 brook trout in 10 units during the electrofishing survey in Wildcat Hollow. Population estimates for young of the year in Wildcat Hollow are significantly higher than estimates in all other tributaries surveyed (Tables 15 and 16). This is also reflected in figure 17B which depicts densities of brook trout cohorts in Wildcat Hollow.

Divers sampled units throughout the unnamed tributary and saw 26 brook trout

young of the year in a pool 24 meters above the starting point but no place else. Although we electrofished eight habitat units selected at random throughout the tributary (not including the previously mentioned pool), we captured no fish. The gradient of the unnamed tributary is very steep for at least the first 350 meters which is the likely reason no fish were seen above the pool at 24 meters.

In the main branch only a few blacknose dace were observed by divers (6 and 2 fish in different pools) and only two were captured in the electrofishing survey (both > 55 mm, total length). No blacknose dace were found in any of the tributaries of Meadow Run.

Miscellaneous

1) The higher depths in Brokenback Run could be attributed to many things such as: date of survey, drainage size, underlying geology, historical uses, adjacent land use, etc.

2) The population estimate of adult brook trout in White Oak Run was the highest for the five main branches. These results differ in what we expected for this basin. White Oak Run, because of its chronic acidic levels , is considered the most acid sensitive of the eight basins surveyed in SNP (Webb et al. 1989).

3) Brook trout are distributed further upstream than blacknose dace in all eight basins surveyed except for Twomile Run.

4) We counted 25 young of the year brook trout, 28 adult brook trout, and 57 blacknose dace in a very large pool approximately 175 meters from the lower SNP boundary of

Twomile Run. On more than one occasion (within a week) we observed this pool used as a swimming hole. There was a lot of trash in the proximity. On the second day of the survey, a thunder storm the previous night caused a large tree with numerous branches to fall into the pool which enhanced the habitat. By evening of the same day the tree had been removed from the water and all the branches and most of the trunk had been trimmed with a chain saw.

5) Although Twomile Run was closed to fishing at the time of the survey, two adult brook trout that we captured electrofishing in a pool approximately 650 meters upstream from the SNP boundary had obvious hook injuries on their jaws.

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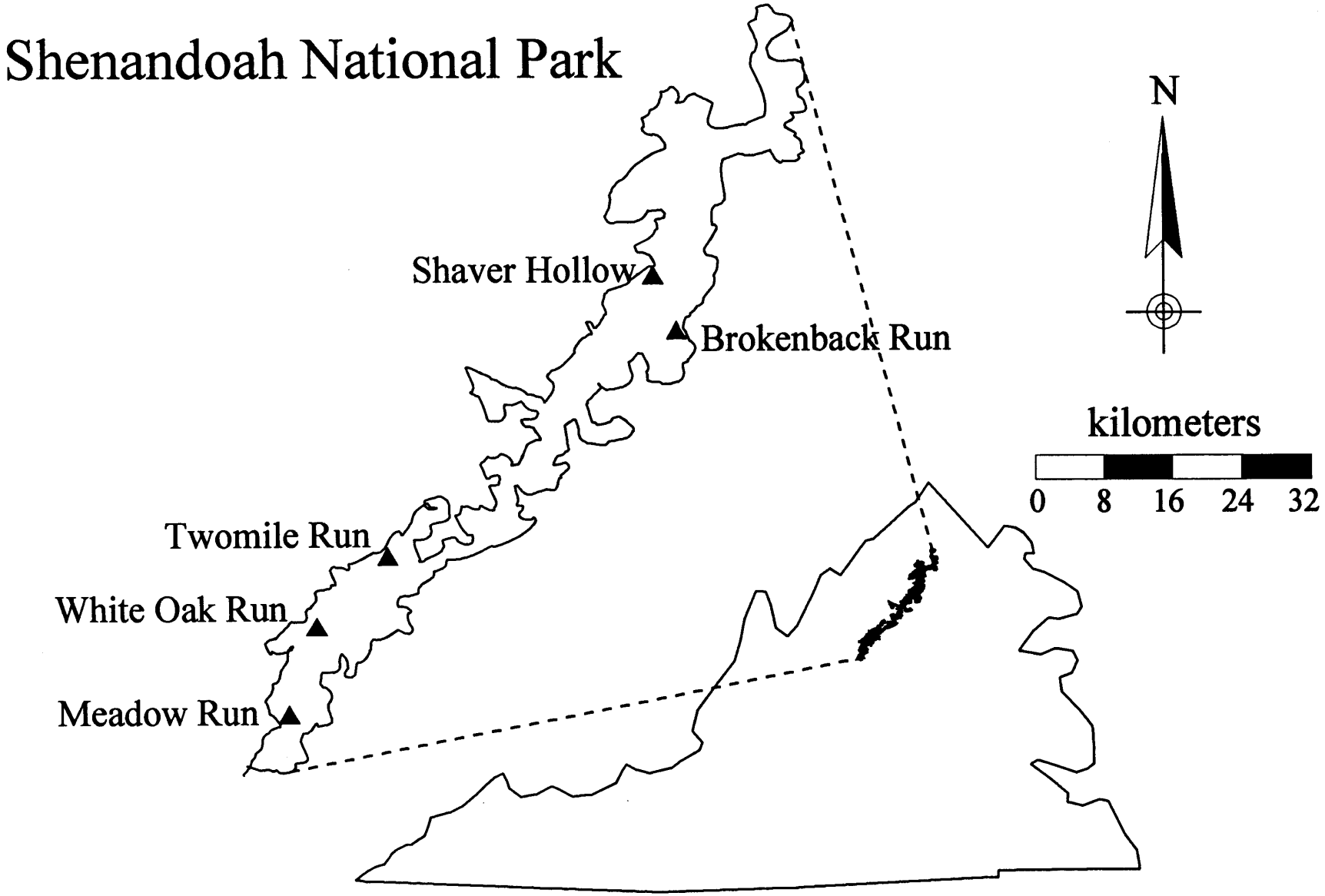

Figure 1. Map of Shenandoah National Park. Triangles indicate the location of each study watershed.

Table 1. Estimates of total habitat area for the five watersheds. Main branches of each watershed are shown in bold.

Stream Reach	Distance (meters)	Habitat Type	Est.Area(m^2) (±95%CI)
Brokenback Run	4,892.9	Pools Riffles	5,181(262) 6,566(475)
Weakley Hollow	1,169.3	Pools Riffles	499(29) 1,063(36)
White Oak Run	3,552.5	Pools Riffles	2,300(64) 2,522(68)
Luck Hollow	1,712.2	Pools Riffles	142(18) 455(22)
Shaver Hollow	1,652.7	Pools Riffles	709(23) 878(51)
Twomile Run	4,161.8	Pools Riffles	3,472(106) 3,799(207)
Twomile Right Fork	499.2	Pools Riffles	47(1) 134(12)
Twomile Tributary	552.4	Pools Riffles	100(8) 135(7)
Meadow Run	5,391.3	Pools Riffles	4,499(113) 7,459(352)
Wildcat Hollow	1,627.1	Pools Riffles	585(54) 1,408(116)
Unamed Tributary	878.3	Pools Riffles	446(19) 513(42)
Cold Spring Hollow	495.2	Pools Riffles	204(23) 376(23)
Meadow Run Right Fork	385.7	Pools Riffles	40(16) 155(61)

Table 2. Estimates of bankfull channel area in the five watersheds surveyed. Main branches of each watershed are shown in bold.

Stream Reach	Distance (meters)	Bankfull Area (m^2) (±95% CI)
Brokenback Run	4,892.9	29,722(648)
Weakley Hollow	1,169.3	4,484(212)
White Oak Run	3,552.8	14,008(350)
Luck Hollow	1,712.2	4,793(59)
Shaver Hollow	1,652.7	6,948(271)
Twomile Run	4,161.8	19,483(409)
Twomile Right fork	499.2	1,470(36)
Twomile Tributary	552.4	1,229(70)
Meadow Run	5,391.3	25,219(1,739)
Wildcat Hollow	1,627.1	4,985(124)
Unnamed Tributary	878.3	2,801(92)
Cold Spring Hollow	495.2	1,073(79)
Meadow Right fork	385.7	715(75)

