Short-Term Response of Physical Habitat and Fish to the Addition of Large Woody Debris in Two Appalachian Mountain Streams

by

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(ABSTRACT)

Large woody debris (LWD) was added to North Fork Stony Creek and North Prong Barbours Creek in southwest Virginia to improve fish habitat. The purposes of this study were to monitor stream channel response to the addition of LWD at a stream reach scale and at a local scale around individual logs, to evaluate changes in fish population parameters, and to observe microhabitat availability and use before and after LWD additions.

In low-gradient Stony Creek, LWD was effective in modifying fish habitat through the formation of pools, the structuring of pool/riffle sequences, and the enhancement of channel complexity. New pools formed from the break up of continuous riffle habitat, increasing the overall number of habitat units and decreasing mean surface areas. Total pool area increased for both treatment sections, while changing little in the reference section where no logs were added. Localized scour and fill was observed for cross-sectional transects around individual logs, creating a more heterogenous environment than in areas without logs. In contrast, physical habitat changed little in moderate-gradient Barbours Creek after LWD was added.

An increase in the relative weight of brook trout in Barbours Creek suggested that although minimal channel changes were observed, logs may have increased channel complexity and cover, providing resting areas of lower velocities next to food pathways, which may have lead to decreased energy expenditure. Observations of microhabitat use revealed that unlike adult brook trout, juvenile brook trout used a limited range of depths

and velocities. Adult brook trout shifted microhabitat use in response to changes in microhabitat available.

Low numbers of fish in Stony Creek may have been related to low pH, but numbers of adult brook trout found in each section increased in 1994. With improved water quality, I believe that fish abundance in Stony Creek would increase through time because of the improved habitat. Although few significant changes were observed for available microhabitat in Stony Creek, changes in physical habitat suggest that over time shifts in microhabitat would be apparent.

## Acknowledgments

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## Introduction to the Thesis

Geomorphologists have long recognized the role of large woody debris (LWD) in shaping stream channel systems (Keller and Swanson 1979; Robison and Beschta 1990). More recently, fisheries biologists and managers have recognized its positive effects on both physical and biological processes in stream ecosystems. Large woody debris (root wads, branches, snags, or detached tree trunks) is an integral part of the natural condition of streams in forested watersheds. It serves as a structural component influencing the physical form of the channel, the routing of water and sediment, the retention of organic matter, and the composition of the biological community by shaping pools for fish and depositional sites for macroinvertebrates (Bisson et al. 1987; Bilby and Ward 1989).

Under natural conditions, large woody debris is abundant in streams flowing through forested areas, but past forest practices have resulted in long-term declines in LWD and debris-related fish habitat in small to medium-sized streams (Bisson et al. 1987; Maser and Sedell 1995). Historically, large rivers were cleared to facilitate log driving and to promote navigation (Sedell and Luchessa 1982) and to remove blockage to anadromous fish migration (Cherry and Beschta 1989). Policies and practices allowed harvesting of all streamside trees and removal of debris from stream channels, yet the large debris left after clear-cutting constitutes the only available supply of wood-created channel structure for several decades (Lisle 1986) and its removal can have long-term adverse effects on stream habitat. In Alaska and elsewhere, the U. S. Forest Service required that all debris introduced by logging be removed within 48 hours (Elliott 1986). Best management practices in Virginia also mandated removal of harvested debris from stream channels (Virginia Department of Forestry 1992). It is now understood that debris removal or 'stream cleaning' can be detrimental to fish populations and some debris is necessary to maintain suitable habitat (Dolloff 1986).

Now that the benefits of LWD are recognized by many, individual logs, groups of logs, and other materials that mimic the role of LWD are added to streams to modify fish habitat (Cherry and Beschta 1989). Many stream restoration and 'enhancement' activities conducted by managers and researchers have concentrated on direct modification of streams with artificial structures, such as deflectors, gabions, log covers, and other devices to create and maintain the habitat diversity desired for aquatic organisms (Saunders and Smith 1962; Hunt 1969; Rinne 1982; Binns 1994). The use of native materials to provide productive fish habitat is a more cost-effective means of treating extensive stream reaches (Orth and White, in press). Native materials, logs from the surrounding forest, were used in this project to elevate levels of large woody debris to those more reflective of undisturbed areas in two streams flowing through second-growth forest in southwest Virginia, providing a basis for study of LWD in the southern Appalachians. The goal of this study was to observe the response of physical habitat and fish populations to the addition of logs. Specific objectives were 1) to evaluate changes in physical habitat at a reach scale and local scale level, and 2) to monitor fish response at both population and microhabitat levels.

## Study Streams

Two streams within the Jefferson National Forest were chosen as study sites. First-order North Fork Stony Creek (hereafter Stony Creek) originates in northern Giles County, Virginia, near the border of West Virginia at about 900 m elevation (2900 feet) and is a tributary to Stony Creek which flows in a southwesterly direction along State Routes 635 and 630 to drain into the New River near Pearisburg (Figure 1.). The study site is located north of State Rt. 635, above where State Rt. 613 turns into Forest Service Road 945. The study section begins 40 m above the ford on Forest Service Road 945 and continues for approximately 1 km.

Within the study section, Stony Creek is a low-gradient stream (<1%), composed primarily of shallow runs and riffles with an average wetted width of 4-5 m. Small and large gravels are the predominant substrate interspersed with sand and cobble, and fine organic debris is an important substrate component during the fall months. Stony flows through a mature second-growth forest composed mainly of hemlock (*Tsuga canadensis*), white pine (*Pinus strobus*), and yellow pine (*Pinus echinata*). The stream is heavily shaded by this riparian canopy and by a dense understory of rhododendron (*Rhododendron maximum*) and mountain laurel (*Kalmia latifolia*).

North Prong of Barbours Creek (hereafter Barbours Creek) is a second-order stream located on the New Castle Ranger District in northeastern Craig County, Virginia at an elevation of 2200 feet or 670 m (Figure 1.). Barbours flows in a southwest direction to Craig Creek, part of the James River drainage. North of New Castle, Barbours parallels State Rt. 617 for much of its length. The study site is located 30 m above the Potts Mountain Trail crossing and extends upwards approximately 1 km before crossing State Rt. 617.

Barbours also flows through a mature second growth forest, but the riparian zone is dominated by oaks (*Quercus* spp.) that are set back from the stream channel by steep banks and boulders. Barbours is a moderate gradient stream (4-5%) with an average wetted width of 5 m. Substrate is primarily composed of large and small gravels and cobbles. Boulders are numerous along the channel perimeter.

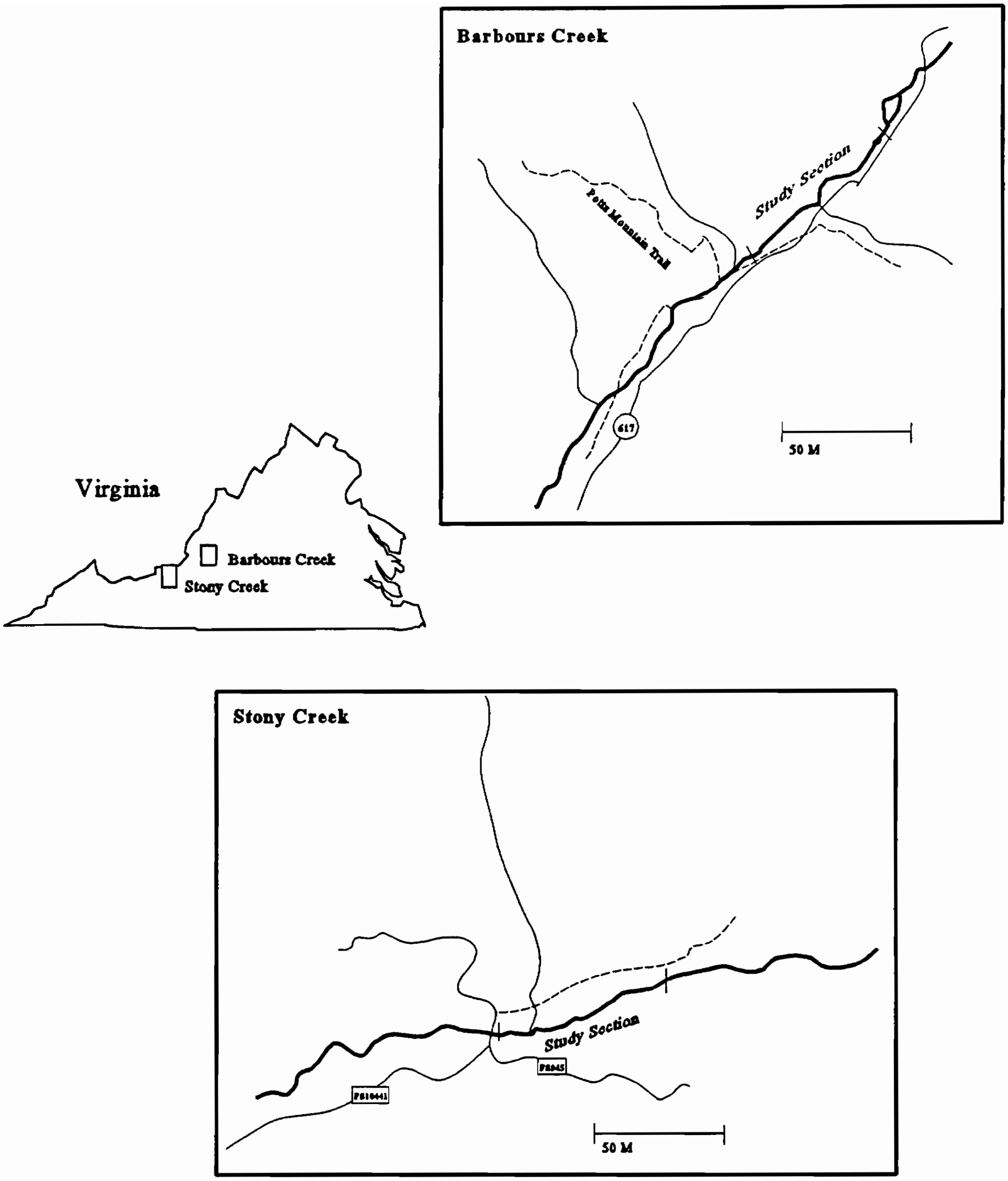



**Figure 1.** Location of North Fork Stony Creek and North Prong Barbours Creek on Virginia map and sketches of study site areas adopted from quadrangle maps.

# CHAPTER 1

## The Influence of Large Woody Debris on Physical Habitat in Two Study Streams: Reach Scale and Local Scale Effects

### Introduction

The effect of large woody debris (LWD) on stream channel morphology and the physical nature of stream ecosystems has been well documented (Heede 1972; Keller and Swanson 1979; Lisle 1986; Bisson et al. 1987; Robison and Beschta 1990). The major importance of debris lies in its structural characteristics and the way these features influence channel hydraulics (Bisson et al. 1987). Functioning as large roughness or frictional elements, large organic debris may greatly affect erosional and depositional processes that locally control channel geometry and in-channel sediment storage (Keller and Swanson 1979). These processes influence the formation of pool habitat and the overall physical heterogeneity of stream channels.

Woody debris is the structural element most often associated with pool formation in small forested streams (Bisson et al.1987, Robison and Beschta 1990). LWD diverts flowing water and influences the local scour of sediment in forested streams, creating the greater depths and lower velocities found in pool habitats (Harmon et al. 1986, Lisle 1986). Robison and Beschta (1990) found that woody debris was associated with 65 to 75 percent of all pools in low gradient southeast Alaskan streams. In a similar study of small low gradient streams, Lisle (1986) compared streams having few debris dams with those having numerous dams and found that debris can increase habitable pool length by more than 100%. In two Washington coastal streams, Bilby (1984) found after removal of debris, high flows reduced the number, area, and volume of pools, while increasing riffle area and volume.

Woody debris increases the diversity of stream habitats by physically obstructing waterflow (Sedell et al. 1988), thereby creating a more complex arrangement of pools and other channel features than would exist without debris (Bisson et al. 1987). Wood maintains a diverse physical habitat by 1) anchoring the position of pools along the direction of the stream, 2) creating backwaters along the stream margin, 3) causing lateral migration of the channel, and 4) increasing depth variability (Sedell et al. 1988). In a British Columbia stream, Fausch and Northcote (1992) found debris removal resulted in simple habitat that was less sinuous, wider, shallower and had less pool volume and overhead cover than complex habitat where debris was retained.

Individual logs can form a stepped longitudinal profile which consists of an upstream sediment deposit, the debris structure, and a downstream plunge pool (Heede 1972). The structure creates a stepped profile, separating primarily low gradient sections by short, steep falls that help to dissipate energy. This results in less available energy for erosion of bed and banks, more sediment storage in the channel, slower routing of organic detritus and greater habitat diversity than in straight, even gradient channels (Swanson and Lienkaemper 1978). Low energy depositional areas created by 'organic stepping' increase the overall storage capacity of stream channels, buffering the sedimentation impacts downstream when there are pulses of sediment input. Bilby (1981) found that removing debris from a New Hampshire stream resulted in a 500% increase in sediment export.

Many studies have documented the positive effects of existing LWD and the adverse effects of debris removal, but few studies have examined channel bed adjustments to experimental additions of LWD through time. The objectives of this study were to evaluate reach scale and local scale changes in physical habitat for a moderate gradient (4%) and a low gradient (<1%) stream in response to large woody debris added in a variety of orientations. Reach scale characteristics examined were pool formation and channel complexity, defined as the number and size of pools and riffles. Local scale changes were evaluated using permanent cross-sectional transects to examine changes in channel bed elevation and substrate distribution around individual logs. My hypothesis was that the addition of LWD in the form of logs would cause changes in the amount, distribution and quality of instream habitat.

## Methods

Addition of Large Woody Debris

In the summer of 1993, large woody debris was placed in two study streams, North Fork Stony Creek, Giles County, VA and North Prong Barbours Creek, Craig County, VA. Both streams were divided into three 225 m-sections separated by 50 m buffer areas. Logs were added to two treatment reaches, described as the random and systematic placement sections. The reach furthest downstream was the random placement section where logs were placed randomly to mimic natural treefall. The middle section was designated the systematic placement section where debris placement was determined by judgment on how to enhance the stream channel. The section furthest upstream was the reference section where no manipulations occurred. In Stony Creek the reference section was 150 m long to avoid effects from upstream beaver activity.