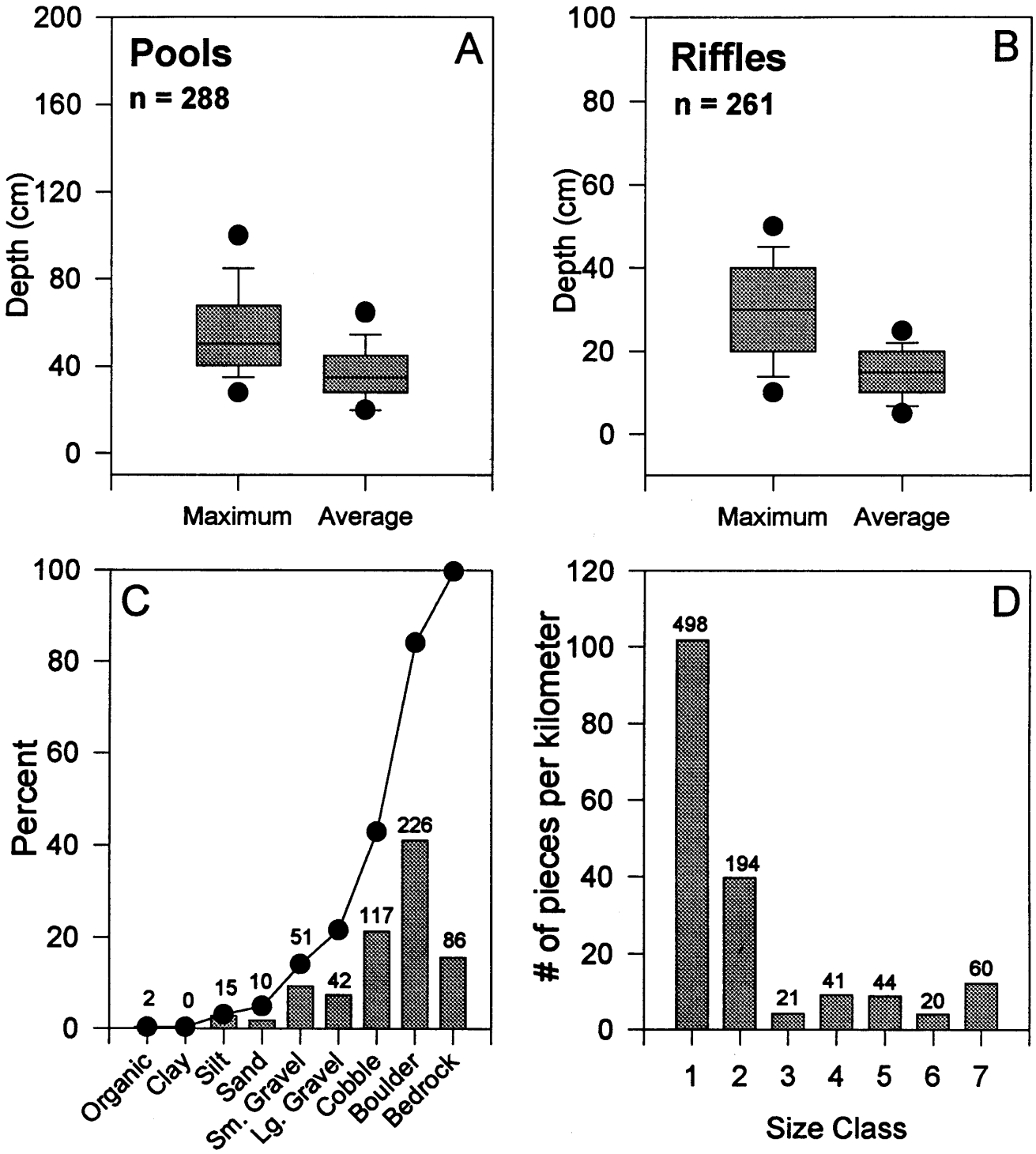

Figure 2. Brokenback Run Habitat Results. (A) and (B) Boxplots of maximum and average depths for pools and riffles. The box encloses the middle 50% of the observations, the capped lines below and above the box represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. (C) Dominant substrate occurences in the stream. Bars represent frequency (percent), dots represent cumulative percent, and numbers above bars represent total number of units in which the size class was dominant. (D) Pieces of large woody debris per kilometer of stream by size class. Bars represent numbers per mile and numbers above bars represent total number of pieces in each size class.

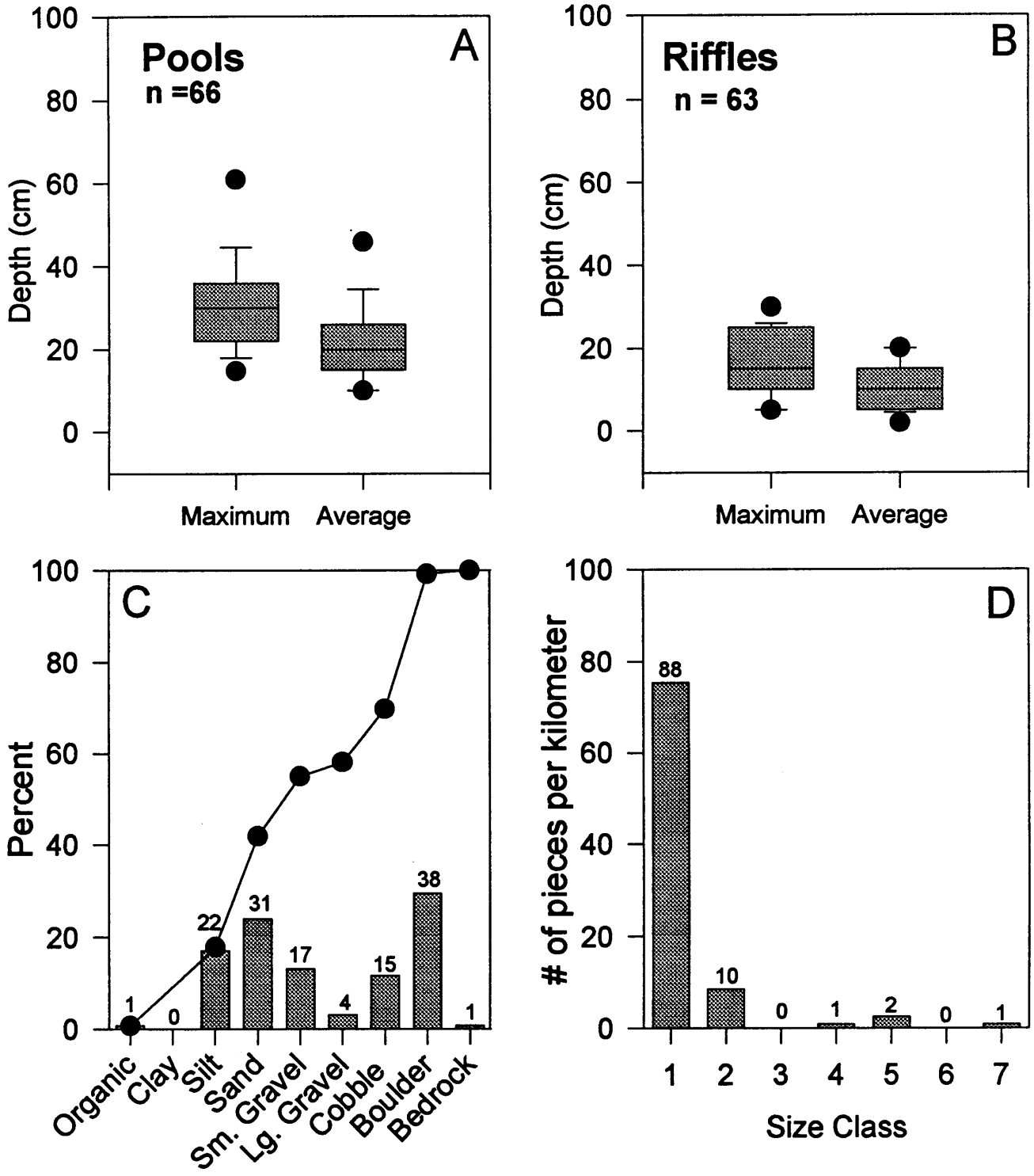

Figure 3. Weakley Hollow Habitat Results. (A) and (B) Boxplots of maximum and average depths for pools and riffles. The box encloses the middle 50% of the observations, the capped lines below and above the box represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. (C) Dominant substrate occurences in the stream. Bars represent frequency (percent), dots represent cumulative percent, and numbers above bars represent total number of units in which the size class was dominant. (D) Pieces of large woody debris per kilometer of stream by size class. Bars represent numbers per mile and numbers above bars represent total number of pieces in each size class.

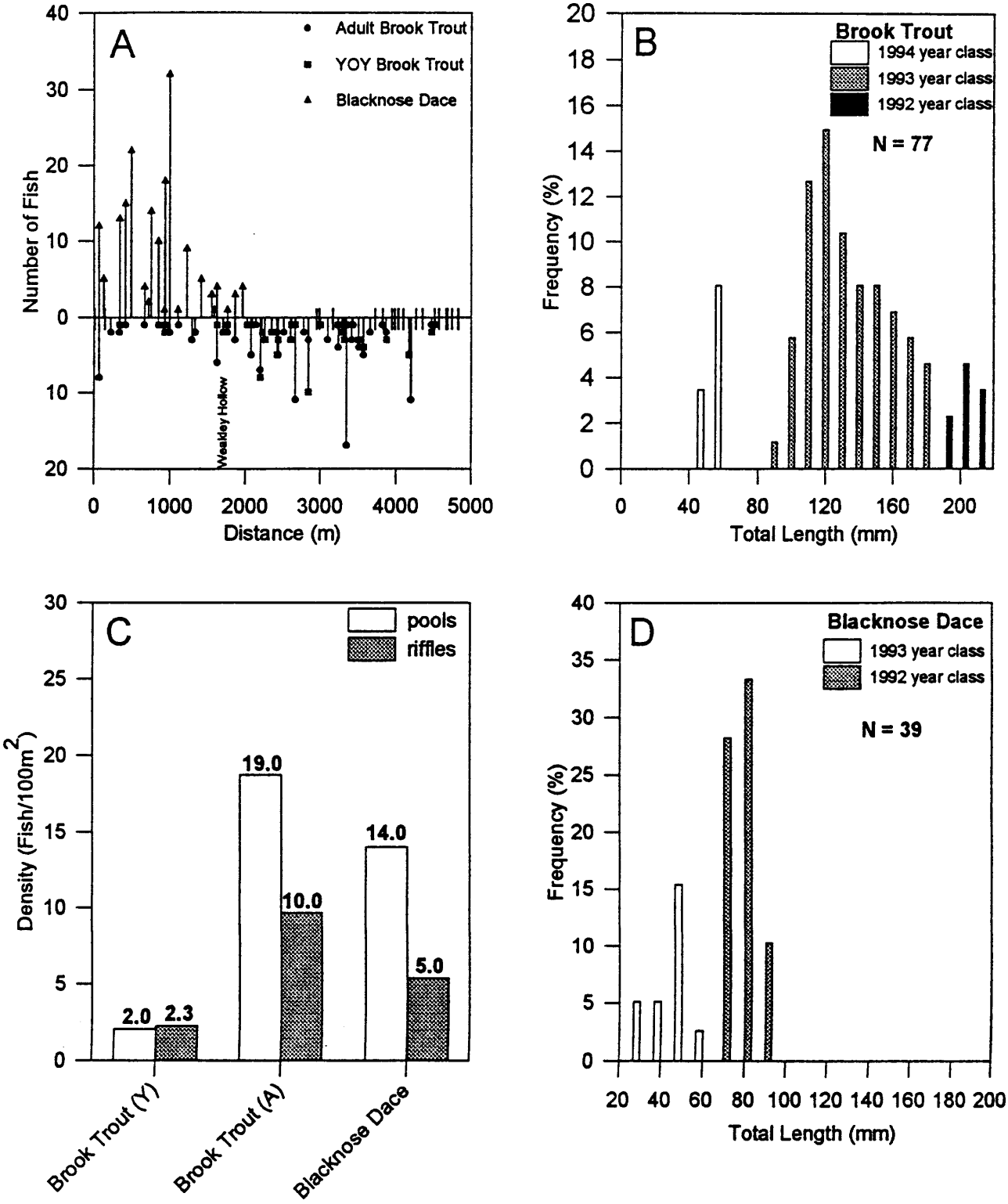

Figure 4. (A) Distribution of fish species in Brokenback Run. Habitat units where divers did not see fish are denoted by vertical marks on the x-axis. (B) Length frequency of brook trout in Brokenback Run. (C) Densities of fish species for pools and riffles in Brokenback Run. Numbers above bars represent actual density. (D) Length frequency distribution of blacknose dace in Brokenback Run.

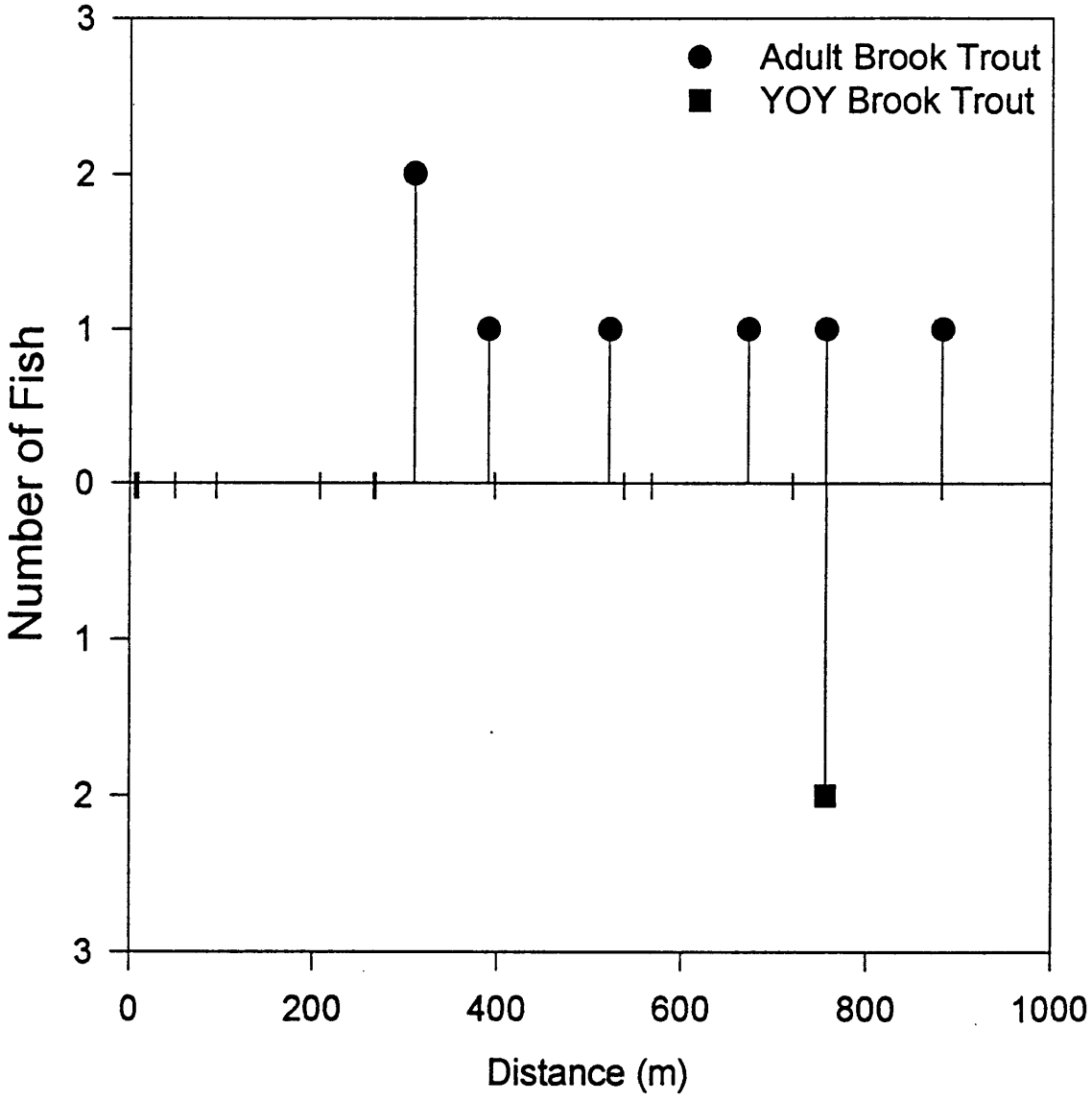

Figure 5. Distribution of fish in Weakley Hollow. Habitat units where divers did not see fish are denoted by vertical marks on the x-axis.

Table 3. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in pools of Brokenback Run. Also included are mean total length and width for all species.

Species	BKTA	BKTY	BND
Calibration ($\hat{R}$)	1.42	0.22	0.37
$\hat{N}$	941	105	333
(± 95% CI)	(338)	(33)	(169)
Mean Total Length	158	60	76
(± 95% CI)	(12)	(1)	(6)
Mean Weight	43.0	2.3	5.9
(± 95% CI)	(7.7)	(0.8)	(1.2)

58 pools were snorkeled and 10 pools were electrofished.

Table 4. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in riffles of Brokenback Run. Also included are mean total length and width for all species.

Species	BKTA	BKTY	BND
Calibration ($\hat{R}$)	4.10	0.52	0.80
$\hat{N}$	602	140	180
(± 95% CI)	(328)	(55)	(192)
Mean Total Length	142	64	68
(± 95% CI)	(9)	(3)	(9)
Mean Weight	35.5	3.3	4.8
(± 95% CI)	(8.4)	(0.7)	(1.9)

27 riffles were snorkeled and 10 riffles were electrofished.

Table 5. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in pools of Weakley Hollow. Also included are mean total length and width for all species.

Species	BKTA	BKTY
Calibration ($\hat{R}$)	4.00	1.00
$\hat{N}$	168	21
(± 95% CI)	(127)	(21)
Avg. Total Length	125	50
(± 95% CI)	(12)	(0)
Avg. Weight	23.2	1.7
(± 95% CI)	(2.7)	(0.0)

11 pools were snorkeled and 4 pools were electrofished.

Table 6. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in riffles of Weakley Hollow. Also included are mean total length and width for all species.

Species	BKTA	BKTY
Calibration ($\hat{R}$)	1.00	1.00
$\hat{N}$	11	0
(± 95% CI)	(41)	(0)
Avg. Total Length	118	NA
(± 95% CI)	(0)	
Avg. Weight	18.4	NA
(± 95% CI)	(0.0)	

6 riffles were snorkeled and 3 riffles were electrofished.

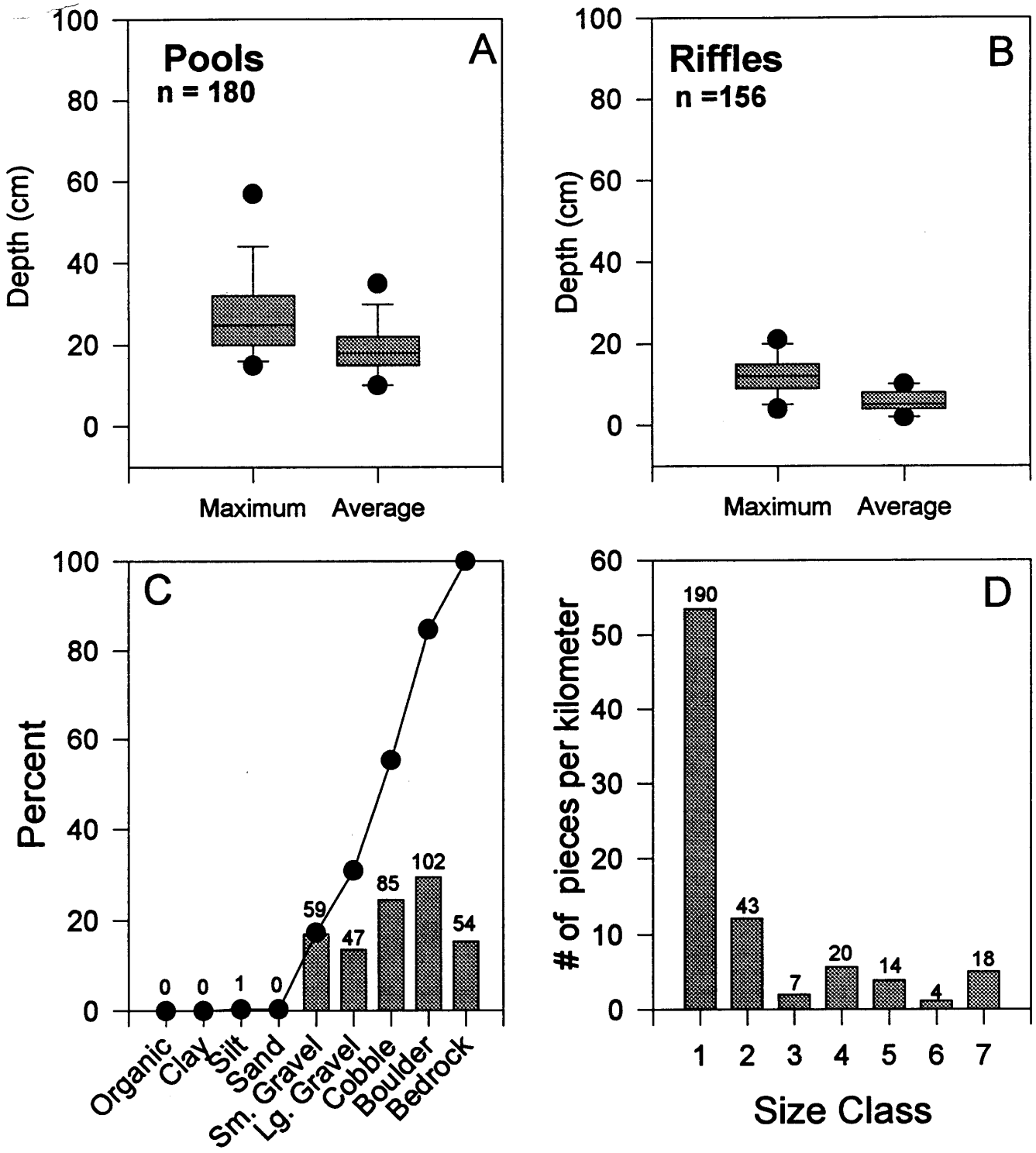

Figure 6. White Oak Run Habitat Results. (A) and (B) Boxplots of maximum and average depths for pools and riffles. The box encloses the middle 50% of the observations, the capped lines below and above the box represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. (C) Dominant substrate occurences in the stream. Bars represent frequency (percent), dots represent cumulative percent, and numbers above bars represent total number of units in which the size class was dominant. (D) Pieces of large woody debris per kilometer of stream by size class. Bars represent numbers per mile and numbers above bars represent total number of pieces in each size class.