A total of 100 logs were placed in Stony Creek and 50 in Barbours Creek; logs were divided evenly between the random and systematic placement sections. Each piece was assigned to an orientation category. Vertical orientations included dams (logs positioned on the channel bed), and ramps (logs partially elevated from the bed) and horizontal orientations included perpendicular (90 degrees), upstream (135 degrees), and downstream (45 degrees) with the butt end at either the left or right bank (Figure 1.1.). For the random placement section, horizontal and vertical orientations and distance from the starting point (five meter intervals) were considered in the randomization process.

Prior to additions, log positions were marked with flagging and the length of log needed was determined for each site. Logs were cut from trees selected in the respective riparian areas, at least 10 m away from the stream bank. Trees were stripped of limbs and each log cut was a minimum of 4 m in length and 25 cm in diameter. A front end loader was used to place logs within the stream and an effort was made to minimize damage to the riparian zone during operation of heavy of equipment. Logs were not anchored to the channel so that pieces were free to move and adjust to channel changes.

Immediately following placement, each log was tagged and measured. Length, diameter at each end, species and orientation were recorded. Locations of logs were recorded on plan-view maps described in the following section. Log volume was calculated for each log by using the average diameter and length measured in the field and assuming the log was a cylinder (Lienkaemper and Swanson 1987):

$$\text{volume} = 3.1416 \times [(\text{butt diameter} + \text{top diameter}) / 4]^2 \times \text{length}.$$

## Habitat Mapping

A detailed map of channel configuration and a record of physical parameters was developed prior to manipulations (May 1993) and the year following (May 1994), allowing changes related to large woody debris to be monitored spatially and temporally.

An inventory of physical habitat units was developed for each stream according to the methods of Bisson et al. (1982). Two general categories of habitat were considered in this study: riffles and pools. A riffle was identified as a shallow stream area with moderate current velocity and moderate turbulence; a pool as an area lacking turbulence with low current velocity and greater depth. Each unit was flagged at both ends and labeled according to habitat type, number in sequence, and distance from the downstream starting point. Any existing large woody debris was counted and tagged with an individual identification number. Each piece was indexed according to length and diameter into four size classes: 1) 10-50 cm in diameter and 1-5 m long, 2) 10-50 cm in diameter and >5 m long, 3) >50 cm in diameter and 1-5 m long, and 4) >50 cm in diameter and >5 m long.

After habitat units and treatment sections were designated, a more intensive mapping process followed. From a downstream starting point, a transit line was established by stretching a measuring tape as far upstream as possible while still permitting a direct line of sight within the stream channel. A permanent reference stake designated the end point of the line and its compass orientation to magnetic north was recorded. Additional transit lines were established for the entire reach of stream studied and were used as reference (zero) lines for the following measurements. Distance to stream bank (bank full width) and water edge (wetted channel width) were recorded as the perpendicular distance (transects) from the transit line. Perpendicular measurements were made at points where habitat changes occurred. For example, transects were established at beginning and end points of a transit line, at transitions between habitat units, and at various points where the channel shape appeared to change markedly. As measurements were recorded, a rough plan-view map was drawn onto a grid.

## Reach Scale Analysis

Average width and total length were determined for each individual habitat unit using the plan-view maps and surface areas were calculated as the product of these measurements. Temporal changes in the length and surface area of pools and riffles were examined using two-way ANOVA testing on ranks (Zar 1984) with treatment (i.e., random, systematic, reference) and year (i.e., before, after) as factors. The total surface area of pools and riffles also was calculated for each section by combining values for like habitat units.

## Channel Elevation Profiles

As described above, plan-view maps were used to examine reach scale changes in stream channel morphology for North Fork Stony and North Prong Barbours Creek. In addition, localized measurements were made using permanent cross-sectional transects around individual logs. Data were collected immediately after log placement (July 1993) and ten months following (May 1994) to evaluate fine-scale channel changes over time.

Transects were established in areas around experimental logs in the random and systematic placement sections and around "phantom logs" (places in the stream measured as if a log had been placed) in the reference section. Approximately 25 percent of experimental logs were randomly chosen to sample. A total of 30 logs were sampled in Stony and 16 in Barbours. Eight “phantom logs” were sampled in the reference sections of Stony; five were sampled in Barbours.

Each experimental log was classified according to its vertical (dam, ramp) and horizontal (downstream, perpendicular, upstream) orientation. Three transect lines were then positioned at 1 m intervals around each selected log; one immediately upstream, one immediately downstream and one 1 m downstream from the log. The transit lines created for the plan-view maps were used as reference (zero) lines for transects. A measuring tape was stretched perpendicular to the transit line between stakes located on each bank to form a cross-sectional transect.

The distance from the horizontal transect tape to the bottom of the channel was measured at fixed intervals along the tape. Depth and elevation measurements were taken with a stadia rod and level every 50 cm from the left streambank. Surveys of each transect took place before and after LWD addition to quantify scour and fill of the channel bed through time.

Analysis of Channel Elevation Profiles

Any logs displaced after high flow events were removed from analysis. Elevations were calibrated against permanent benchmarks in the surrounding forest. Changes in stream channel elevation were calculated by subtracting each 1994 data point from its corresponding 1993 data point.

The indices used to evaluate cross-sectional data were net percent change in area (NET%) and absolute percent change in area (ABS%) from Olson-Rutz and Marlow (1992). NET% change in area ($\Delta A\%$) quantifies net aggradation or degradation of a cross-section, computed as:

$$\Delta A\% = \frac{\sum_{i=1}^{n}(Y_i\text{before} - Y_i\text{after})}{\sum_{i=1}^{n} Y\text{ before}} \times 100,$$

where $Y_i$ represents the distance from the line to the streambed at the $_i$th point along the transect; n is the number of $Y_i$ values measured along the transect. Equal amounts of scour and fill for a transect can result in no net change in area. To avoid potential bias in interpretation, ABS% was also considered. ABS% change in area quantifies cumulative channel change including erosion and deposition. It is computed as:

$$|\Delta A\%| = \frac{\sum_{i=1}^{n}|(Y_i\text{before} - Y_i\text{after})|}{\sum_{i=1}^{n} Y\text{ before}} \times 100.$$

Values calculated for ABS% change represent total movement in streambed material.

Fisher Exact Tests (Zar 1984) were used to test the null hypothesis that changes in channel bed elevation, described as scour or fill, were independent of large woody debris additions.

Substrate Size Distribution

Substrate was characterized for each log or "phantom log" sampled using a modification of the Wolman pebble count method (Wolman 1954). This method involved randomly choosing 100 substrate particles from the streambed within the three transects by walking across stream widths heel to toe and categorizing each particle the toe touched. Substrate was characterized according to a modified Wentworth scale (Table 1.1.). Substrate samples were taken at the same time channel elevation measurements were collected.

Frequency and cumulative frequency distributions were constructed for each individual log or "phantom log" and for all logs combined within a section. The Kolmogorov-Smirnov approximate test was used to test for change in the distribution of substrate around each log and for change in substrate distribution around all logs within each section after LWD was added (Sokal and Rohlf 1995). Expected values ($D_\infty$) calculated as $D_\infty = K_\infty(n_1 + n_2/n_1n_2)$, $K_{.05} = 1.35810$ and $K_{.01} = 1.62762$ are compared to $D_{max}$ or the maximum difference between the two cumulative frequency distributions to determine whether the distributions are significantly different.

**Table 1.1.** Classification of stream substratum by particle size used to classify the dominant and subdominant substratum in Barbours and Stony Creek.

| Substrate Classes | | |
|---|---|---|
| Class | Type | Particle Size |
| 1 | organic debris | |
| 2 | silt | |
| 3 | sand | silt - 2mm |
| 4 | small gravel | 2 - 10 mm |
| 5 | large gravel | 1 - 10 cm |
| 6 | cobble | 11 - 30 cm |
| 7 | boulder | 30 cm |
| 8 | bedrock | |

# LOG ORIENTATIONS

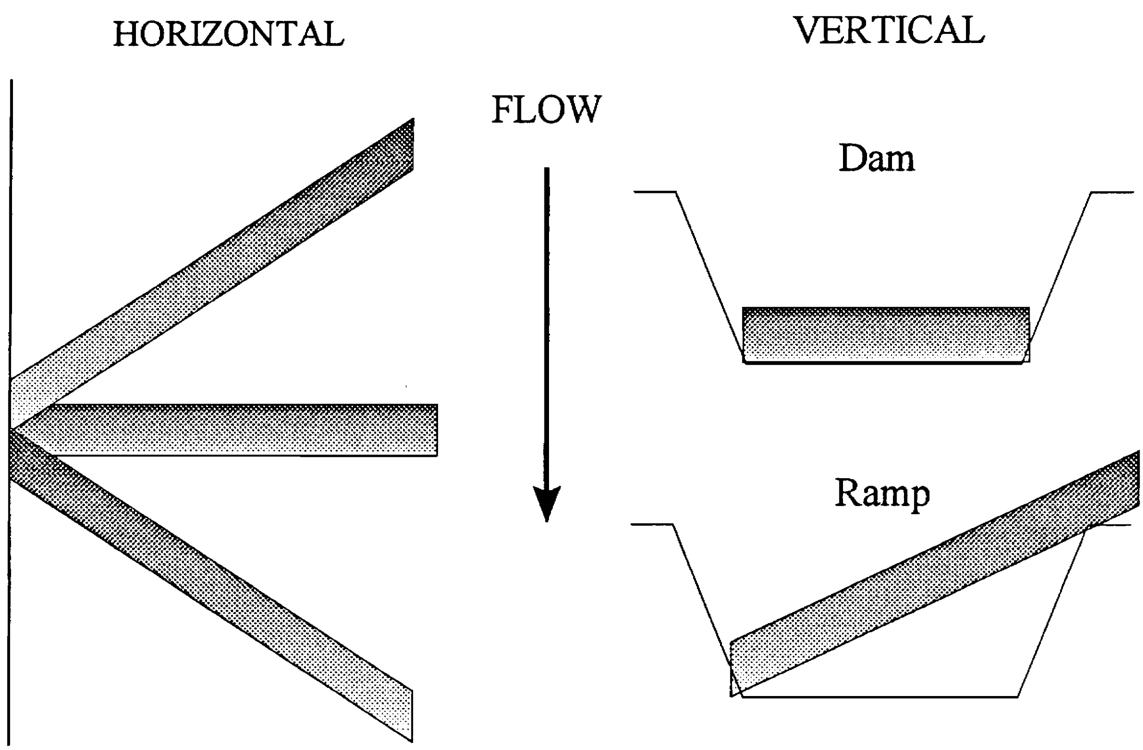



**Figure 1.1.** Horizontal (plan-view) and vertical (cross-section) orientations of woody debris placed in North Fork Stony Creek and North Prong Barbours Creek. Arrow indicates direction of streamflow.

## Results

Reach Scale Effects of LWD

*North Fork Stony Creek*

A preliminary inventory of existing large woody debris in Stony Creek revealed an average of four pieces per 100 m with smaller size classes representing the majority of wood. Experimental log additions contributed another 20 pieces per 100 m; an additional 30 $m^3$ per section. Logs averaged 6.4 m in length with a mean butt diameter of 37.5 cm for the random placement section; 6.3 m in length with a mean butt diameter of 39.8 cm for the systematic placement section. The size-class distribution of woody debris changed little. Figures 2a and 2b in Hilderbrand et al. (1997) represent size-class distribution of naturally recruited and experimentally added LWD.

The number of habitat units, both pools and riffles, increased after LWD additions in both placement sections, but remained similar in the reference section. The number of pools increased from five to eight in the random placement section; riffles from four to six (Table 1.2.). The three created pools were a result of ponding or scouring action around experimental woody debris. Log 17 dammed a section to form a dam pool upstream and a scour pool downstream. Log 26 caused a partial damming effect, enhancing habitat to create a pool. Ten additional logs were noted as enhancing (i.e., deflecting flow, forming chutes, creating scour) or maintaining pool habitat in the random section.

In the systematic placement section, the number of pools doubled from five to ten (Table 1.2.). Three of the pools were created by experimental logs. A combination of three logs (Logs 64, 65, and 67) formed a scour pool. Log 91 formed a dam that created an upstream dam pool and a downstream plunge pool. The number of riffles increased from six to nine (Table 1.2). As in the random placement section, an additional ten logs were noted as enhancing or maintaining pool habitat.

In contrast, the number of pools and riffles remained similar in the reference section of Stony Creek after LWD was added (Table 1.2.). One additional pool resulted from separation of a pool unit by an existing piece of LWD. This separation caused mean pool area to decrease by 23% (Table 1.2.), but statistical testing demonstrated that the change in median pool area and length was not significant. Riffle lengths and surface areas in the reference section did not change significantly in 1994 (Table 1.2.). In the random and systematic placement sections, lengths and surface areas of pools and riffles (Table 1.2.) were not significantly different after LWD was added.

The total area, all habitat units combined, of pools and riffles was also considered for each section of Stony Creek, but was not tested for significance because of low sample size. For the random placement section, total pool area increased by 20%; riffle area decreased by 10% (Figure 1.2.). Total surface area of pools increased dramatically for the systematic placement reach (171%) after LWD was added, while total area of riffles decreased (40%). In contrast, total pool area in the reference section decreased minimally (4%) and riffle area stayed the same (Figure 1.2.).

*North Prong Barbours Creek*

Naturally recruited woody debris averaged 5.2 pieces per 100 m in Barbours Creek before experimental log additions. Log placement added an extra 10 pieces per 100 m. Total volume of wood added was 29 $m^3$ for each section. The average length of logs added was 7.7 m and the average diameter was 49 cm. Naturally recruited LWD dominated the first two size classes (diameter = 10-50 cm), but was evenly distributed for log length. Size frequency distribution changed little after log placement (from Figures 2a and 2b, Hilderbrand et al. 1997).

Prior to LWD additions, 14 pools and 11 riffles existed in the random placement section (Table 1.3.). Arrangement of habitat units shifted in the random section after LWD placement, but the only change in numbers was for riffles (n = 10). Logs 6 and 21 helped to create two new pools through scouring action, but the number of pools did not change because two other pools reverted to riffle habitat in 1994. Logs 3, 7 and 8 were also noted as enhancing habitat in the random section. The systematic placement section contained 9 pools and 8 riffles in 1993; one pool and riffle each were added after LWD placement (Table 1.3.). Log 44 formed a dam to create a new pool and four additional logs were noted as enhancing or maintaining habitat. Unlike the treatment sections, the number of habitat units found in the reference section remained the same after LWD was added; 7 pools and 6 riffles (Table 1.3.).