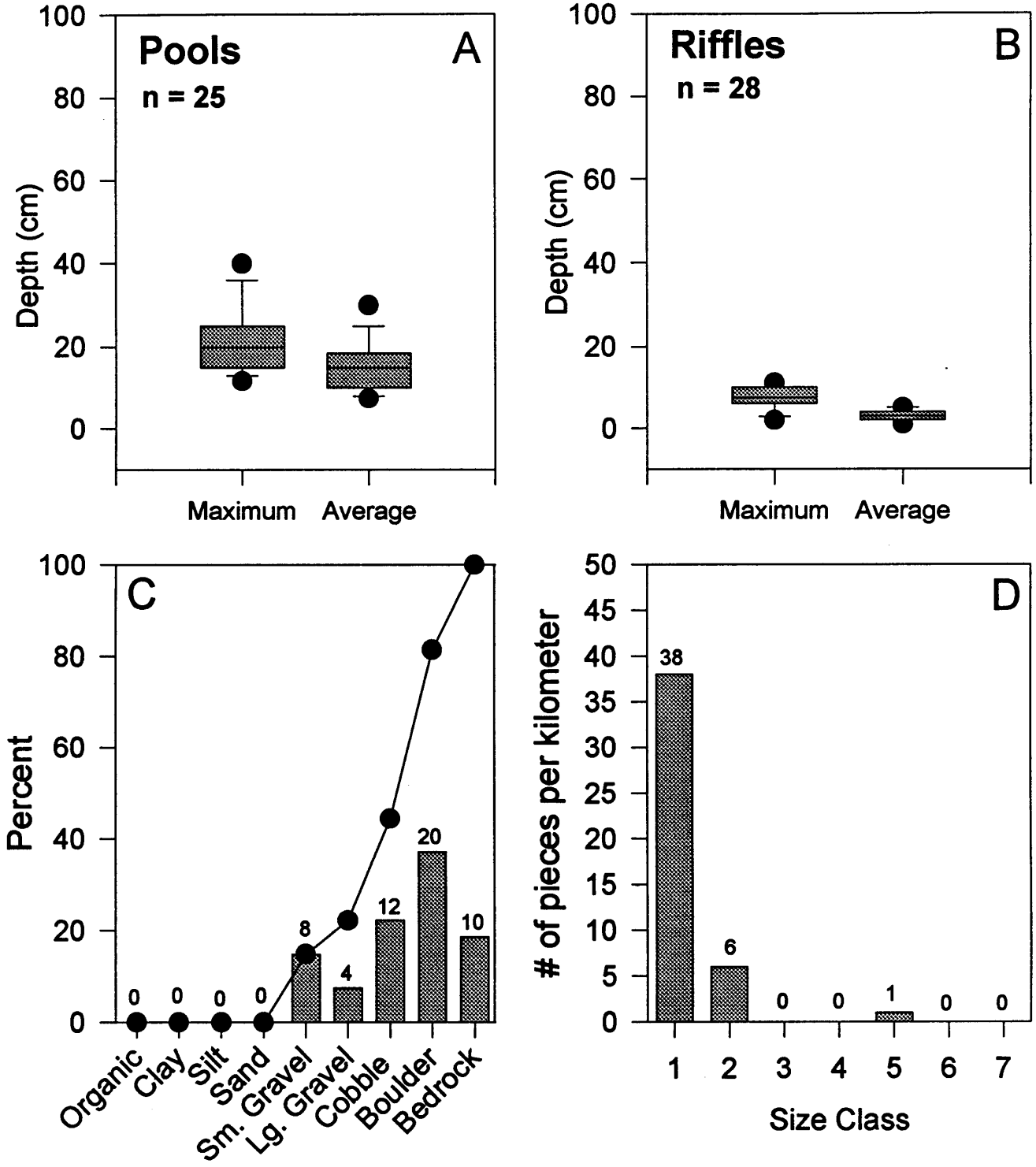

Figure 7. Luck Hollow Habitat Results. (A) and (B) Boxplots of maximum and average depths for pools and riffles. The box encloses the middle 50% of the observations, the capped lines below and above the box represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. (C) Dominant substrate occurences in the stream. Bars represent frequency (percent), dots represent cumulative percent, and numbers above bars represent total number of units in which the size class was dominant. (D) Pieces of large woody debris per kilometer of stream by size class. Bars represent numbers per mile and numbers above bars represent total number of pieces in each size class.

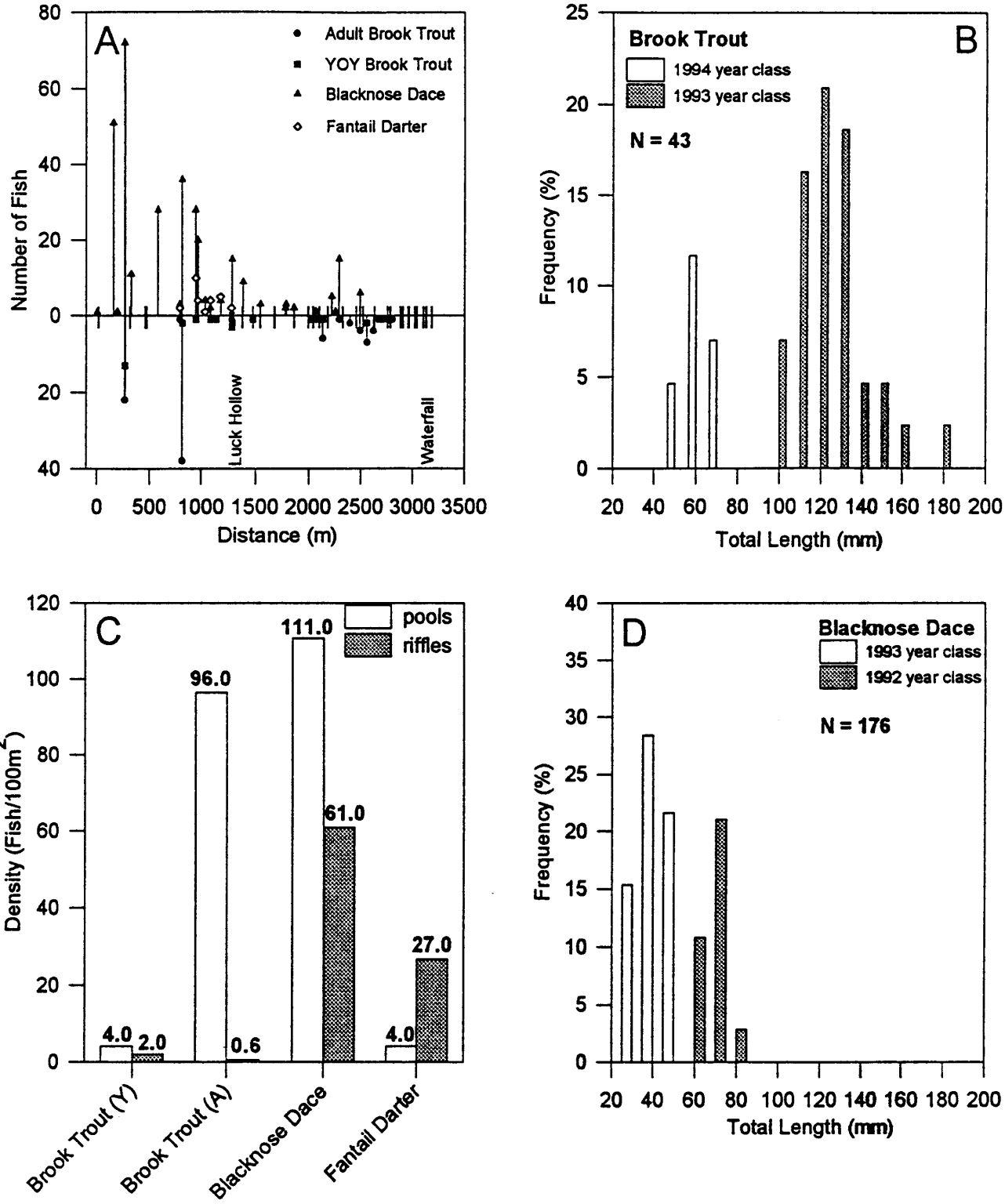

Figure 8. (A) Distribution of fish species in White Oak Run. Habitat units where divers did not see fish are denoted by vertical marks on the x-axis. (B) Length frequency of brook trout in White Oak Run. (C) Densities of fish species for pools and riffles in White Oak Run. Numbers above bars represent actual density. (D) Length frequency distribution of blacknose dace in White Oak Run.

Table 7. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in pools of White Oak Run. Also included are mean total length and width for all species.

Species	BKTA	BKTY	BND	FTD
Calibration ($\hat{R}$)	5.00	0.67	1.35	0.64
$\hat{N}$	2217	95	2171	52
(± 95% CI)	(559)	(52)	(1132)	(137)
Avg. Total Length	131	56	56	51
(± 95% CI)	(6)	(0)	(3)	(6)
Avg. Weight	26.0	2.0	2.1	1.9
(± 95% CI)	(2.3)	(0.0)	(0.5)	(0.9)

37 pools were snorkeled and 10 pools were electrofished.

Table 8. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in riffles of White Oak Run. Also included are mean total length and width for all species.

Species	BKTA	BKTY	BND	FTD
Calibration ($\hat{R}$)	1.00	1.64	6.38	1.21
$\hat{N}$	15	52	1235	256
(± 95% CI)	(24)	(147)	(540)	(181)
Avg. Total Length	121	69	52	59
(± 95% CI)	(16)	(4)	(3)	(4)
Avg. Weight	20.0	3.7	1.7	2.3
(± 95% CI)	(10.9)	(0.8)	(0.2)	(0.1)

31 riffles were snorkeled and 10 riffles were electrofished.

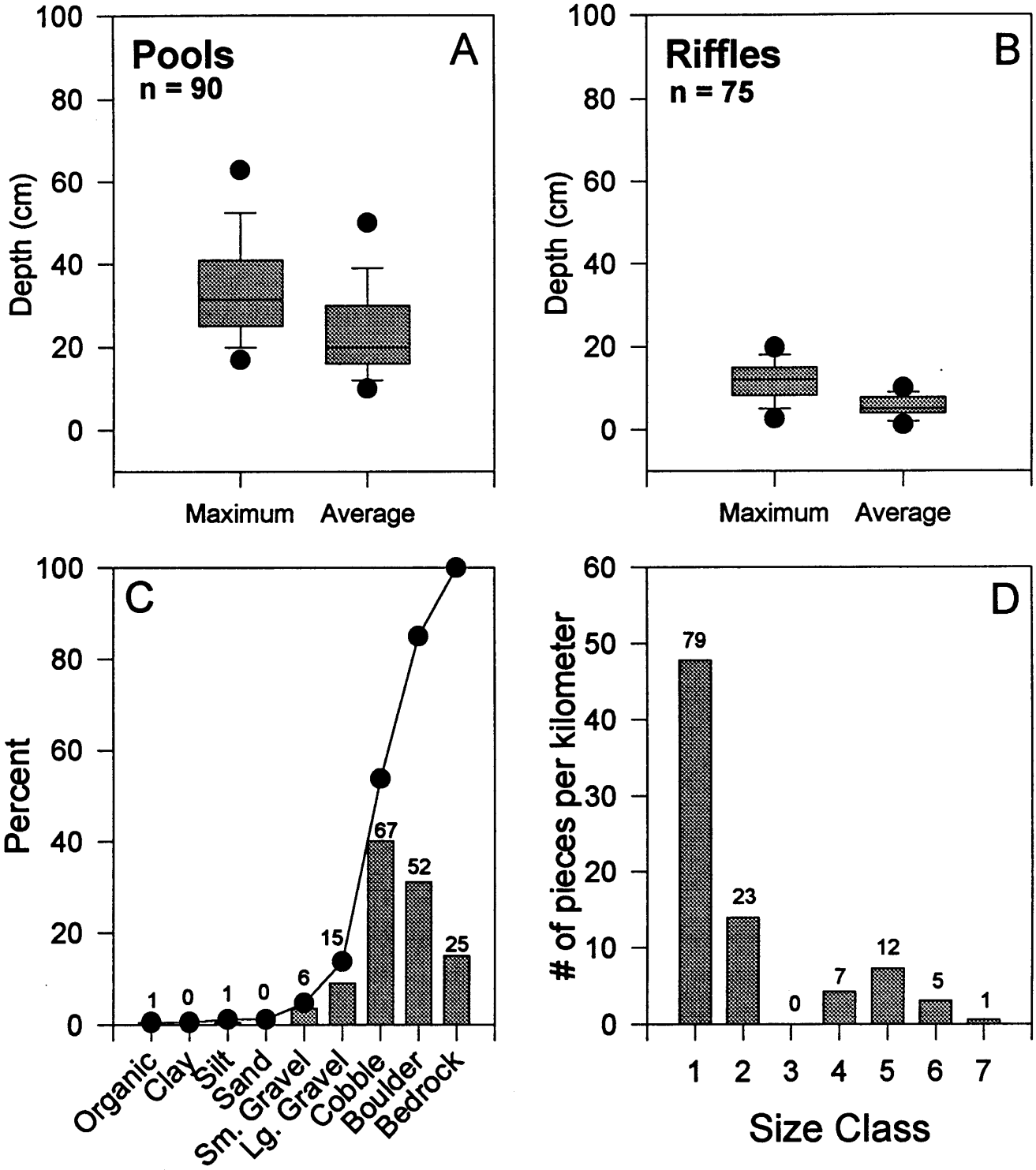

Figure 9. Shaver Hollow Habitat Results. (A) and (B) Boxplots of maximum and average depths for pools and riffles. The box encloses the middle 50% of the observations, the capped lines below and above the box represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. (C) Dominant substrate occurences in the stream. Bars represent frequency (percent), dots represent cumulative percent, and numbers above bars represent total number of units in which the size class was dominant. (D) Pieces of large woody debris per kilometer of stream by size class. Bars represent numbers per mile and numbers above bars represent total number of pieces in each size class.

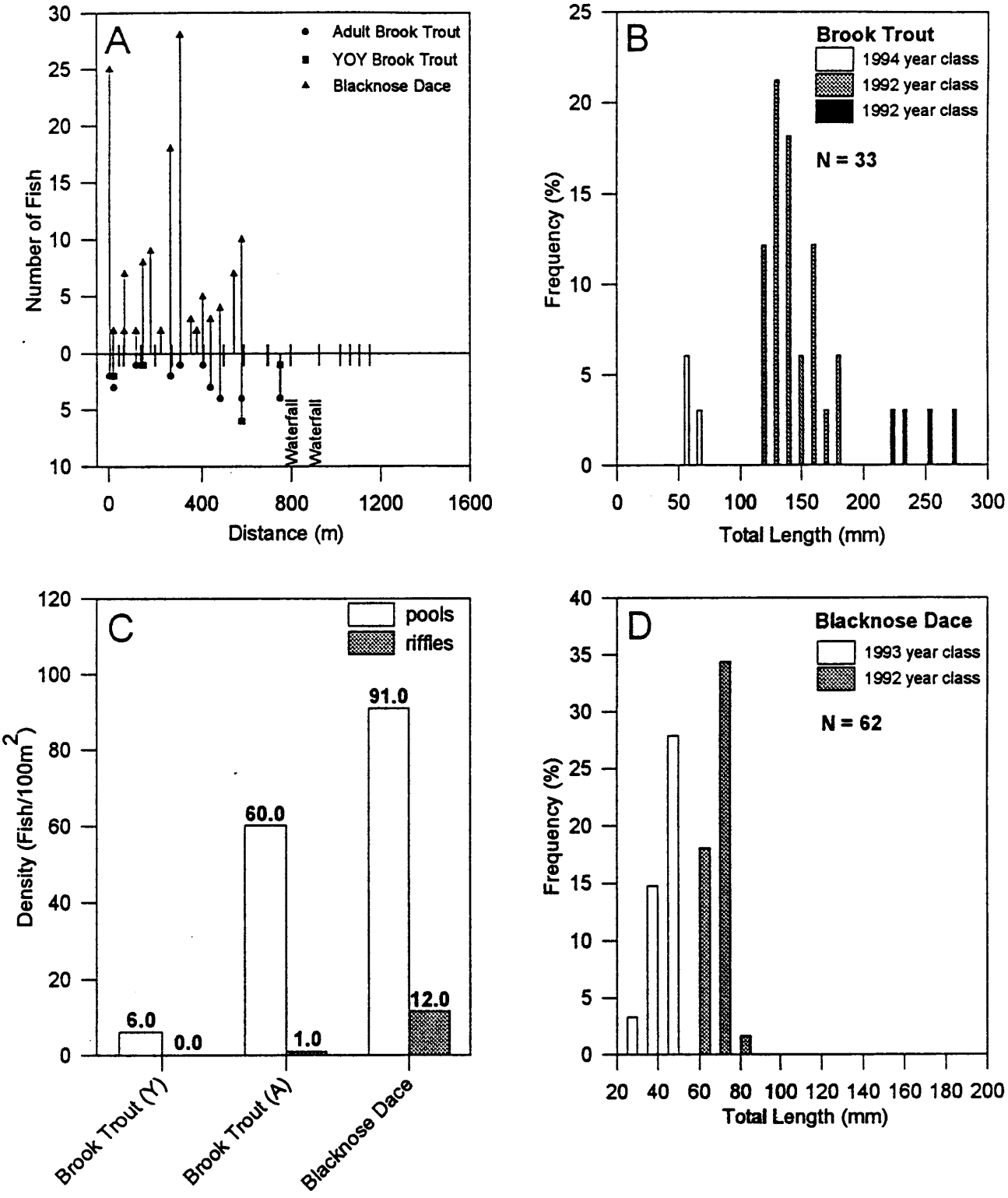

Figure 10. (A) Distribution of fish species in Shaver Hollow. Habitat units where divers did not see fish are denoted by vertical marks on the x-axis. (B) Length frequency of brook trout in Shaver Hollow. (C) Densities of fish species for pools and riffles in Shaver Hollow. Numbers above bars represent actual density. (D) Length frequency distribution of blacknose dace in Shaver Hollow.

Table 9. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in pools of Shaver Hollow. Also included are mean total length and width for all species.

Species	BKTA	BKTY	BND
Calibration ($\hat{R}$)	3.00	0.50	0.61
$\hat{N}$	270	21	309
(± 95% CI)	(110)	(27)	(147)
Avg. Total Length	160	69	61
(± 95% CI)	(14)	(3)	(3)
Avg. Weight	48.9	3.8	2.5
(± 95% CI)	(16.0)	(1.8)	(0.4)

26 pools were snorkeled and 11 pools were electrofished.

Table 10. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in riffles of Shaver Hollow. Also included are mean total length and width for all species.

Species	BKTA	BKTY	BND
Calibration ($\hat{R}$)	1.00	1.00	1.80
$\hat{N}$	5	0	49
(± 95% CI)	(15)	(0)	(145)
Avg. Total Length	134	0	65
(± 95% CI)	(0)	(0)	(7)
Avg. Weight	23.6	0.0	3.0
(± 95% CI)	(0.0)	(0.0)	(0.6)

14 riffles were snorkeled and 6 riffles were electrofished.