Similarly, length and surface area for pools and riffles in the reference section did not change significantly in 1994 (Table 1.3.). In the random and systematic placement sections, differences in length and surface area of pool and riffle habitat (Table 1.3.) were not significant. Total surface area for like habitat units (i.e., pools, riffles) also was examined. Total pool area increased in both the random and systematic placement sections by 9 and 16%, respectively, after LWD was added (Figure 1.3.). Conversely, riffle area decreased by 9% and 5% in the respective sections. No change was observed for total surface area of pool and riffle habitat in the reference section in 1994 (Figure 1.3.).

**Table 1.2.** Numbers of habitat units, mean lengths and surface areas of pools and riffles in three sampled reaches of North Fork Stony Creek before and after the addition of LWD.

| | Pools | | Riffles | | Total | |
|---|---|---|---|---|---|---|
| Section | Before | After | Before | After | Before | After |
| | | | **Number of Habitat Units** | | | |
| Random Placement | 5 | 8 | 4 | 6 | 9 | 14 |
| Systematic Placement | 5 | 10 | 6 | 9 | 11 | 19 |
| Reference | 4 | 5 | 3 | 3 | 7 | 8 |
| | | | **Mean Length (m) ± Standard Deviation** | | | |
| Random Placement | 11.8 (8.4) | 9.4 (7.1) | 43.3 (72.5) | 26.2 (22.9) | ---- | ---- |
| Systematic Placement | 9.7 (3.9) | 13.8 (9.3) | 31.9 (30.0) | 11.4 (7.4) | ---- | ---- |
| Reference | 15.9 (15.3) | 12.7 (11.9) | 28.0 (22.6) | 28.0 (22.6) | ---- | ---- |
| | | | **Mean Area ($m^2$) ± Standard Deviation** | | | |
| Random Placement | 69.4 (55.2) | 52.2 (46.7) | 242.0 (404.7) | 146.2 (126.6) | ---- | ---- |
| Systematic Placement | 47.3 (12.2) | 63.9 (39.5) | 142.9 (133.6) | 57.2 (31.0) | ---- | ---- |
| Reference | 84.9 (80.6) | 65.3 (55.7) | 131.4 (89.3) | 131.4 (89.3) | ---- | ---- |

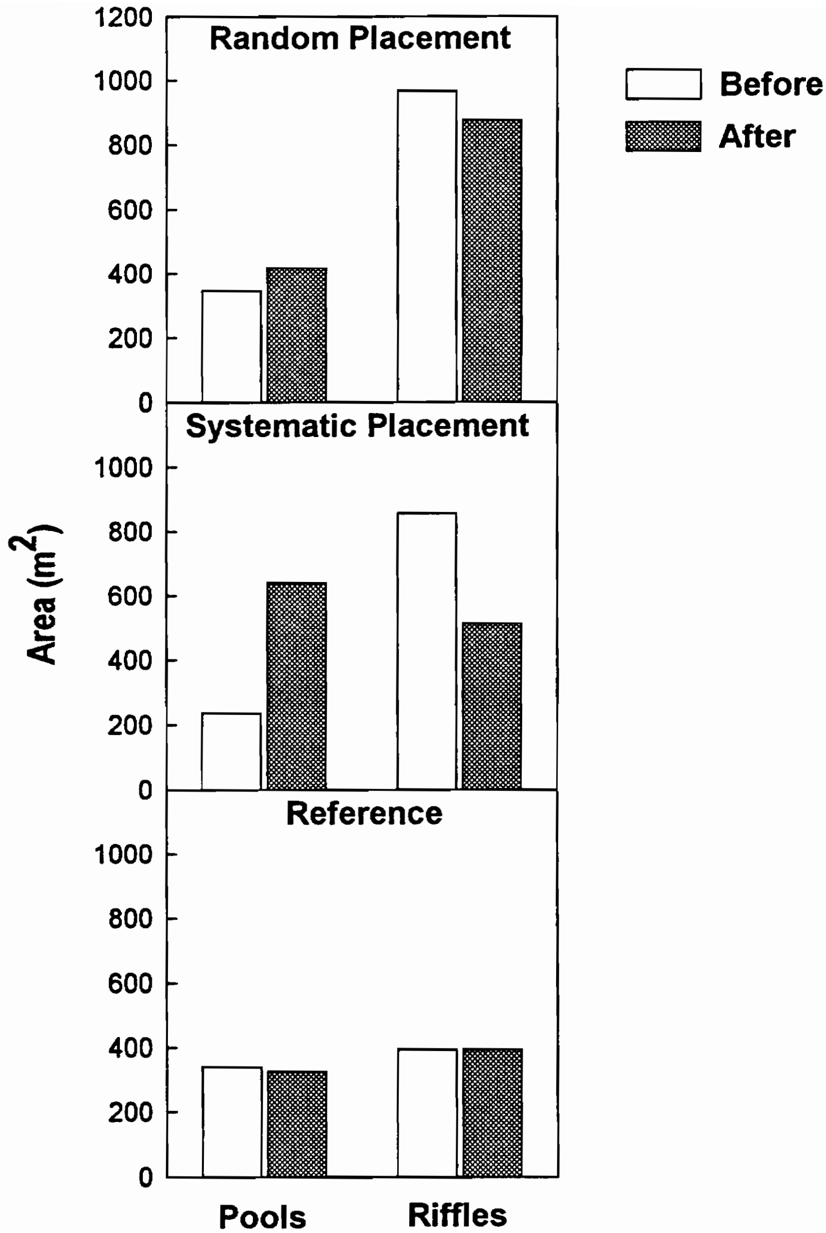



**Figure 1.2.** Total surface area of pools and riffles in sampled reaches of North Fork Stony Creek before and after the addition of LWD.

**Table 1.3.** Numbers of habitat units, mean lengths and surface areas of pools and riffles in three sampled reaches of North Prong Barbours Creek before and after the addition of LWD.

| Section | Pools Before | Pools After | Riffles Before | Riffles After | Total Before | Total After |
|---|---|---|---|---|---|---|
| | | | **Number of Habitat Units** | | | |
| Random Placement | 14 | 14 | 11 | 10 | 25 | 24 |
| Systematic Placement | 9 | 10 | 8 | 9 | 17 | 19 |
| Reference | 7 | 7 | 6 | 6 | 13 | 13 |
| | | | **Mean Length (m) ± Standard Deviation** | | | |
| Random Placement | 8.3 (4.4) | 9.1 (4.1) | 12.1 (6.5) | 12.2 (5.0) | ---- | ---- |
| Systematic Placement | 8.4 (3.9) | 8.9 (4.0) | 23.1 (23.6) | 19.0 (23.1) | ---- | ---- |
| Reference | 12.0 (6.7) | 12.0 (6.7) | 28.6 (23.4) | 28.6 (23.4) | ---- | ---- |
| | | | **Mean Area ($m^2$) ± Standard Deviation** | | | |
| Random Placement | 38.9 (20.8) | 42.5 (19.3) | 54.1 (30.9) | 54.4 (18.6) | ---- | ---- |
| Systematic Placement | 36.9 (15.0) | 38.5 (15.0) | 108.0 (122.4) | 91.3 (120.6) | ---- | ---- |
| Reference | 41.1 (28.7) | 41.1 (28.7) | 109.6 (92.8) | 109.6 (92.8) | ---- | ---- |

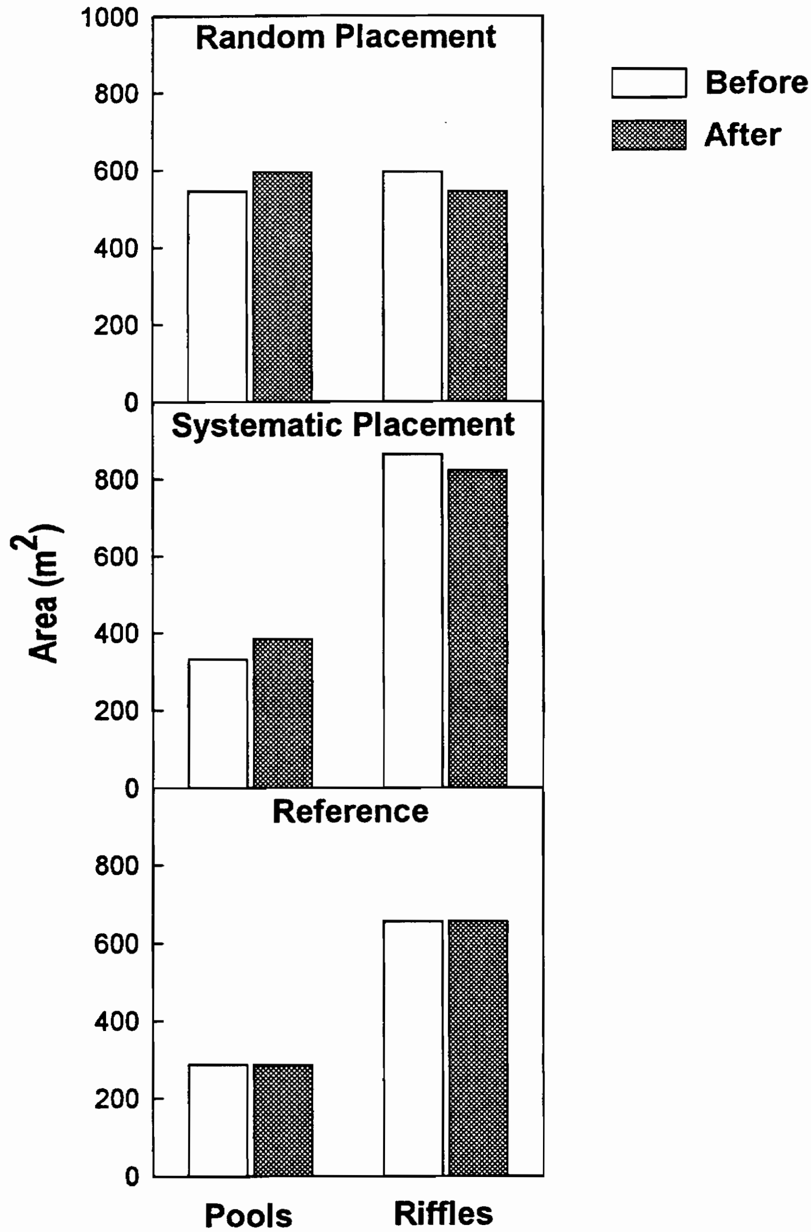



**Figure 1.3.** Total surface area of pools and riffles in sampled reaches of North Prong Barbours Creek before and after the addition of LWD.

## Local Scale Effects of LWD

*North Fork Stony Creek*

Permanent cross-sections were established for thirty logs in Stony Creek in 1993, but eight logs were displaced by 1994 and were removed from analyses. A total of 22 logs were analyzed in the random and systematic placement sections of Stony; 4 dams and 18 ramps. Three transects, one directly upstream, one directly downstream and one 1m downstream (hereafter referred to as T1, T2 and T3), were sampled for each log for a total of 66 transects. Eight 'phantom logs' were sampled in the reference section for a total of 24 transects. Cross-sectional profiles were compared for each transect before and after LWD additions (Figure 1.4.).

Net and absolute percent change (NET and ABS) in streambed elevation were calculated for each transect. Results from the random and systematic placement sections were combined for analysis. Scouring was evident for 65% of all transects around logs in the treatment sections. Examining T1, T2 and T3 separately yielded similar results: 64%, 68% and 64%, respectively. There was also a trend toward scouring in the reference section, but to a greater extent; 92% of those transects around "phantom logs" showed a negative percent change. The proportion of transects that showed scour around 'phantom logs' was significantly greater than the proportion of transects that showed a net scouring around logs ($P = 0.016$).

Means calculated for net percent change of all logs combined showed overall degradation for transects in the placement and reference sections, but again "phantom logs" showed the greatest amount of scour (Table 1.4.). On average, those transects immediately downstream of log (T2) also showed a greater amount of scouring as compared to those above or 1 m below (Table 1.4.). Ramps showed more degradation of the channel bed (NET = -4.1%) than dams (NET = -1.8%).

An examination of total bed movement (scour and fill), calculated as the mean absolute percent change, indicated the least amount of bed movement took place in areas with no logs (Table 1.4.). Logs positioned as ramps caused the most movement of sediments (Table 1.4.).

A total of 820, 1050 and 838 substrate particles were counted in areas sampled around logs or 'phantom logs' for the random placement, systematic placement and reference sections of North Fork Stony, respectively. Substrate frequency and cumulative frequency distributions were constructed for each section (Figure 1.5.).

Dominant and subdominant substratum was large gravel and small gravel for all sections in 1993 and 1994 (Figure 1.5.). No bedrock and very few boulders were apparent in Stony Creek. Substrate frequency distributions changed significantly in the random and systematic placement sections after LWD was added ($P = 0.01$). In the random placement section, Logs 5, 11, and 45 showed significant changes ($P = 0.01$, 0 .05 and 0.05) in substrate distribution after LWD placement. For all logs, the percentage of substrate that was organic debris increased in 1994. In the systematic section, four substrate counts around logs showed significant differences in 1994 at the 0.01 level: Log 51, 73-74, 92, and 93. Substrate distributions shifted toward larger size classes for Logs 51, 73-74, and 92, while log 93 had a greater amount of organic debris and silt in 1994. Conversely, no significant changes were found for the reference section or for any "phantom log".

*North Prong Barbours Creek*

Sixteen logs, 7 dams and 9 ramps, were sampled in the random and systematic placement sections of Barbours Creek. As for Stony Creek, three transects (T1, T2, and T3) represented each log. Five "phantom logs" were considered in the reference section.

The net percent change calculated for streambed elevation around logs showed that 57% of transects in the random and systematic placement sections had scour; 43% had fill. In contrast, 77% of the transects in the reference section showed deposition. Interestingly, transects above logs also showed a trend toward deposition (67%). Values for transects below logs indicated that more scouring action took place in these areas (T2 = 56% scour, T3 = 80% scour). Fisher Exact tests showed that the presence of large woody debris did not significantly affect changes in the stream channel.

Mean values for net percent change (NET) in stream bed elevation were calculated (Table 1.5.). Transects immediately upstream (T1) from logs and around "phantom logs" showed a net aggradation, while transects downstream from logs (T2 and T3) showed a net degradation in the channel bed. Logs that were dams demonstrated a net bed movement of scour (NET = -1.5%), while ramps showed a net movement of fill (NET = 0.8%).