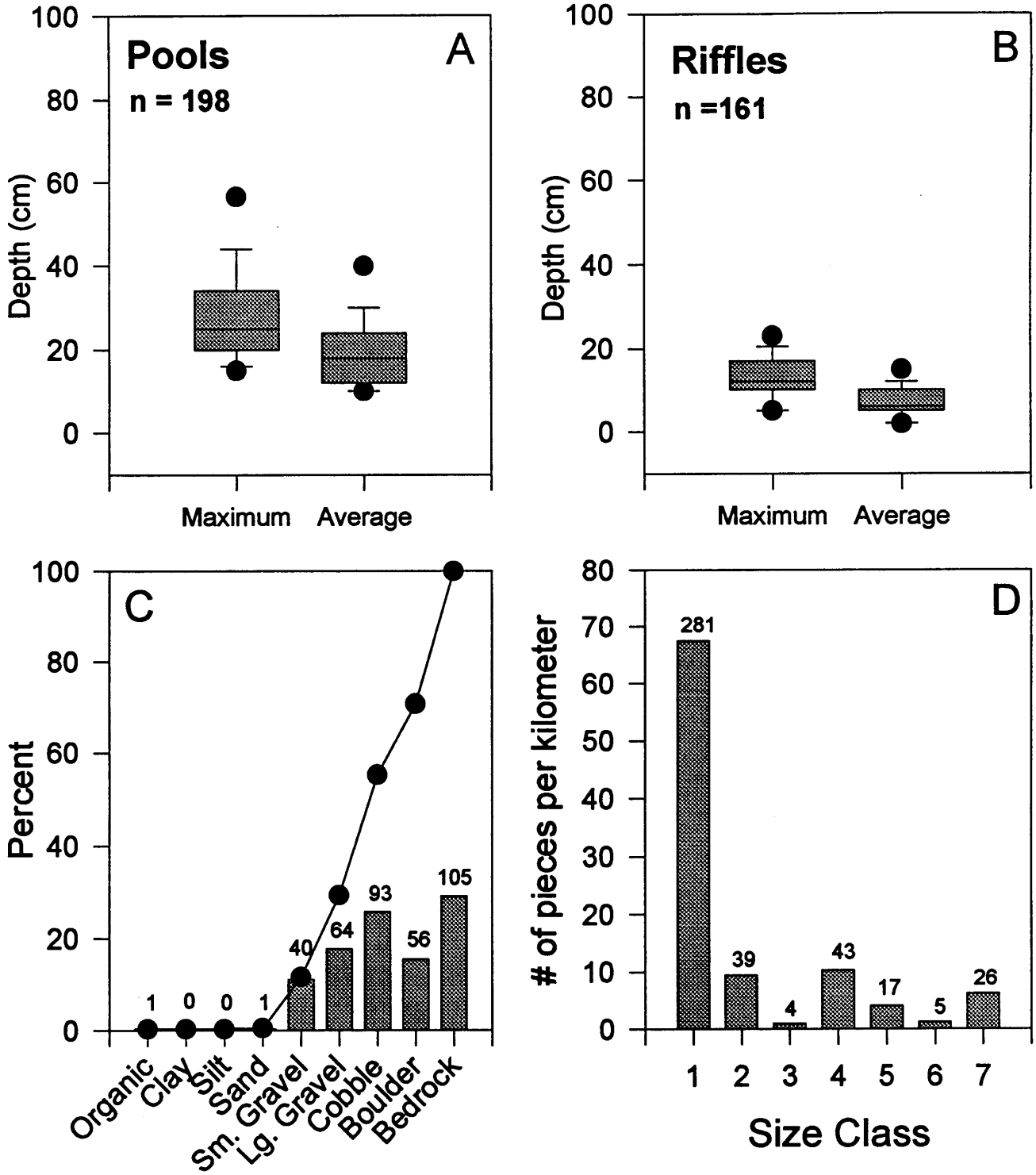

Figure 11. Twomile Run Habitat Results. (A) and (B) Boxplots of maximum and average depths for pools and riffles. The box encloses the middle 50% of the observations, the capped lines below and above the box represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. (C) Dominant substrate occurences in the stream. Bars represent frequency (percent), dots represent cumulative percent, and numbers above bars represent total number of units in which the size class was dominant. (D) Pieces of large woody debris per kilometer of stream by size class. Bars represent numbers per mile and numbers above bars represent total number of pieces in each size class.

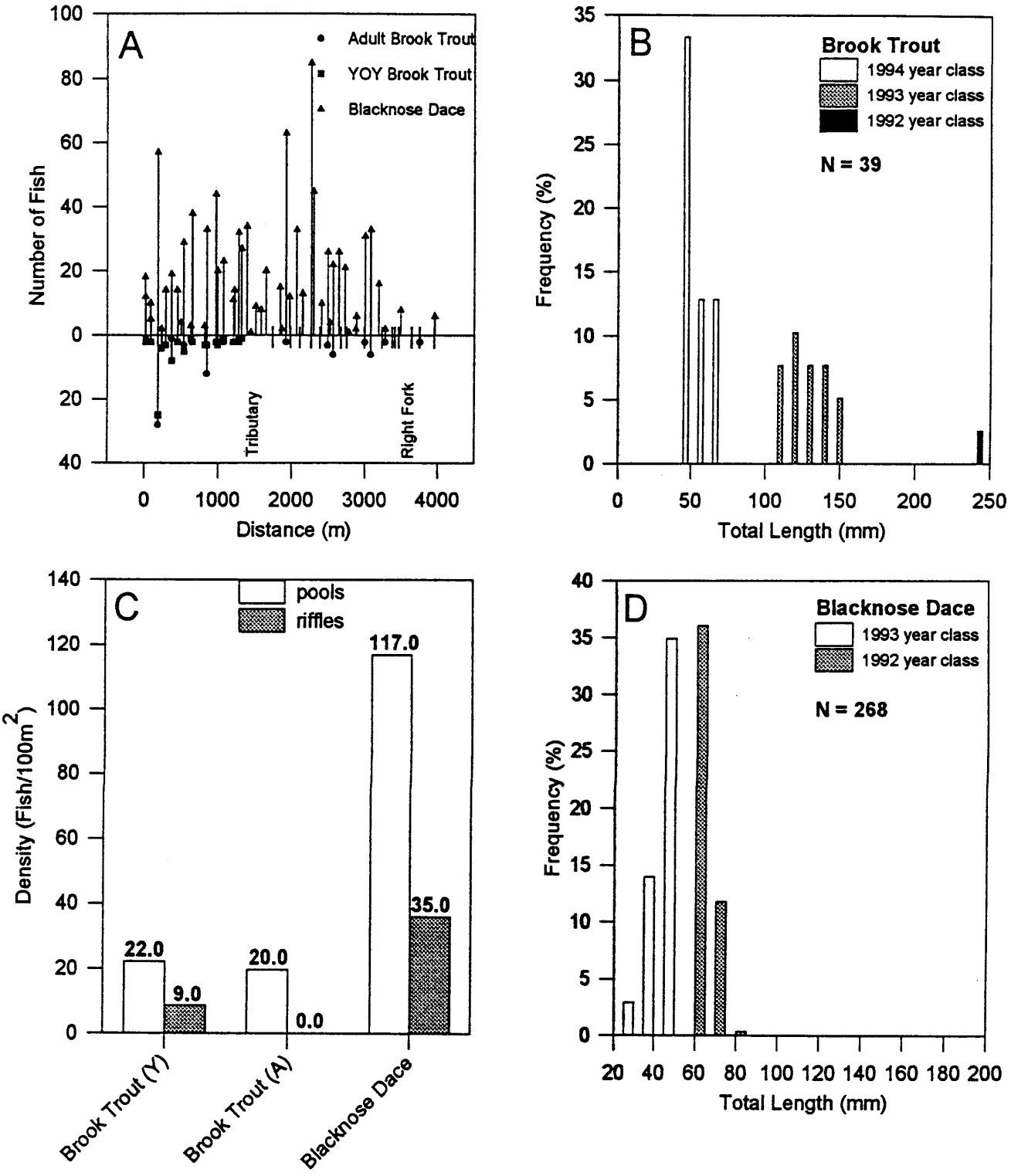

Figure 12. (A) Distribution of fish species in Twomile Run. Habitat units where divers did not see fish are denoted by vertical marks on the x-axis. (B) Length frequency of brook trout in Twomile Run. (C) Densities of fish species for pools and riffles in Twomile Run. Numbers above bars represent actual density. (D) Length frequency distribution of blacknose dace in Twomile Run.

Table 11. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in pools of Twomile Run. Also included are mean total length and width for all species.

Species	BKTA	BKTY	BND
Calibration ($\hat{R}$)	2.00	1.75	0.93
$\hat{N}$	675	328	4054
(± 95% CI)	(200)	(94)	(1317)
Avg. Total Length	141	66	60
(± 95% CI)	(15)	(8)	(1)
Avg. Weight	30.2	2.8	2.1
(± 95% CI)	(8.3)	(0.2)	(0.2)

40 pools were snorkeled and 10 pools were electrofished.

Table 12. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in riffles of Twomile Run. Also included are mean total length and width for all species.

Species	BKTA	BKTY	BND
Calibration ($\hat{R}$)	1.00	2.00	2.06
$\hat{N}$	0	139	1369
(± 95% CI)	(0)	(203)	(610)
Avg. Total Length	0	60	55
(± 95% CI)	(0)	(4)	(2)
Avg. Weight	0	2.1	1.7
(± 95% CI)	(0)	(0.6)	(0.2)

32 riffles were snorkeled and 10 riffles were electrofished.

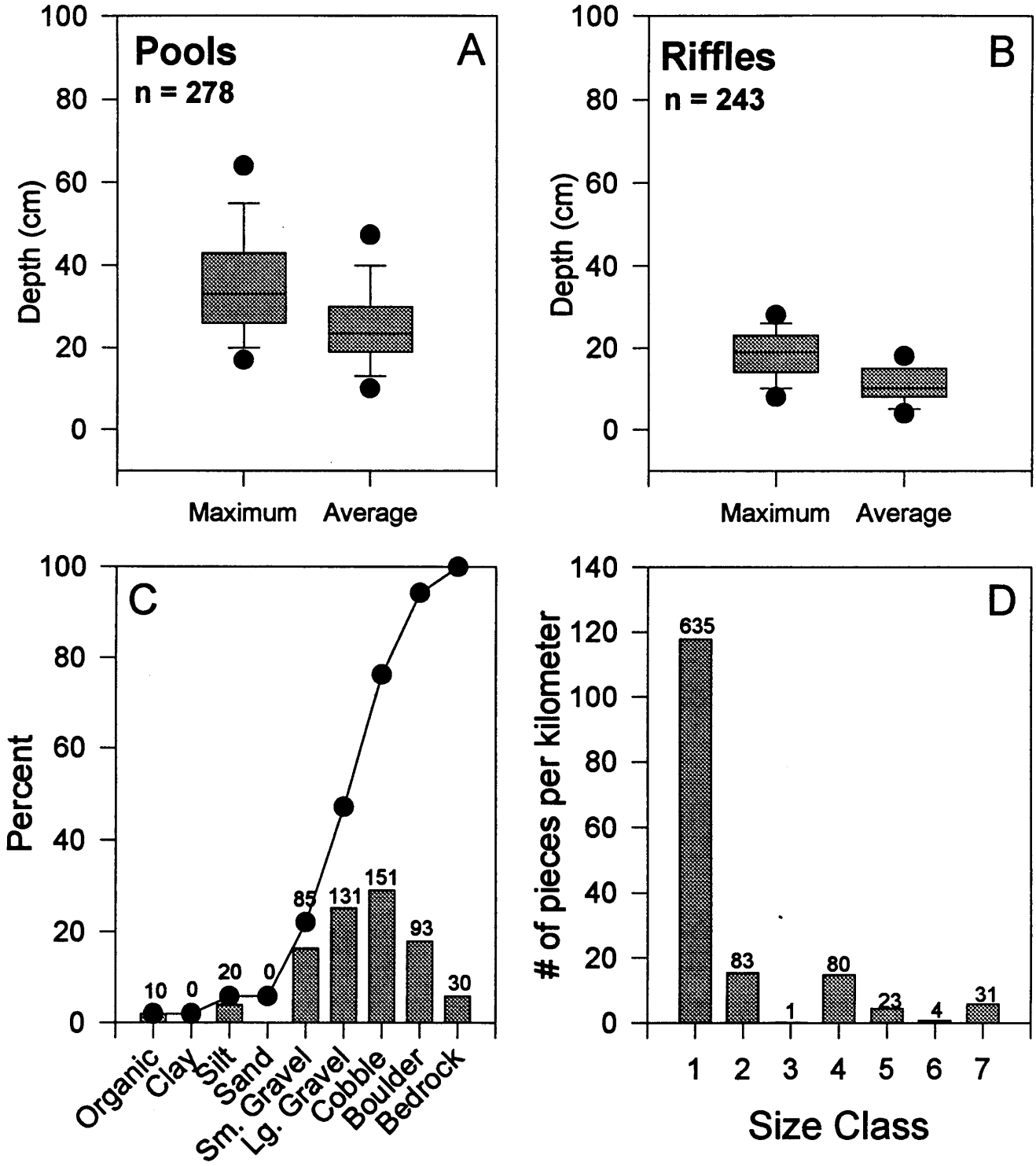

Figure 13. Meadow Run Habitat Results. (A) and (B) Boxplots of maximum and average depths for pools and riffles. The box encloses the middle 50% of the observations, the capped lines below and above the box represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. (C) Dominant substrate occurences in the stream. Bars represent frequency (percent), dots represent cumulative percent, and numbers above bars represent total number of units in which the size class was dominant. (D) Pieces of large woody debris per kilometer of stream by size class. Bars represent numbers per mile and numbers above bars represent total number of pieces in each size class.

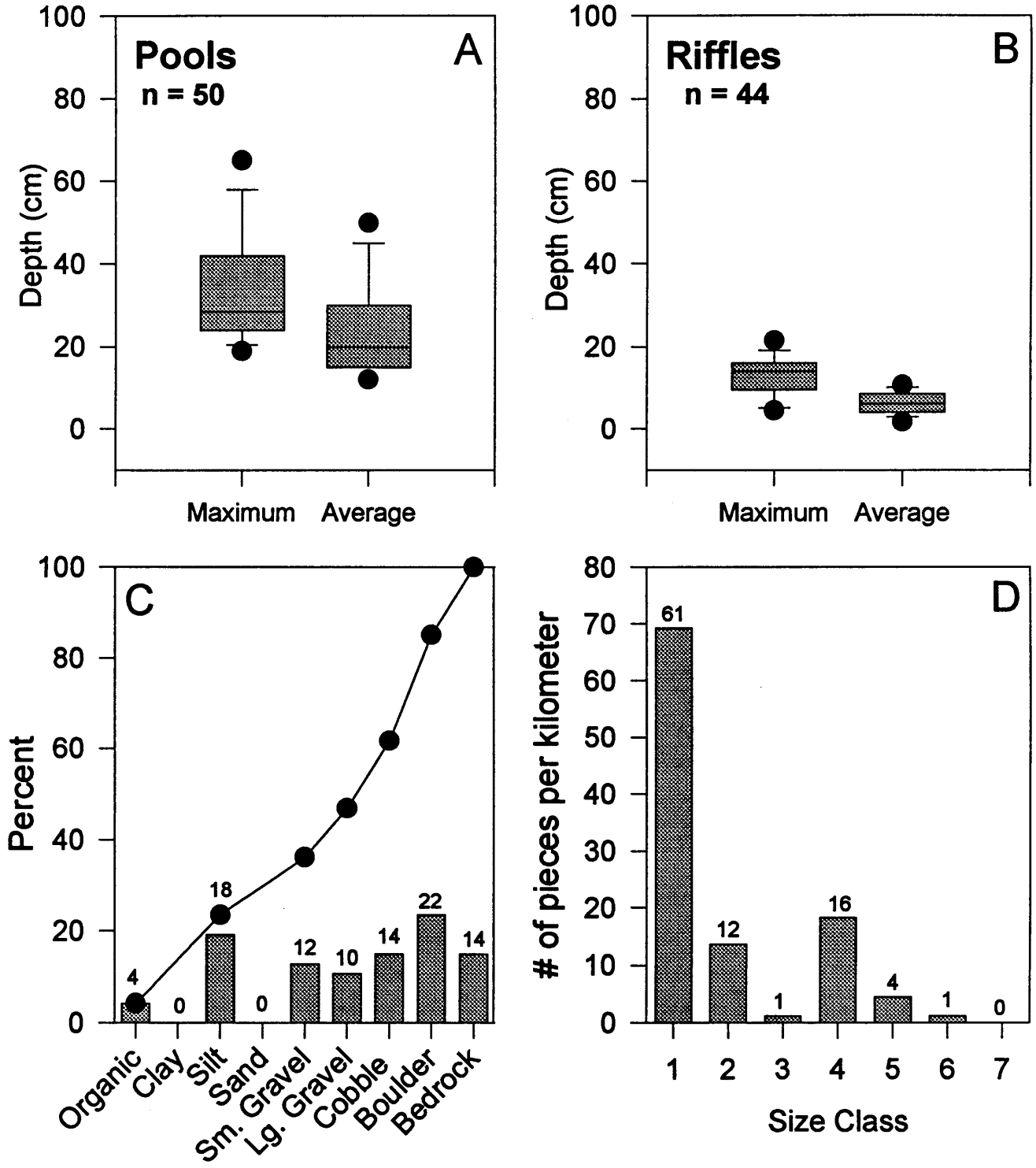

Figure 14. Unamed tributary Habitat Results. (A) and (B) Boxplots of maximum and average depths for pools and riffles. The box encloses the middle 50% of the observations, the capped lines below and above the box represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. (C) Dominant substrate occurences in the stream. Bars represent frequency (percent), dots represent cumulative percent, and numbers above bars represent total number of units in which the size class was dominant. (D) Pieces of large woody debris per kilometer of stream by size class. Bars represent numbers per mile and numbers above bars represent total number of pieces in each size class.

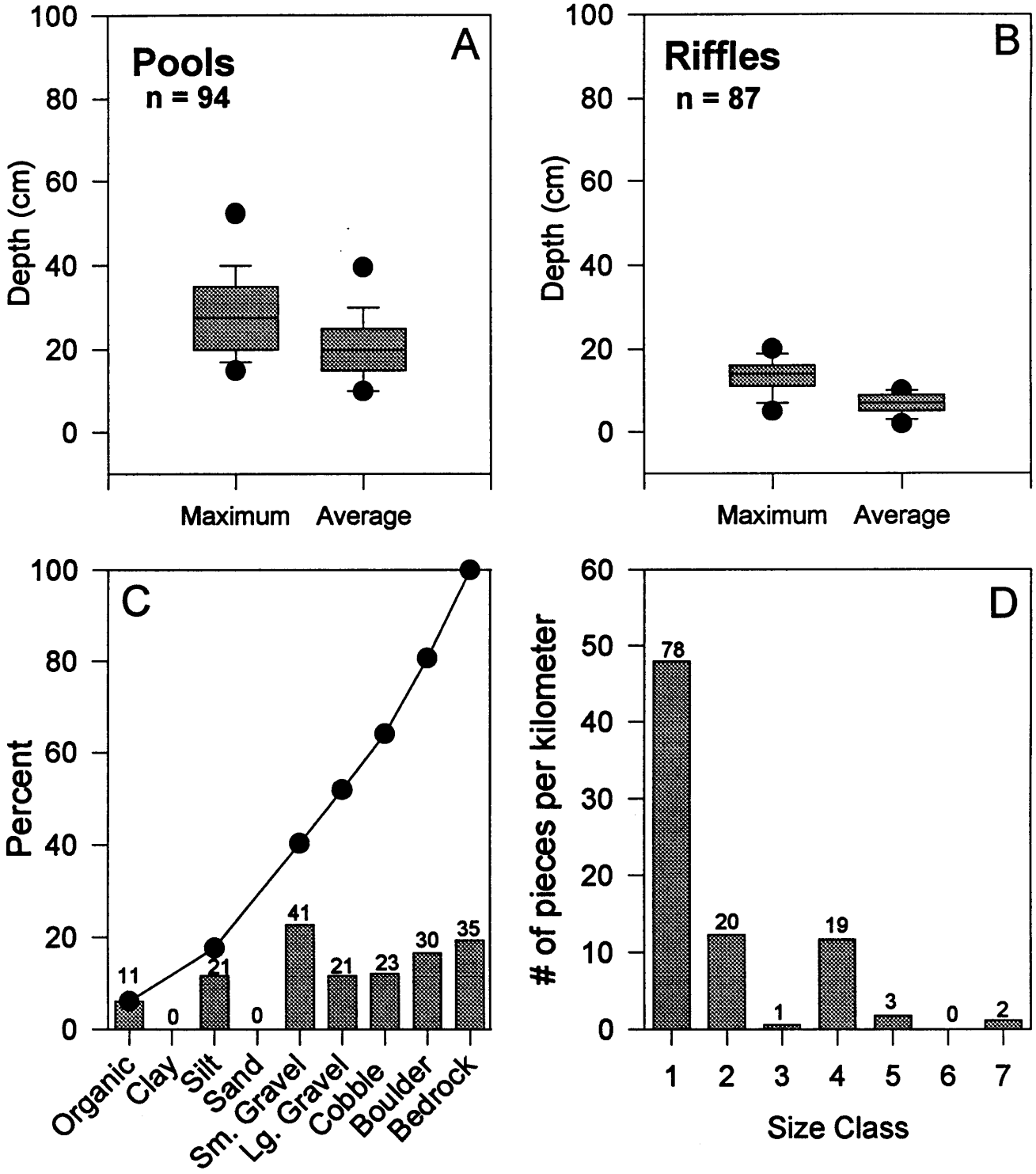

Figure 15. Wildcat Hollow Habitat Results. (A) and (B) Boxplots of maximum and average depths for pools and riffles. The box encloses the middle 50% of the observations, the capped lines below and above the box represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. (C) Dominant substrate occurences in the stream. Bars represent frequency (percent), dots represent cumulative percent, and numbers above bars represent total number of units in which the size class was dominant. (D) Pieces of large woody debris per kilometer of stream by size class. Bars represent numbers per mile and numbers above bars represent total number of pieces in each size class.