Absolute percent change (ABS) in the channel bed was also calculated to demonstrate total movement (positive and negative) of sediment. Transects downstream from logs showed the greatest movement of channel bed sediments, while transects in the reference section showed the least amount of movement (Table 1.5.). Absolute change in the channel bed was similar for dams and ramps (Table 1.5.)

Substrate particles counted for Barbours Creek totaled 802, 633, and 547 in the random, systematic, and reference sections, respectively. Dominant substratum for each section was large gravel in both 1993 and 1994 (Figure 1.6.). For 1993 and 1994, boulders were the subdominant substratum in the random placement section and small gravels were in the systematic placement and reference sections (Figure 1.6.).

For Barbours Creek, no significant difference was found for substrate frequency distributions between 1993 and 1994 for the random placement section or for any log within this section. Significant changes were found in the systematic placement section after LWD was added (P = 0.01). Substrate frequency distributions were significantly different for Logs 29, 39 and 50 at the 0.05 level. In each distribution, the percentage of organic debris, cobbles, and boulders increased, while percentage of sand, small and large gravels decreased. No significant differences were found for the reference section or for any "phantom log" within the section.

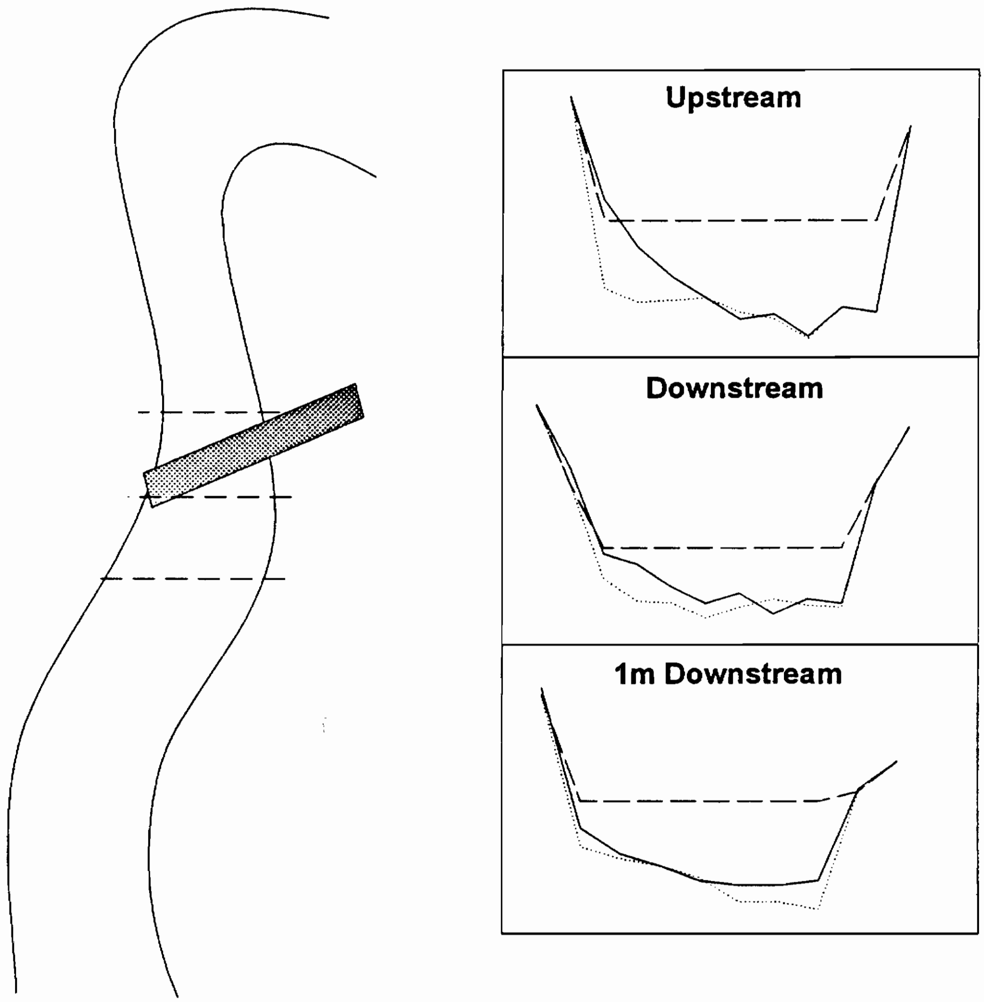



**Figure 1.4.** An example of channel cross-sections and resulting elevational profiles from logs sampled in Stony and Barbours Creek. Experimental Log 15 from the random placement section of Stony Creek is shown.

**Table 1.4.** Means (±SE) of channel cross-sectional indices for logs in the random and systematic sections and for "phantom logs" in the reference section of North Fork Stony Creek.

| Treatment | No. of Transects | Net Percent Change | Absolute Percent Change |
|---|---|---|---|
| All Logs (T1, T2 and T3) | 66 | -3.7 (0.8) | 9.5 (0.6) |
| **'Phantom Log' in Reference** | **24** | **-5.5 (0.8)** | **7.7 (0.5)** |
| Immediately Upstream of Log | 22 | -3.7 (1.3) | 9.4 (1.1) |
| Immediately Downstream of Log | 22 | -5.0 (1.3) | 10.2 (1.0) |
| 1-2 Meters Downstream of Log | 22 | -2.4 (1.5) | 8.8 (0.9) |
| Dam (T1, T2 and T3) | 12 | -1.8 (1.6) | 8.1 (1.1) |
| Ramp (T1, T2 and T3) | 54 | -4.1 (0.9) | 9.8 (0.7) |

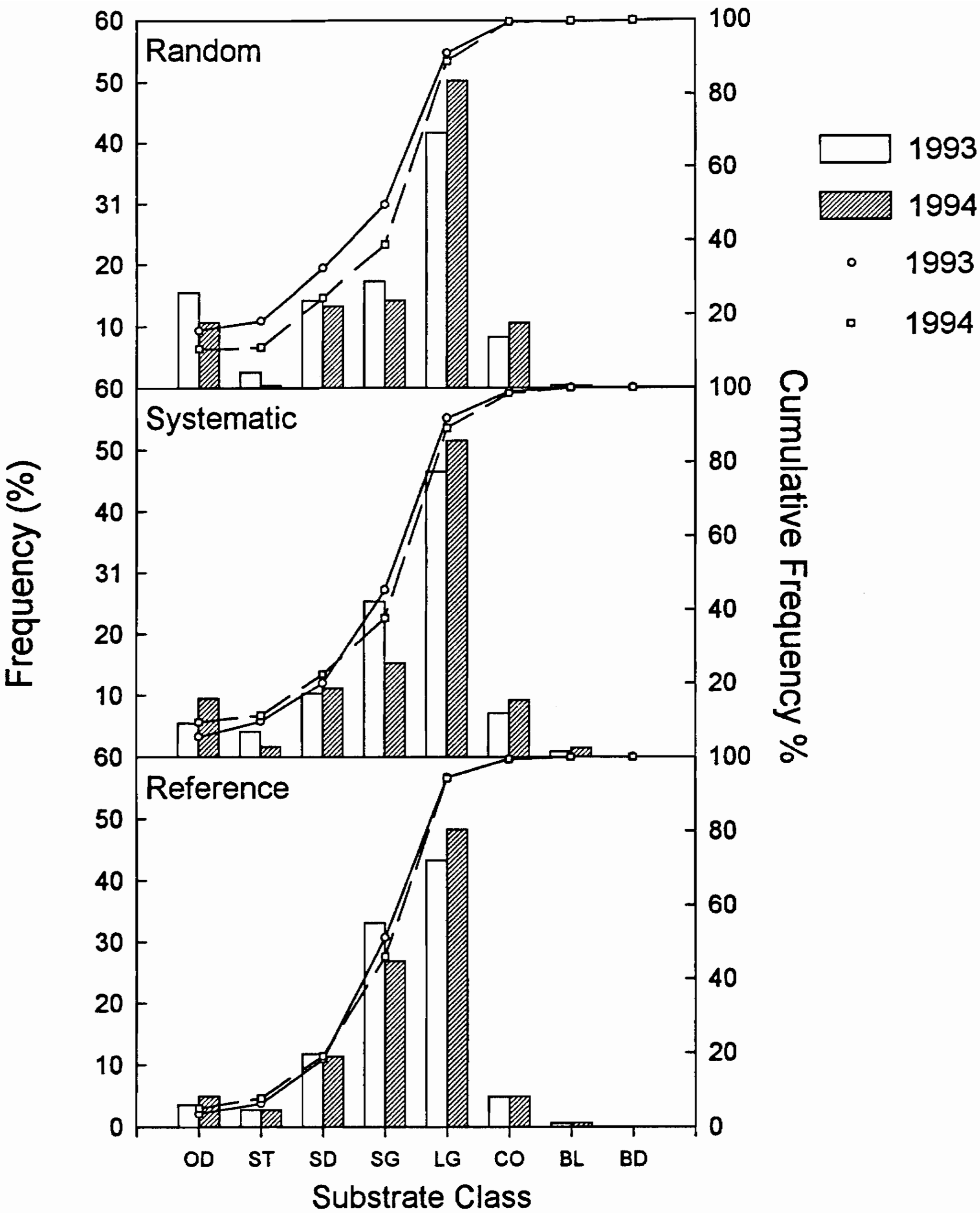



**Figure 1.5.** Frequency and cumulative frequency distributions of substrate in areas around logs and 'phantom logs' in the sampled reaches of North Fork Stony Creek in July 1993 and May 1994. Substrate categories include OD=organic debris, ST=silt, SD=sand, SG=small gravel, LG=large gravel, CO=cobble, BL=boulder, and BD=bedrock.

**Table 1.5.** Means (±SE) of channel cross-sectional indices for logs in the random and systematic sections and for "phantom logs" in the reference section of North Prong Barbours Creek.

| Treatment | No. of Transects | Net Percent Change | Absolute Percent Change |
|---|---|---|---|
| All Logs (T1, T2 and T3) | 48 | -0.2 (0.6) | 7.0 (0.5) |
| **'Phantom Log' in Reference** | **15** | **1.5 (0.8)** | **5.6 (0.7)** |
| Immediately Upstream of Log | 16 | 0.5 (1.2) | 6.5 (0.8) |
| Immediately Downstream of Log | 16 | -0.6 (1.4) | 7.5 (0.9) |
| 1-2 Meters Downstream of Log | 16 | -0.7 (0.6) | 7.0 (0.8) |
| Dam (T1, T2 and T3) | 21 | -1.5 (1.0) | 6.9 (0.7) |
| Ramp (T1, T2 and T3) | 27 | 0.8 (0.8) | 7.0 (0.7) |

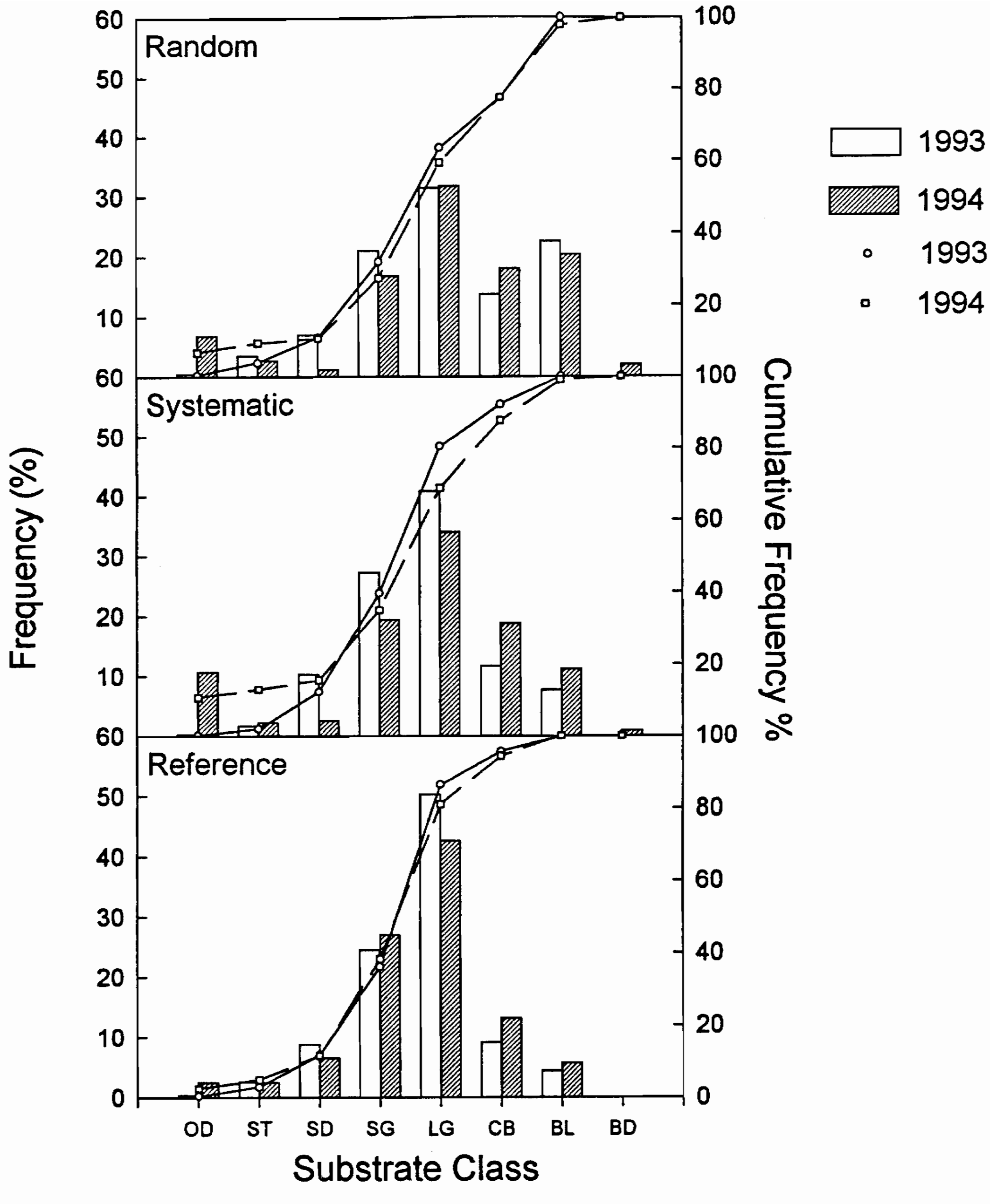



**Figure 1.6.** Frequency and cumulative frequency distributions of substrate in areas around logs and 'phantom logs' in the sampled reaches of North Prong Barbours Creek in July 1993 and May 1994. Substrate categories include OD=organic debris, ST=silt, SD=sand, SG=small gravel, LG=large gravel, CO=cobble, BL=boulder, and BD=bedrock.

## Discussion

Preliminary inventories of North Fork Stony and North Prong Barbours revealed that each stream flowed through mature second-growth forests and had an average of 4 and 5.2 pieces of LWD per 100 m, respectively. The majority of studies of streams in second-growth forests have demonstrated that the input of LWD from these stands is significantly reduced relative to debris inputs from old-growth stands (Bisson et al. 1987). An inventory of debris loadings in three Appalachian streams reported 18 and 26 pieces per 100 m for old-growth streams compared to 5 pieces per 100 m for a second-growth stream (Flebbe and Dolloff 1995). Debris loadings found in five old-growth watersheds in Alaska ranged from 25 to 42 pieces per 100 m (Robison and Beschta 1990).

The intent was to restore debris loadings in Stony and Barbours Creek to levels found in undisturbed watersheds through experimental additions of large woody debris. By 'jumpstarting' the process of forest maturation and natural recruitment of LWD to the stream channel, it was hoped that habitat conditions for fish and macroinvertebrate populations would improve. Experimental debris added to Stony and Barbours increased levels to those found in relatively undisturbed watersheds, 24 and 15 logs per 100 m, respectively.

### Reach Scale Effects of LWD

In Stony, the number of both pools and riffles increased in the treatment sections after LWD was added. Three additional pools in each of the placement sections were created by experimental logs added to the stream through scouring, ponding and damming action. The formation of pool habitat split great lengths of riffle habitat in Stony, increasing the total number of habitat units and the complexity of the stream channel. Bisson et al. (1987) point out that by providing a physical obstruction to water flow, woody debris increases the complexity of stream habitats by forming and maintaining pool habitat, causing lateral migration of the channel, creating backwaters and increasing depth variability. In comparison to changes in the treatment sections, the reference section of Stony Creek changed little. One additional pool was formed in the reference by an existing piece of LWD that acted as a dam to separate one large existing pool.

If large woody debris increases channel complexity by forming new habitat units, more pools and riffles would be expected within a given reach that had more LWD. LWD not only increased the number of habitat units in the placement sections of Stony, but also decreased average lengths and surface areas of individual units. This trend was not statistically significant, but is reflective of characteristics found in undisturbed systems. Flebbe and Dolloff (1995) found that two streams in old-growth wilderness areas contained more LWD and more and smaller pools and riffles than did a stream in second-growth area managed as wilderness. In a British Columbia stream, Fausch and Northcote (1992) found debris removal resulted in simple habitat that was less sinuous, wider, shallower and had less pool volume and overhead cover than the complex habitat where debris was retained. Pool-riffle sequences are desirable for fish habitat. Shirvell and Dungey (1983) suggest that habitat use is specific for different activities, such as foraging or spawning. For foraging, salmon and trout favor locations that provide maximum exposure to drifting food organisms, but that require a minimum expenditure of energy (Fausch 1984), such as the head of a pool. Bozek and Rahel (1991) observed many young cutthroat trout in small, low-velocity pools within gravel riffle areas, suggesting that this may be an important habitat arrangement that allows young trout to emerge and immediately occupy suitable habitat. The pool-riffle interface provides preferred spawning sites, while the lower current velocities and greater depths in pools afford refuge from streamflow and predators.

The total surface area of pools combined in Stony Creek increased in both the random and systematic placement sections, but to a greater extent in the systematic section. This may suggest that a few well-placed logs can modify channel morphology more effectively than randomly heaving logs into low-gradient stream channels (Hilderbrand et al. 1997).

Changes in Barbours Creek after LWD additions were much less dramatic than in Stony Creek. Pool habitat was formed in treatment sections by experimental logs, but to a lesser degree; two were formed in the random placement and one was formed in the systematic placement section. Total surface area of pool habitat increased by 9 and 16% in the random and systematic sections, respectively. No changes were apparent for the reference section. There could be a number of reasons for the difference in results for the two streams. Although similar volumes of wood were added to both streams, Barbours Creek received half the number of logs. Also, logs placed into Barbours Creek were elevated above the channel, whereas in Stony we were able to place them on the stream bed. But the contrast in the physical characteristics of the two streams is probably the most definitive factor contributing to these results.

Barbours Creek is similar to an 'A type' stream according to Rosgen (1996), described as a steep, entrenched, step\pool stream with a boulder dominated channel. In contrast, Stony Creek is more similar to a 'B type' stream with a low gradient, moderately entrenched, riffle-dominated channel characterized by smaller substrates. Channel changes such as localized scouring and pool formation were evident in low gradient Stony Creek. Andrus (1988) found that stream characteristics such as gradient and bedload composition appear to be important determinants in the formation of debris-associated pools.

## Local Scale Effects of LWD

One of the most important factors governing stream habitat diversity in forested streams is the natural input of LWD (Swanson et al. 1976). Without the presence of woody debris such streams could be effectively 'channelized' with a more rapid transfer of sediment through the channel system and a reduction in stable substrate and depositional sites upon which much of forested streams invertebrate community is dependent (Keller and Swanson 1979). It was hoped that the addition of LWD would create a more heterogenous environment and encourage both aggradation and degradation within the channel bed. Localized measurements of areas around logs and 'phantom logs' allowed direct observation of these changes.

Results from Stony Creek suggested that large woody debris did affect the channel bed at a local scale. A significant relationship was found between the presence of wood and the number of transects that showed degradation and aggradation; areas measured around 'phantom logs' or where no wood was added showed a trend toward scouring, while those areas measured around experimental logs showed a mixture of scour and fill. Bilby (1984) found large changes in channel structure during the first high flow after cleaning a small Washington stream of LWD; looking at net changes in channel cross sections, he found a general pattern of scouring and lowering of the streambed, probably due to the removal of debris that was retaining sediment. Examining the absolute percent changes (scour and fill) in channel bed elevation indicated places devoid of logs showed less total bed movement than places with experimental logs added. Separating results of transects around logs into those upstream, immediately downstream, and 1 m downstream, I found that transects immediately below LWD showed more evidence of scouring. The fact that scour was not predominant for transects 1 m below suggests that sediments may have been redistributed to this area. Ramps caused degradation of the channel and more bed movement than pieces oriented as dams, but these results may be biased because of the low numbers of transects sampled around dams. These findings do agree though with results from a flume study of dowels mimicking logs, which indicated that partially elevated logs (similar to my ramps) tend to produce more localized scour than logs positioned on the channel bed (Cherry and Beschta 1989).

Substrate frequency distributions in Stony Creek changed significantly for the treatment sections but not in the reference section, further supporting the idea that there was more bed movement in areas where manipulations took place. The amount of silt and small gravels decreased in the treatment sections, while the percentage of large gravels and cobbles increased. Examination of substrate around individual logs that showed significant differences revealed an increase in fine organic debris in the random placement section, suggesting that LWD was helping to retain these substrates. In the systematic placement section, organic debris increased around Log 93, but the other three logs that changed significantly shifted toward larger substrate classes. Smith (1993) points out that although LWD is generally found to increase sediment storage, hydraulic conditions created by LWD can affect sediment storage in complex ways. While depositional areas can form and encourage storage of water and sediment, turbulence and flow convergence can create local sites of scouring.

Although wood did not significantly cause changes in channel bed elevation of Barbours Creek, there was a stronger trend toward deposition in the reference section, while the placement section was more variable. Transects below logs showed a stronger tendency toward scouring and overall movement of the channel bed. Transects upstream of logs showed a positive net percent change or deposition. The least amount of bed movement was observed in the reference section. The only change observed in distribution of substrate was in the systematic placement section, which appeared to result from decrease in large gravel substrates, and an increase in cobble and boulder substrate (Figure 1.6).

The degree of influence LWD had on physical habitat was greater in Stony; the presence of wood had a statistically significant result on changes in channel elevations, while only qualitative statements could be made about its effects on Barbours. This result coincides with our findings from comparisons of reach scale effects on the two streams. Lower sample sizes may have affected statistical significance testing in Barbours Creek. But again, the contrast in the physical characteristics of the two streams and the placement of LWD within their channels are probably the most definitive factors contributing to these results. Because of steep banks and boulders on the edges of the channel in Barbours, logs were often elevated above the wetted width of the channel, exerting less influence on stream sediments. Barbours has a steeper gradient than Stony and the boulders within its channel act as a surrogate for LWD by acting as the 'roughness elements' necessary to dissipate energy and create stepped pools.

In conclusion, I feel that large woody debris can be an important tool in the management of fish habitat. In low-gradient Stony Creek, LWD was effective in modifying fish habitat through the formation of pools, the structuring of pool/riffle sequences, and the enhancement of channel complexity. In contrast, physical habitat changed little in moderate-gradient Barbours Creek after LWD was added. A-type channels do not respond strongly to the addition of habitat improvement structures because large roughness elements are typically present and contribute to habitat (Rosgen and Fittante 1986). Although changes in physical habitat are typically small in streams such as Barbours, logs may still provide cover and complex habitat for fish.

# CHAPTER 2

# The Influence of Large Woody Debris on Fish in Two Study Streams: Population and Microhabitat Level Effects

## Introduction

Large woody debris is an integral part of streams in forested watersheds. If left to run its course, the surrounding forest provides preferred fish habitat as trees fall across the stream to form pools, smaller woody debris and root systems provide instream cover, and the forest canopy provides overhead cover and shade (Bjornn et al. 1991). Fallen trees provide shelter from current and concealment from predators and competitors (White 1973). Woody debris forms complex habitat matrices that visually isolate individuals, therefore partitioning more territories and reducing the frequency of aggressive encounters between competitors (Dolloff 1983; Lisle 1986). This permits higher population densities in a given area. The greater depths resulting from the scouring and the ponding of water around large woody debris allow coexisting fish species or age classes to 'stack', that is, to occur in layers within the water column (Fraser 1969).

Relatively few undisturbed watersheds associated with old-growth forests remain in the Appalachian Mountains, thus many streams are devoid of large woody debris. Habitat improvement devices are installed to imitate the natural input of large woody debris in hopes of improving fish habitat, thereby increasing the number or size of fish in a population. Hunt (1974) found that loss of trout during the 'winter period', due to natural mortality and emigration, was greatly reduced after stream improvements in response to 'space-refuge' factors such as protective cover, increased depths and pool areas.

Experiments suggest that physical structures forming habitat for stream salmonids provide three features relevant to the trade-offs among foraging, intraspecific and interspecific competition, and predation risk (Fausch 1993); these features are velocity refuge, visual isolation, and overhead cover (Campbell and Neuner 1985). In an Alaskan stream, populations of Dolly Varden char decreased by 80% after debris removal, presumably because of loss of suitable cover (Elliott 1979). Approaching intruders pose a less threatening stimulus to fish closer to cover, resulting in shorter reactive distance and more time devoted to foraging (Grant and Noakes 1987). Structures can allow fish to hold low-velocity positions adjacent to swifter currents and may thereby maximize their energy intake from drifting invertebrates while minimizing the cost of swimming to maintain position (Everest and Chapman 1972; Fausch 1984). Trials conducted in an artificial stream revealed that rainbow trout preferred edge microhabitats with substantial amounts of debris and slow, deep microhabitats (Grossman and Boule 1991). In a similar study of Dolly Varden char, Dolloff and Reeves (1990) found that larger individuals rarely strayed from protective cover, although smaller conspecifics and coho salmon would forage further from cover.

Although habitat enhancement projects are most often aimed at improving salmonid habitat, many other species of fish also benefit greatly from the natural accumulation of LWD. Habitat use by individuals of a given species may be influenced by the presence of individuals of another or the same species. Differences in fish use of habitat may occur diurnally, seasonally, or behaviorally between size classes or life stages, and under various conditions of intra- and interspecific competition (Campbell and Neuner 1985).

In this study, I evaluated the short-term response of brook trout, *Salvelinus fontinalis*, and blacknose dace, *Rhinichthys atratulus*, populations to the addition of LWD. I examined characteristics such as density, biomass, fish size and condition, and fish movement to evaluate the population level response and I compared the availability and use of microhabitat characteristics such as depth, velocity, substrate, and cover before and after the addition of large woody debris.

## Methods

Stocking

Preliminary observations of North Fork Stony Creek, Giles County, VA indicated low numbers of brook trout throughout the stream. Reasons for low numbers were unknown, although it was suspected that water quality could be a limiting factor for this high elevation stream. High elevation streams in the southern Appalachians are often acid-sensitive; water quality measurements from a representative sample of native brook trout streams in Virginia indicated that 93% of the streams were acid-sensitive (Webb et al. 1989). Recent data (1995-present) on pH collected from a HydroLab indicate that pH falls as low as 3.5 at times in Stony Creek (personal communication, Holly Jennings, Forest Service Coldwater Research Fisheries Unit, Blacksburg, VA). Known densities of fish ($\approx$1fish/m$^2$) were stocked into Stony to observe changes in population characteristics in relation to LWD additions. Two months before manipulations, 559 brook trout fingerlings (average size = 70.3 cm, 3.9 g) were stocked into the stream. Brook trout were stocked into each habitat unit and marked (explanation of procedure below) according to the unit it was released in. It was assumed that fingerlings would adust to their new surroundings and establish themselves among the natural population or would move within the six week interval before the first sampling period.

Quantification of Fish Population Parameters and Fish Movement

Fish were collected from two streams in western Virginia, North Fork Stony Creek and North Prong Barbours Creek, to examine population characteristics of brook trout and blacknose dace. Fish were collected using a backpack electroshocker in June 1993, before LWD was added, and in October 1993 and June 1994, following the addition of LWD. A multiple-pass removal procedure (Zippen 1958) was used for the summer sampling periods, while a mark-recapture technique (Ricker 1975) was used in the fall.

All habitat units were surveyed in each section and were isolated with fine-meshed (5 mm) block seines when using multiple pass removal techniques.