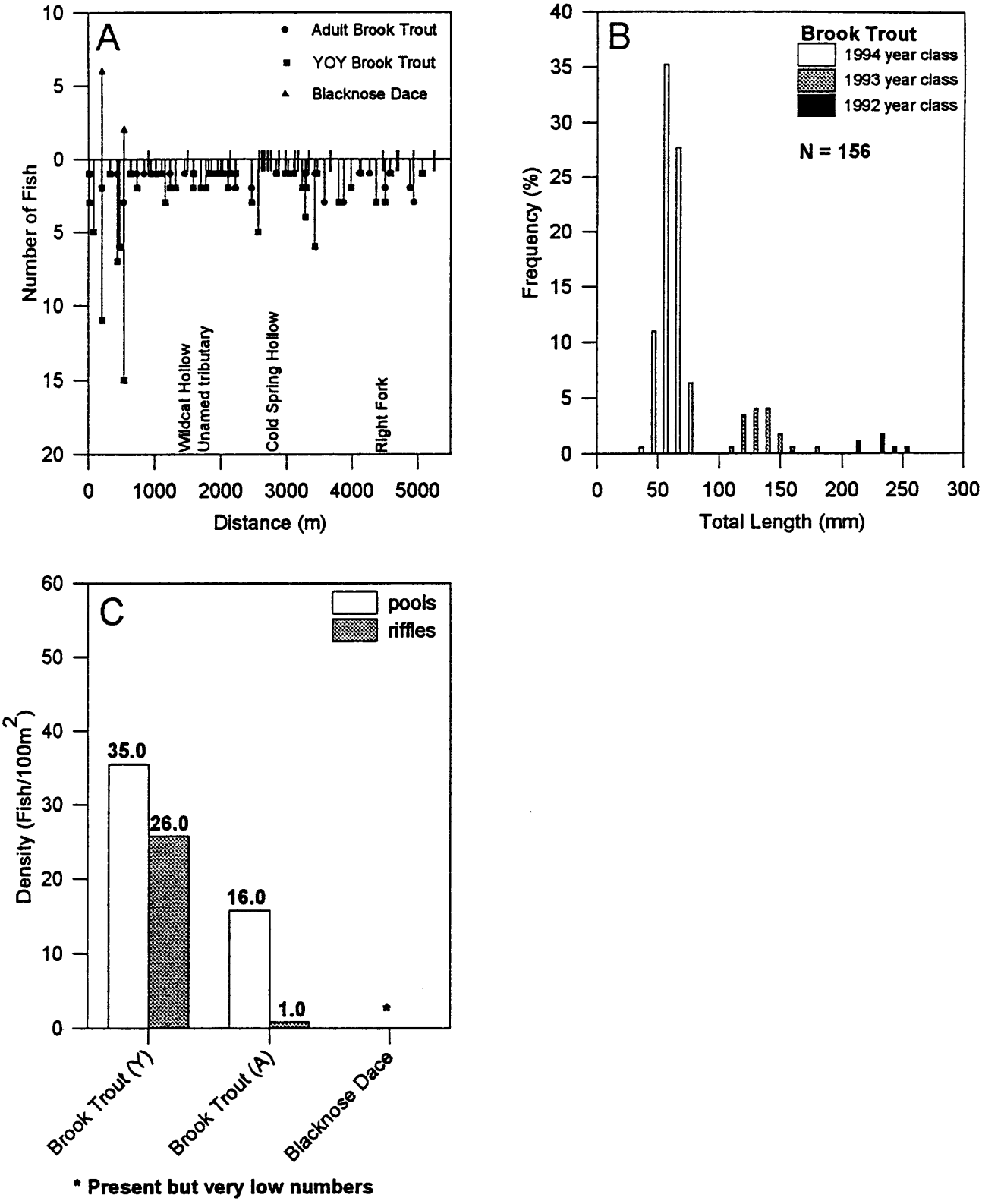

Figure 16. (A) Distribution of fish species in Meadow Run. Habitat units where divers did not see fish are denoted by vertical marks on the x-axis. (B) Length frequency of brook trout in Meadow Run. (C) Densities of fish species for pools and riffles in Meadow Run. Numbers above bars represent actual density.

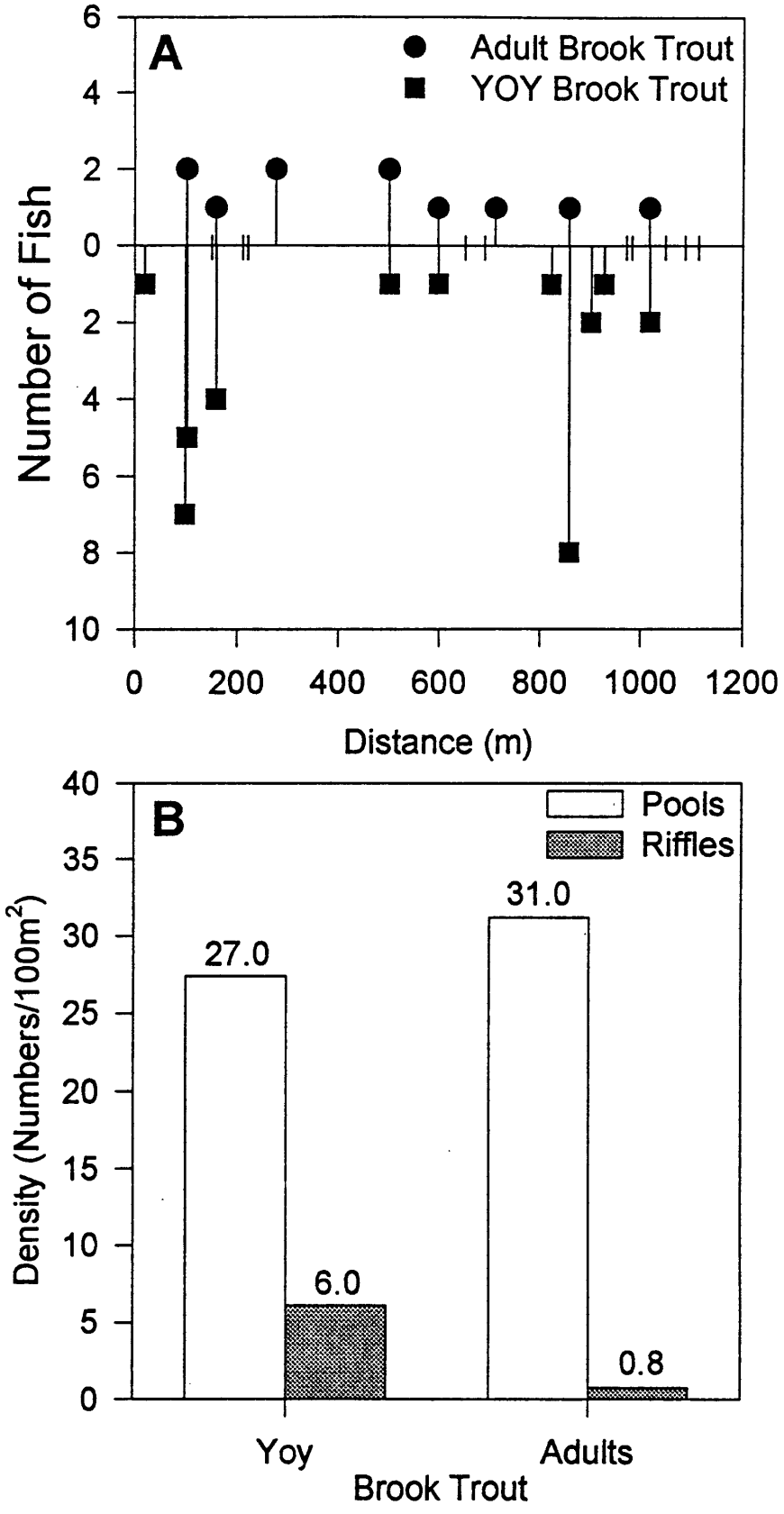

Figure 17. (A) Distribution of fish in Wildcat Hollow. Habitat units where divers did not see fish are denoted by vertical marks on the x-axis. (B) Densities of brook trout in Wildcat Hollow for Wildcat Hollow. Numbers above the bars represent actual density.

Table 13. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in pools of Meadow Run. Also included are mean total length and width for all species.

Species	BKTA	BKTY	BND
Calibration ($\hat{R}$)	3.43	0.18	9.80
$\hat{N}$	708	1597	19
(± 95% CI)	(421)	(981)	(33)
Avg. Total Length	166	68	69
(± 95% CI)	(16)	(2)	(21)
Avg. Weight	44.8	3.0	3.2
(± 95% CI)	(11.3)	(0.3)	(0.0)

56 pools were snorkeled and 10 pools were electrofished.

Table 14. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in riffles of Meadow Run. Also included are mean total length and width for all species.

Species	BKTA	BKTY	BND
Calibration ($\hat{R}$)	2.03	1.00	1.00
$\hat{N}$	63	1921	0
(± 95% CI)	(73)	(1386)	(0)
Avg. Total Length	128	68	0
(± 95% CI)	(8)	(2)	(0)
Avg. Weight	18.1	3.0	0.0
(± 95% CI)	(4.3)	(0.4)	(0.0)

25 riffles were snorkeled and 10 riffles were electrofished.

Table 15. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in pools of Wildcat Hollow. Also included are mean total length and width for all species.

Species	BKTA	BKTY
Calibration ($\hat{R}$)	3.00	1.00
$\hat{N}$	183	160
(± 95% CI)	(240)	(106)
Avg. Total Length	148	69
(± 95% CI)	(25)	(5)
Avg. Weight	35.5	2.9
(± 95% CI)	(8.1)	(0.2)

17 pools were snorkeled and 5 pools were electrofished.

Table 16. BVET results of the calibration ratio($\hat{R}$)and population estimates($\hat{N}$)for all species in riffles of Wildcat Hollow. Also included are mean total length and width for all species.

Species	BKTA	BKTY
Calibration ($\hat{R}$)	1.00	1.00
$\hat{N}$	11	86
(± 95% CI)	(19)	(54)
Avg. Total Length	111	64
(± 95% CI)	(0)	(9)
Avg. Weight	12.4	2.7
(± 95% CI)	(0.0)	(0.6)

16 riffles were snorkeled and 5 riffles were electrofished.

Appendix 1a. Substrate classification criteria.

SUBSTRATE CLASSES

1		organic debris
2		clay
3		silt
4	silt- 2mm	sand
5	2-10mm	small gravel
6	1-10cm	large gravel
7	11-30cm	cobble
8	30cm	boulder
9		bedrock

Appendix 1b. Large woody debris (LWD) classification criteria.

LWD SIZE CLASSES

1 $\geq$ 1 and < 5 m (length), 5-10cm (diameter)
2 $\geq$ 1 and < 5 m (length), 10-50cm (diameter)
3 $\geq$ 1 and < 5 m (length), > 50cm (diameter)
4 $\geq$ 5m(length), 5-10cm (diameter)
5 $\geq$ 5m(length),10-50cm (diameter)
6 $\geq$ 5m(length), > 50cm (diameter)
7 root wads