Fish from each pass were retained in separate buckets and later anesthetized in dilute tricaine methane sulfonate (MS-222). Each fish was identified by species, measured to the nearest 1.0 mm total length (TL), and weighed to the nearest 0.1 g with an electronic balance. All fish over 50.0 mm were marked. Adult brook trout (>150 mm) received an individually numbered visual implant tag (VI tag) inserted into adipose tissue located behind the eye. Brook trout less than 150 mm and adult blacknose dace were marked with freeze brands (Bryant and Walkotten 1980). Each fish was marked with a distinguishing brand that corresponded to the habitat unit where they were captured. As fish recovered, they were returned to the unit of capture. In surveys following the initial marking period, fish were examined carefully for brands and VI tags to monitor movement.

Brook trout and blacknose dace were divided into age classes according to length-frequency distributions. Dace were divided into young-of-the-year (YOY) and adults, while brook trout were divided into juvenile (age 0+) and adults (age 1+ and older). Population estimates and biomass were calculated for each age class using the software program MICROFISH (Van Deventer and Platts 1989) for June 1993 and June 1994 data. A modified Peterson estimate (Krebs 1989) was used to calculate fish abundance for the fall sample: $N = ((M+1)(C+1)/(R+1))-1$.

An estimate of well-being or condition was desirable for each fish. For juvenile brook trout and blacknose dace of both age classes, Fulton's condition factor (K) was calculated for each individual fish using the following equation: $K = (W/L^3) * 10^5$, where L = total length of fish in mm and W = weight of fish in grams (Anderson and Neumann 1996). Relative weight ($W_r$) was used as a measure of condition for adult brook trout greater than 130 mm (Wege and Anderson 1978). Relative weight is calculated as $W_r = W/W_s * 100$, where $W_s$ is the length-specific standard weight predicted by a weight-length regression constructed to represent the species as a whole. This allows for interpopulational comparisons by making the standard weight value species-specific rather than population-specific or state-specific (Murphy et al. 1991).

Analyses of Fish Population Parameters

A Kruskal-Wallis One Way Analysis of Variance on Ranks (Zar 1984) was used to detect variability in median densities ($n/100m^2$), biomass ($g/100m^2$), total length and condition indices for age 0+ and 1+ brook trout and blacknose dace among the three surveyed sections. If significant differences were found, Dunn's Multiple Comparison Procedure was used to make all pairwise comparisons.

Additionally, Mann-Whitney Rank Sum Tests (Zar 1984) were used to compare density and biomass between sampling periods (June-October 1993 and June 1993-June 1994) for brook trout and blacknose dace.

Quantification of Microhabitat Availability and Use

Available habitat was described by water column depth, water column velocity, and substrate composition. Data were collected before LWD addition (June 1993) and one year after (May 1994). Data were collected every 50 cm along twenty cross-sectional transects in the treatment and reference sections of Barbours Creek. In Stony Creek, sixteen cross-sectional transects were used in both placement sections, while ten transects were used in the reference section. Each transect was chosen randomly according to distance from the downstream end of a section and the first reading along a transect was randomly selected within 30 cm of the bank.

Water column velocity was measured to the nearest 0.01 m/s at 0.6 of the water depth using a Marsh McBirney current meter. Dominant and subdominant substrate was visually characterized within 25 cm of the point on the transect using a modified Wentworth scale (Table 1.1.).

Data on habitat use were collected on the same day that habitat availability data were collected within a section. Microhabitat observations were made on clear days from 0900 to 1400 hours. A snorkeler would begin at the downstream end of a reach and move slowly upstream. If a fish remained undisturbed, its location was marked with a painted nut with flagging attached. Markers for aggregations of dace were placed in the center of the group. A recorder followed to sketch and number fish positions on a map of the stream reach. Species and age groups (0+ or >1) were noted. Identification of an age group was based on relative size differences and parr marks on brook trout. Approximate distance from stream bottom (% of water column) also was noted for each fish.

For each fish observed, the following microhabitat measurements were recorded: (1) water column depth, (2) focal point elevation, the distance between the snout of the fish and the bottom, (3) water column velocity, measured at 0.6 depth, (4) focal point velocity, velocity at snout of fish, and (5) substrate type, characterized within 25 cm of the marker. Focal point elevations and velocities were not recorded for blacknose dace because they do not hold position within the water column as do brook trout. Water column depth and velocity for dace found in groups were recorded by taking a mean of measurements at the anterior, posterior and the center of the group.

Distances to cover, LWD, nearest conspecific and nearest fish were also assessed for brook trout. Cover was defined as 'broken' water surface or bubbles, LWD (logs, rootwads, branches), boulders, or undercut banks. If no cover, LWD, or fish was visible within a reasonable distance determined by the author at the time of sampling, a value was not recorded.

Quantification of Microhabitat Availability and Use

Data typically did not follow a normal distribution, so nonparametric tests were used. Kruskall-Wallis tests were used to compare water column depth and water column velocity for habitat availability and use among the random placement, systematic placement and reference sections in 1993 and 1994 (Zar 1984). If significant differences were found among sections, a Multiple Comparison Procedure (Dunn's method) was used to determine which sections varied significantly (Zar 1984). These comparisons also were made for focal point velocity and depth, distance to cover, LWD, fish and nearest conspecific for habitat use. If no value was recorded for association to cover, LWD, or fish, a dummy variable was substituted for each individual fish (i.e., 3 m for cover and LWD, 4 m for fish or conspecific). Kolmogorov-Smirnov tests for discrete data were used to compare distributions of dominant and subdominant substratum between sections (Sokal and Rohlf 1995).

Mann-Whitney tests were used to compare medians before and after LWD was added for availability and use for all continuous variables. Mann-Whitney tests were also used to compare use and availability for water column depth and water column velocity (Zar 1984). For these comparisons of dominant and subdominant substrate, Kolmogorov-Smirnov tests for discrete data were used (Sokal and Rohlf 1995). Cumulative frequencies were calculated and the maximum difference ($D_{max}$) between samples compared to a calculated $D_{.01}$ and $D_{.05}$ to find significance according to the equation:

$$D_{\infty} = K_{\infty}((n_1+n_2)/n_1n_2),\ K_{.05} = 1.35810 \text{ and } K_{.01} = 1.62762.$$

## Results

***Characteristics of Fish Populations***

<u>North Prong Barbours Creek</u>

*Brook Trout Abundance*

Patterns of density and biomass of juvenile brook trout were similar among the three experimental reaches of Barbours Creek (Figure 2.1.). Juvenile brook trout density did not change from summer to fall, 1993, but densities and biomass increased dramatically by June 1994 (P<0.001; Figure 2.1.).

In June 1993, adult brook trout densities were significantly higher in the reference section as compared to the systematic placement section ($P<0.05$; Figure 2.2.). Densities did not vary significantly among sampled reaches in October 1993 or June 1994. Biomass of adult brook trout was similar for all sections of Barbours before and after LWD was added (Figure 2.2.). Densities and biomass of adult brook trout did not change significantly after LWD was added.

*Blacknose Dace Abundance*

Density and biomass for young-of-the-year and adult blacknose dace were examined in June 1993 and 1994. Sampling of blacknose dace in the fall was not adequate to calculate population estimates.

There were no significant differences in densities or biomass of young-of-the-year blacknose dace among treatment sections in either collection period (Figure 2.3.). Densities of YOY dace increased significantly in the random placement section one year after LWD was added ($P<0.001$), but not for the other sections (Figure 2.3.). Biomass of YOY blacknose dace increased significantly in the random placement and reference sections in 1994 ($P=0.003$ and $P=0.012$, respectively; Figure 2.3.). Densities and biomass of adult blacknose dace were similar among sections in 1993 and 1994 and did not change significantly for any section after LWD additions (Figure 2.4.).

*Brook Trout Mean Length*

No significant differences were found in total length of juvenile brook trout among surveyed reaches in 1993. In 1994, total lengths of juvenile brook trout were significantly different among the three reaches ($P<0.05$); juveniles in the random placement section were shortest and those in the reference section were longest (Figure 2.5.). Length of juvenile brook trout decreased significantly in each section after LWD was added ($P<0.001$; Figure 2.5.).

Total lengths of adult brook trout were significantly greater in the systematic placement section than in the random placement and reference sections in June 1993 ($P<0.05$), but lengths were similar among sections in 1994 (Figure 2.5.). No significant changes in median TL of adults were apparent one year after LWD was added for any section of Barbours Creek (Figure 2.5.).

*Blacknose Dace Mean Length*

Total lengths of young-of-the-year blacknose dace were greater in the systematic placement section than the random placement or reference sections in 1993 ($P<0.05$), but were similar among sampled reaches in 1994 (Figure 2.6.). Total lengths of YOY decreased significantly in the systematic section after LWD was added ($P<0.001$; Figure 2.6.). Total lengths of adult blacknose dace were similar among sections in 1993, but in 1994 adult dace in the reference section were longer than in the systematic placement section ($P<0.05$; Figure 2.6.). Median length of adults was significantly shorter in the systematic placement after LWD was added ($P=0.008$; Figure 2.6.).

*Brook Trout Condition*

Condition factors (K) of juvenile brook trout were similar among experimental reaches of Barbours in 1993, but all were significantly different in 1994 (Figure 2.7.). During this sampling period, juveniles in the random section possessed the lowest values of condition and those in the reference section had the highest ($P<0.05$). Condition of juveniles increased significantly in both the systematic and reference sections ($P<0.001$) one year after manipulations (Figure 2.7.).

Relative weight ($W_r$) was used as a measure of condition for adult brook trout over 130 mm. Relative weights of adult brook trout were similar among sampled reaches in 1993, but in 1994, relative weights were significantly lower in the reference section than in the systematic section ($P<0.05$; Figure 2.7.). Relative weights increased significantly for adult brook trout in the two treatment sections after the addition of LWD ($P<0.05$; Figure 2.7.).

*Blacknose Dace Condition*

Condition factors for juvenile blacknose dace were similar among the three reaches in 1993, but in 1994 the random placement section had lower condition factors as compared to the other two sections (Figure 2.8.; $P<0.05$). Condition factors of juveniles increased significantly in both the systematic ($P=0.002$) and reference sections ($P<0.001$) one year after LWD was added (Figure 2.8.). No differences were apparent in condition of adult blacknose dace among sections before LWD was added. In 1994, condition factors were significantly lower in the random section than in the reference section ($P<0.05$; Figure 2.8.). Significant increases in condition were found for adult blacknose dace in all sections in 1994 ($P<0.05$; Figure 2.8.).

*Movement of Brook Trout*

Brook trout and blacknose dace were marked before LWD was added to Barbours Creek to monitor movement over time. Brook trout and blacknose dace were examined for brands in October 1993, 111 days after being marked. Of 114 adult blacknose dace branded in June, only two marked fish were recovered in the fall (1.7%). The recovery of marked fish was much higher for brook trout; of 145 brook trout freeze branded in the summer of 1993, 50 were recaptured (34%) during the fall sampling period (Table 2.1.). In addition, 83 brook trout over 150 mm received visible implant (VI) tags in June, but recovery of VI tags was unsuccessful in the fall. Each brook trout tagged in the summer received an adipose fin clip to indicate that it had been marked in case of tag loss; only two tags were recovered, but fin clips were noted in an additional 33 fish for a tag retention rate of <6% (Table 2.1.).

The brook trout recaptured in the fall sample provided information on movement for 25 juveniles and 27 adults. Most of the recaptured juvenile brook trout remained in the habitat units where they were marked (56%) or moved upstream of their original locations (44%; Table 2.2.). Recaptured adults were found in the same unit as marked (42%), upstream (50%), and downstream (8%) from their original location (Table 2.2.). All juvenile and adult brook trout were found within the where section they had been captured and marked. Mean distance moved for adult and juvenile fish combined was 10.7 m, and one tagged individual moved as far as 82.2 m upstream (Figure 2.9.).

During the fall sample, captured fish were marked according to the habitat unit in which they were captured and those with a mark from the previous sampling period received an additional brand (Table 2.1.). Also, since high tag loss was noted early on, fish over 150 mm received both freeze brands and VI tags. Fish were next examined for marks in the June 1994 sampling period. It was not possible to discern whether a fish had been marked in the fall or the summer of 1993 unless a fish possessed two brands, so distances moved were considered from the initial marking period. At this time, 55 brook trout were captured with distinguishable brands and one adult had a VI tag (Table 2.1.). Thirty adult trout were captured that had an adipose fin clip but no VI tag, but percentage of tag loss could not be determined without knowing when the fish had been tagged (June or October 1993). Fish tended be found in the same unit captured (44%) or upstream (36%), while 20% moved downstream (Table 2.2.). Average distance moved was 32.8 m, with those recovered in the reference section moving an average of 61.8 m. Three individuals had moved >150 m upstream from the systematic placement section into the reference (Figure 2.9.). Of four individuals found with two brands (recaptured in the fall also), two remained in the same unit and two moved <20 m or one habitat unit.

North Fork Stony Creek

As noted in the methods section, fish numbers were low in North Fork Stony Creek, so hatchery brook trout fingerlings were stocked into study sections in April of 1993. An average density of 0.75 fish/ $m^2$ was stocked into each habitat unit for a total of 559 fish. Sampling six weeks later revealed low numbers of hatchery trout remaining within the study sections; 34 hatchery trout total were recaptured in Stony Creek at this time.

*Brook Trout Abundance*

Abundance of juvenile and adult brook trout in Stony Creek before and after manipulations was not analyzed statistically because of low sample sizes. Total densities of juvenile brook trout increased in the random placement section by 88% after LWD was added, but decreased in the systematic placement (87%) and reference (7%) sections (Figure 2.10.). Although juvenile densities increased after LWD was added in the random placement section, biomass of juvenile brook trout decreased (Figure 2.10.). This was probably a result of 5 of the 7 fish captured in this section in 1993 being hatchery trout. Biomass for juveniles decreased for the systematic placement and reference sections in 1994 (Figure 2.10.). Densities and biomass of adult trout increased dramatically in every section of Stony Creek after manipulations took place, with the greatest increase taking place in the systematic section (Figure 2.10.). Unfortunately, it was not possible to distinguish which, if any, of the fish captured in 1994 were hatchery trout.

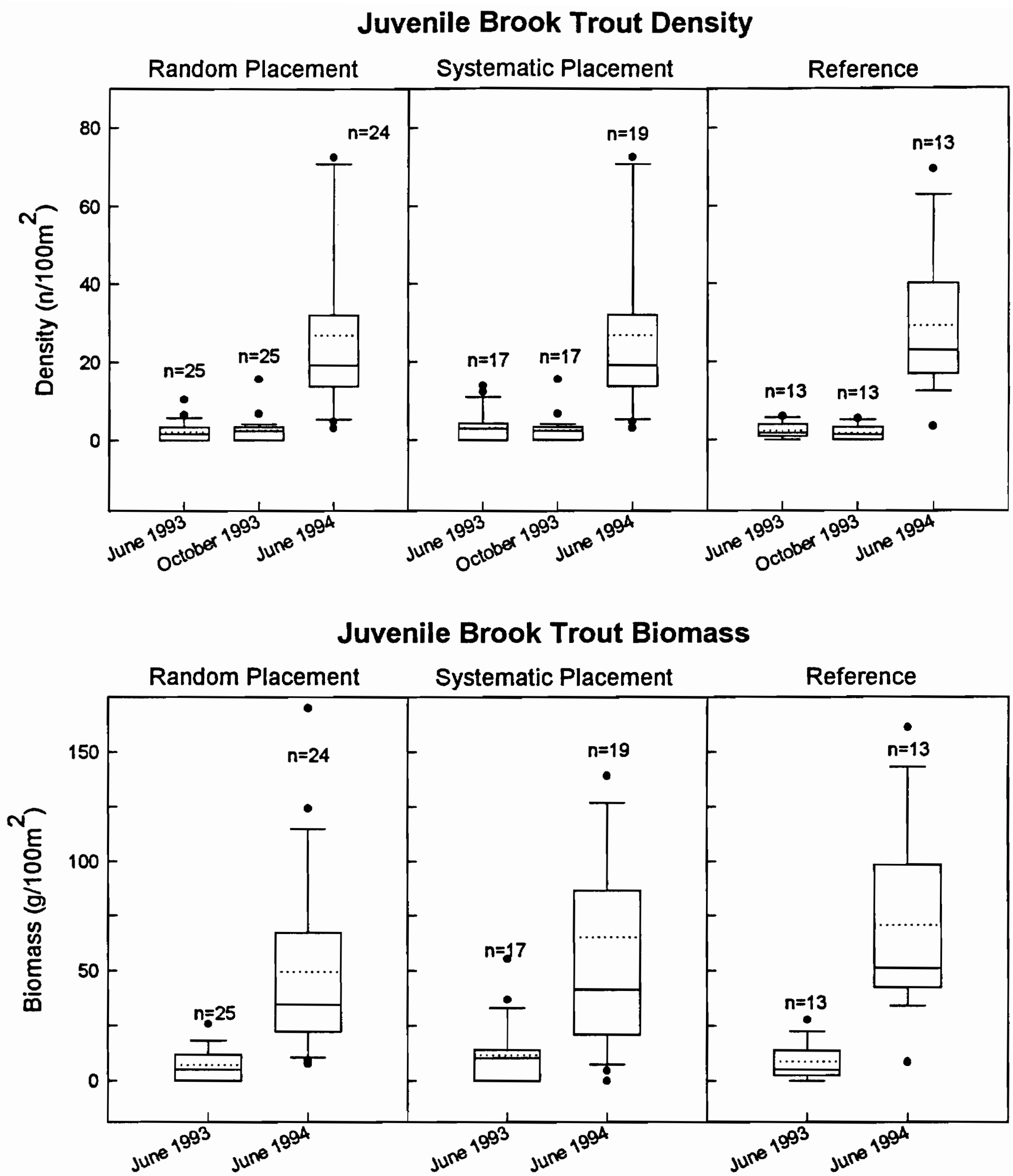



**Figure 2.1.** Boxplots showing the median, quartile distribution, and 10th and 90th percentile distribution (error bars) of densities and biomass of juvenile brook trout in habitat units of three sampled reaches of Barbours Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols. N=number of habitat units.

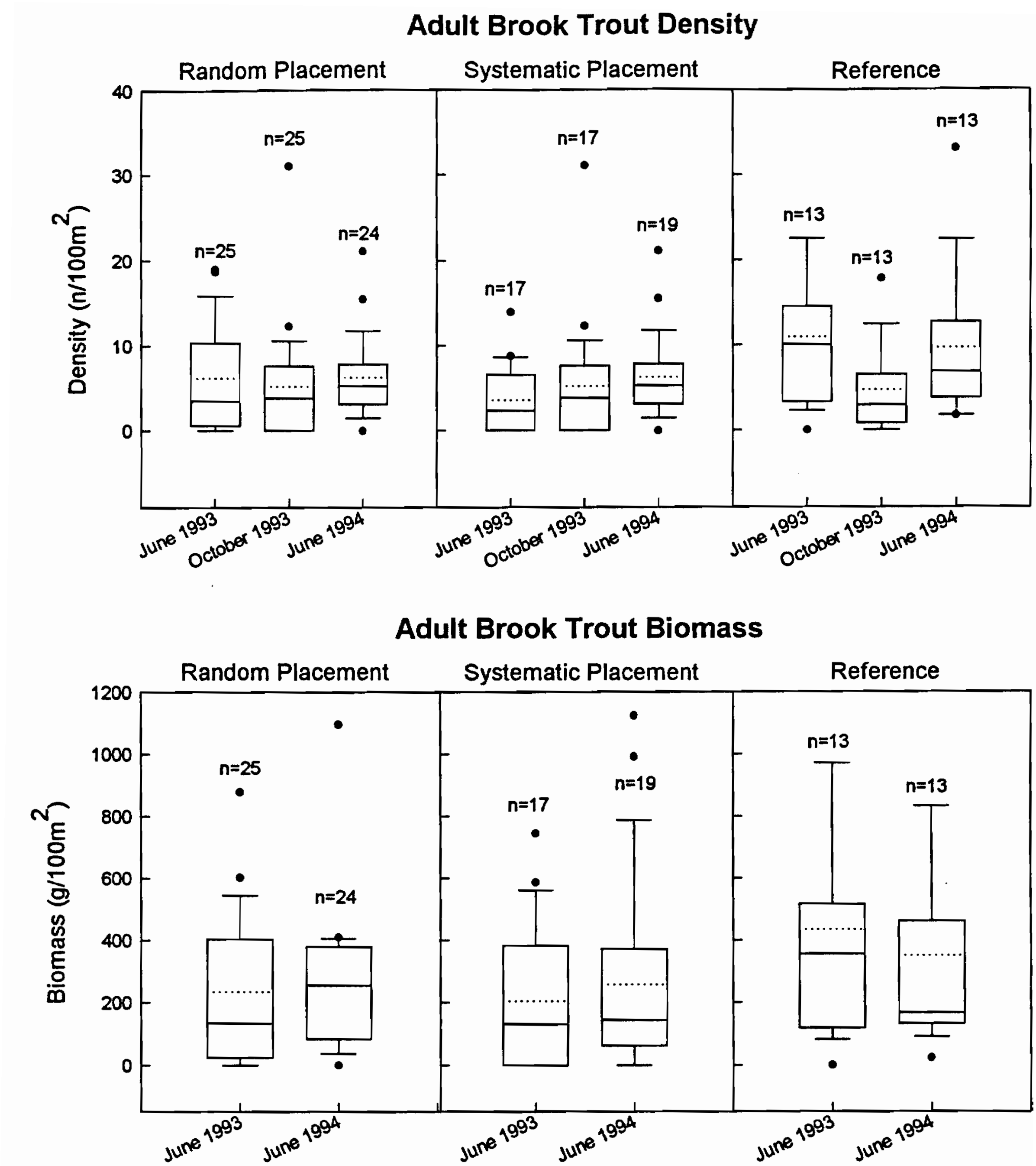



**Figure 2.2.** Boxplots showing the median, quartile distribution, and 10th and 90th percentile distribution (error bars) of densities and biomass of adult brook trout in habitat units of three sampled reaches of Barbours Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols. N=number of habitat units.

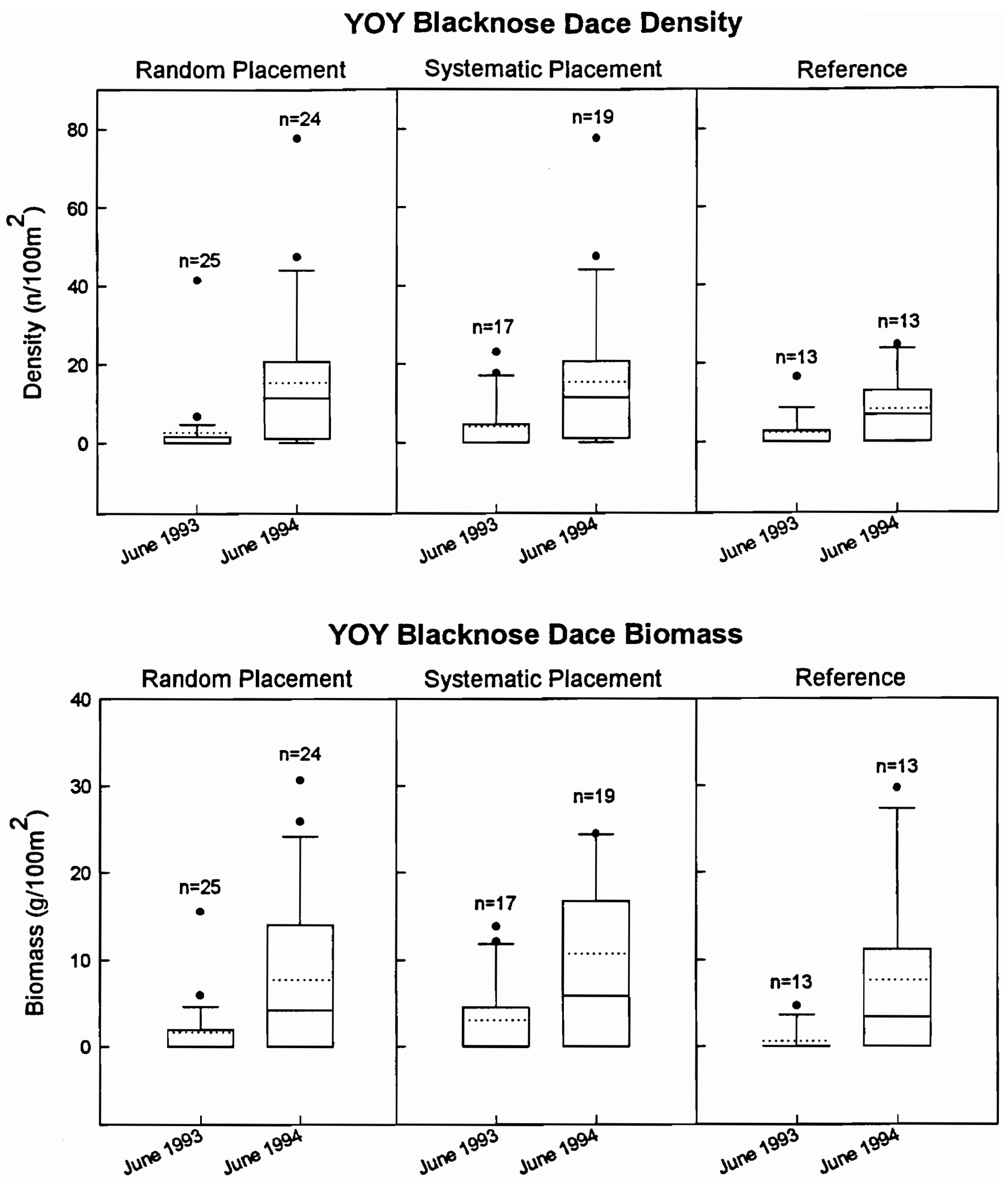



**Figure 2.3.** Boxplots showing the median, quartile distribution, and 10th and 90th percentile distribution (error bars) of densities and biomass of young-of-the-year blacknose dace in habitat units of three sampled reaches of Barbours Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols. N=number of habitat units.

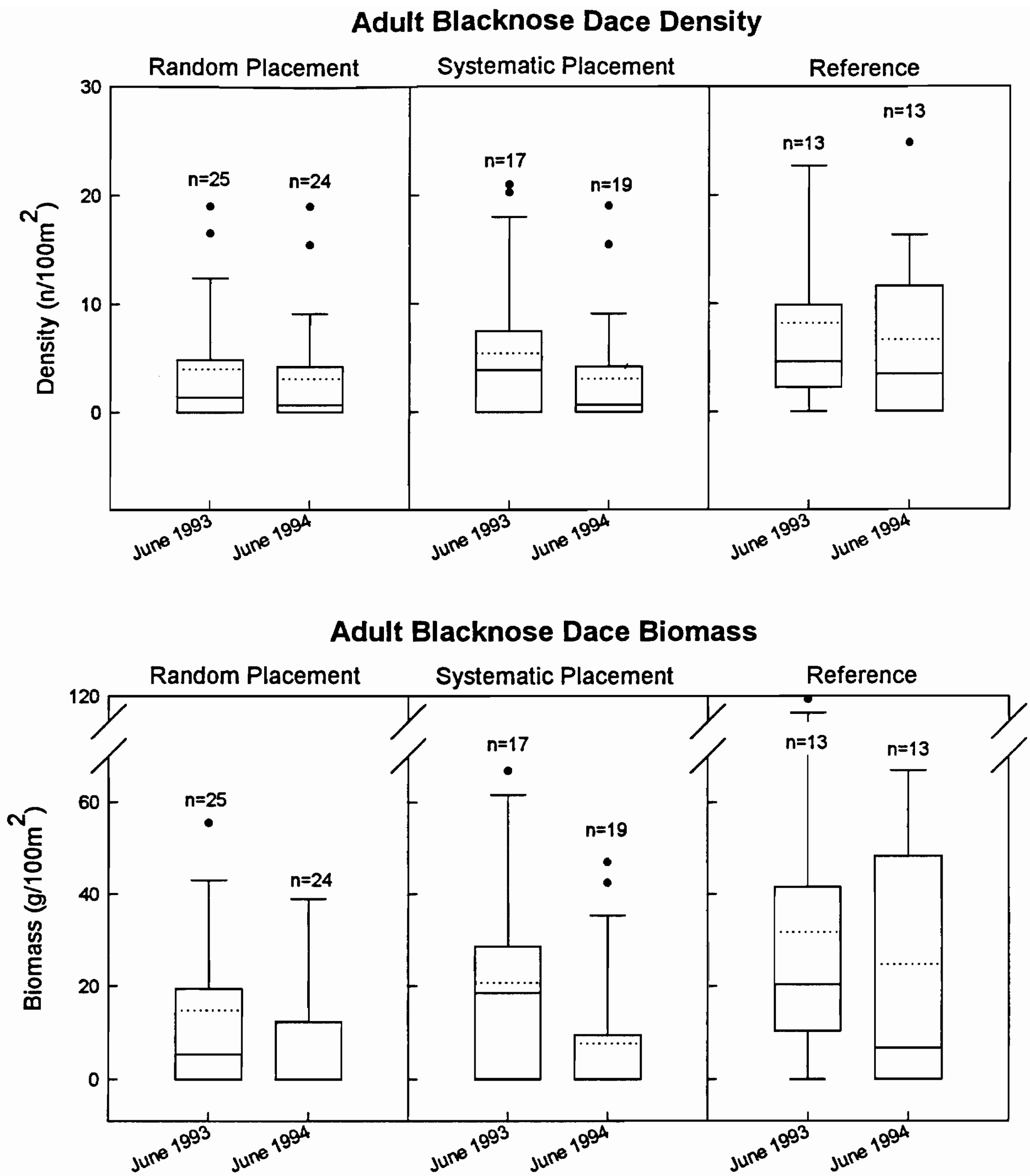
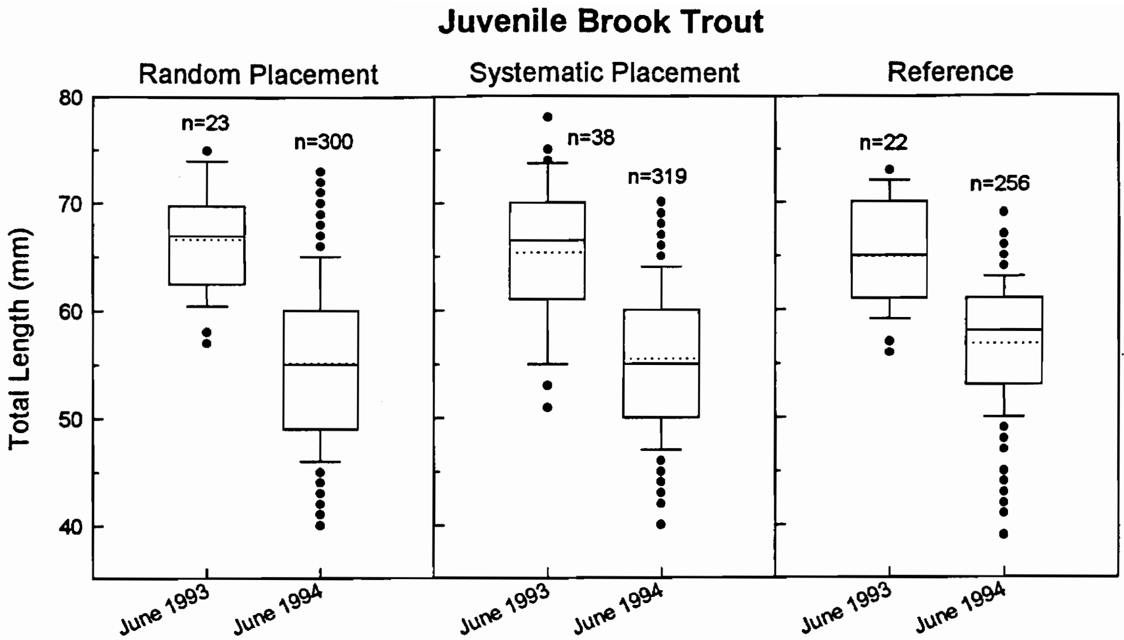



**Figure 2.4.** Boxplots showing the median, quartile distribution, and 10$^{th}$ and 90$^{th}$ percentile distribution (error bars) of densities and biomass of adult blacknose dace in habitat units of three sampled reaches of Barbours Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols. N=number of habitat units.



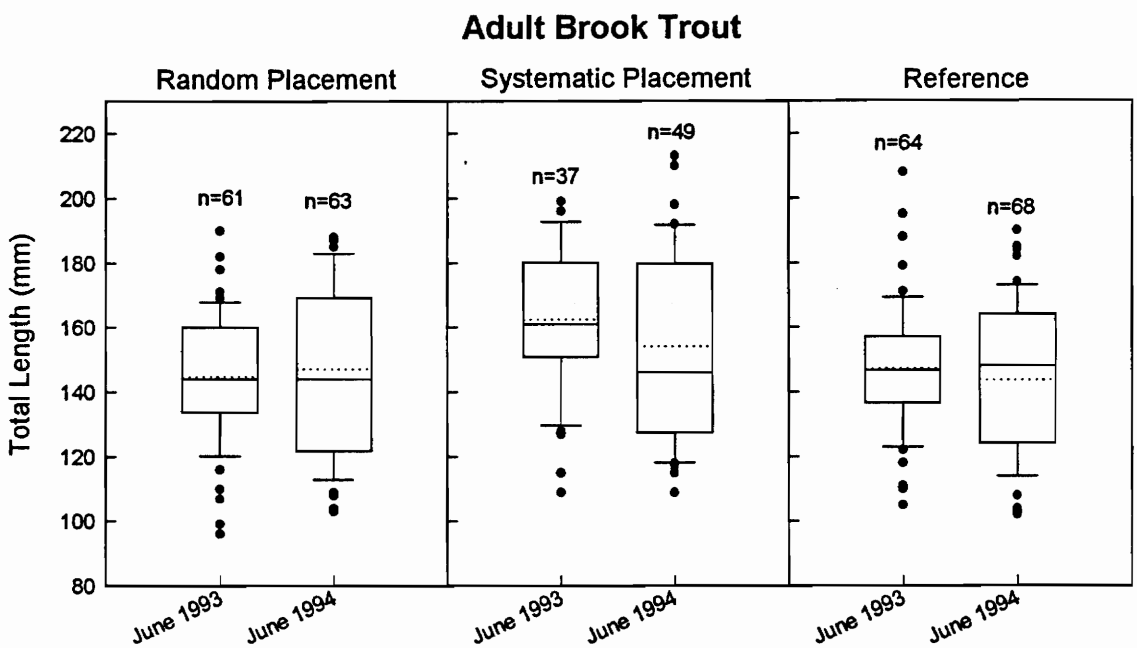




**Figure 2.5.** Boxplots showing the median, quartile distribution, and 10th and 90th percentile distribution (error bars) of total lengths of adult and juvenile brook trout in three sampled reaches of Barbours Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols. N=number of fish.

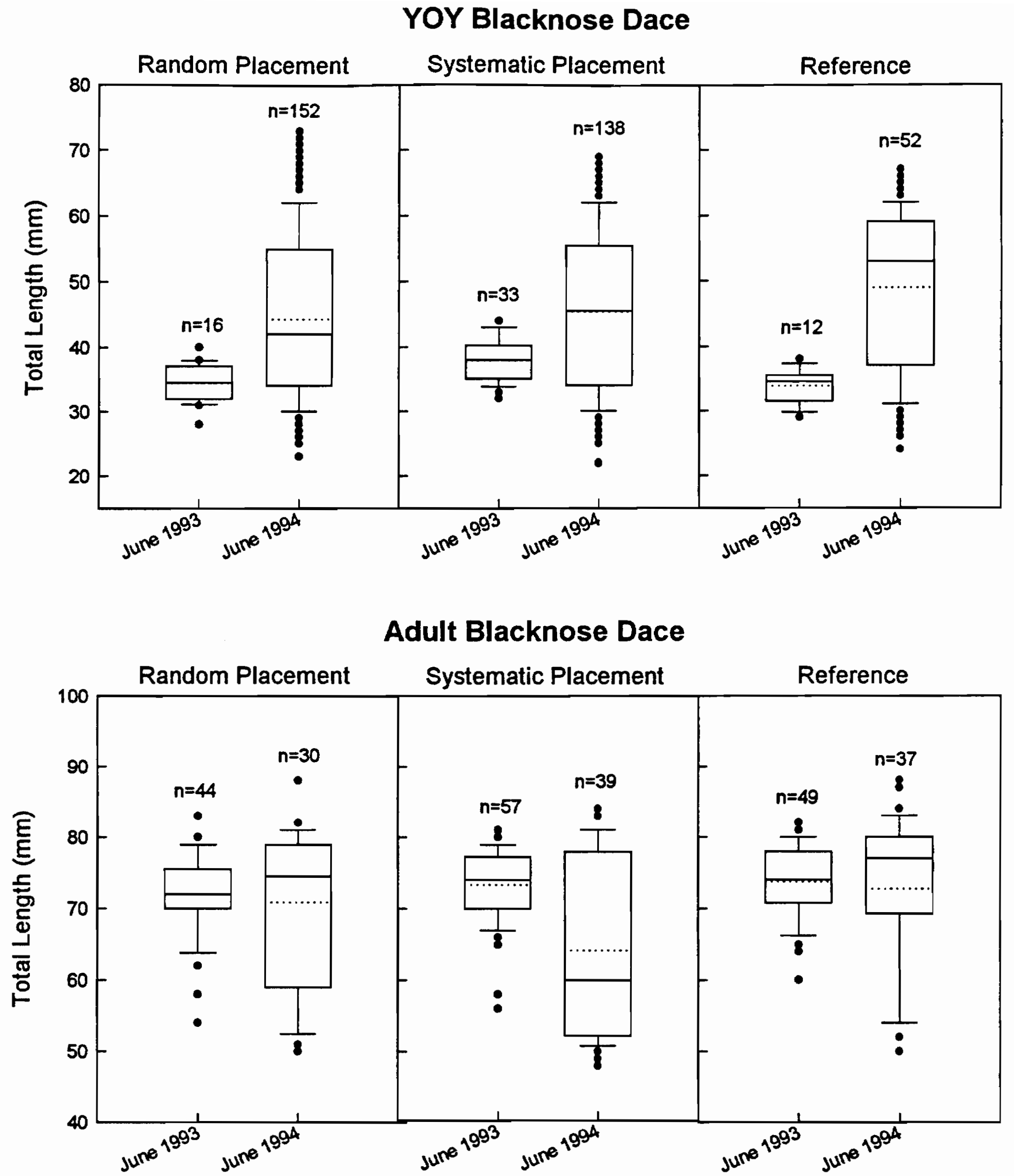



**Figure 2.6.** Boxplots showing the median, quartile distribution, and 10th and 90th percentile distribution (error bars) of total lengths of adult and juvenile blacknose dace in three sampled reaches of Barbours Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols. N=number of fish.

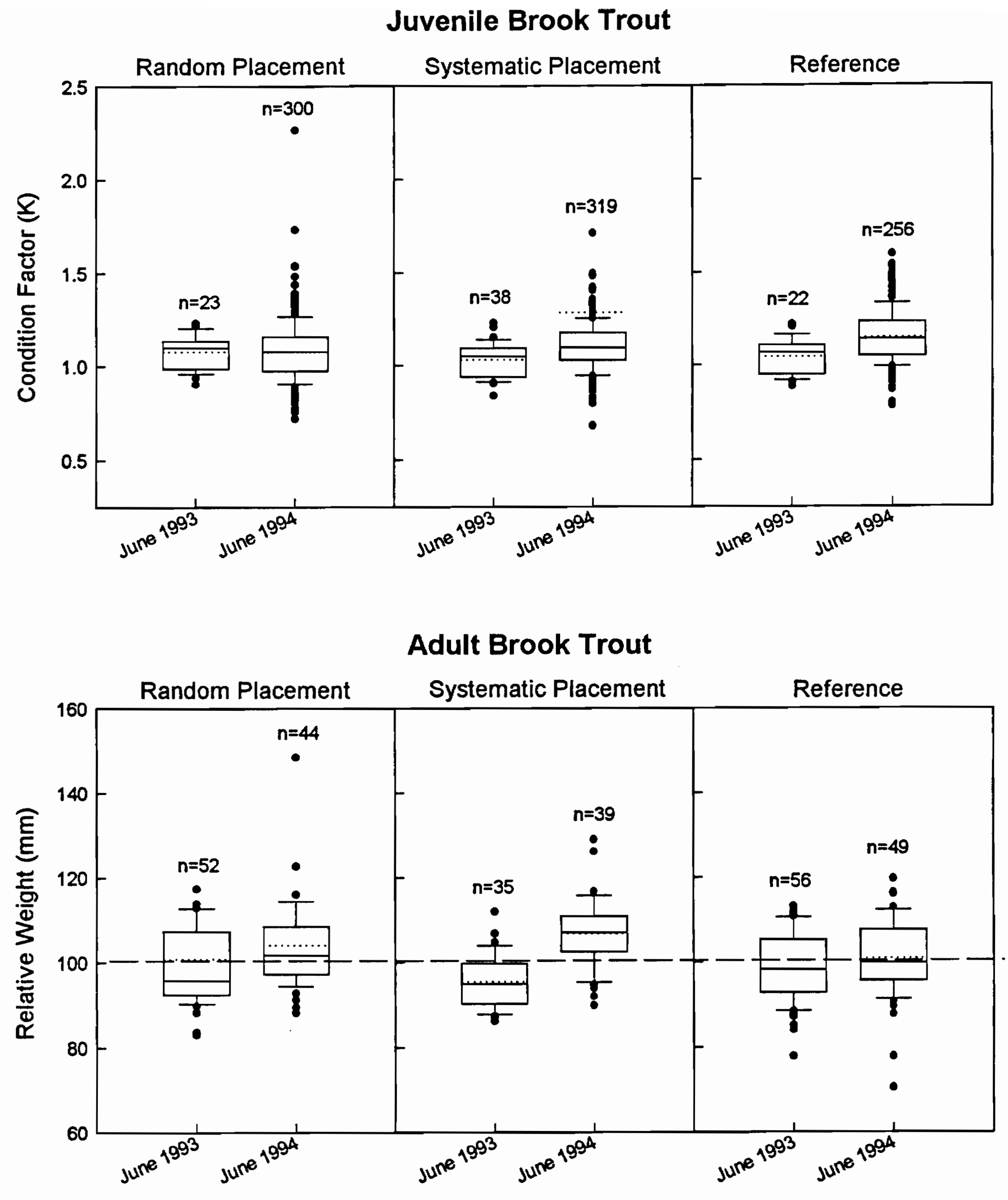



**Figure 2.7.** Boxplots showing the median, quartile distribution, and 10th and 90th percentile distribution (error bars) of condition factors for juvenile brook trout and relative weights of adult brook trout in three sampled reaches of Barbours Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols. N=number of fish.

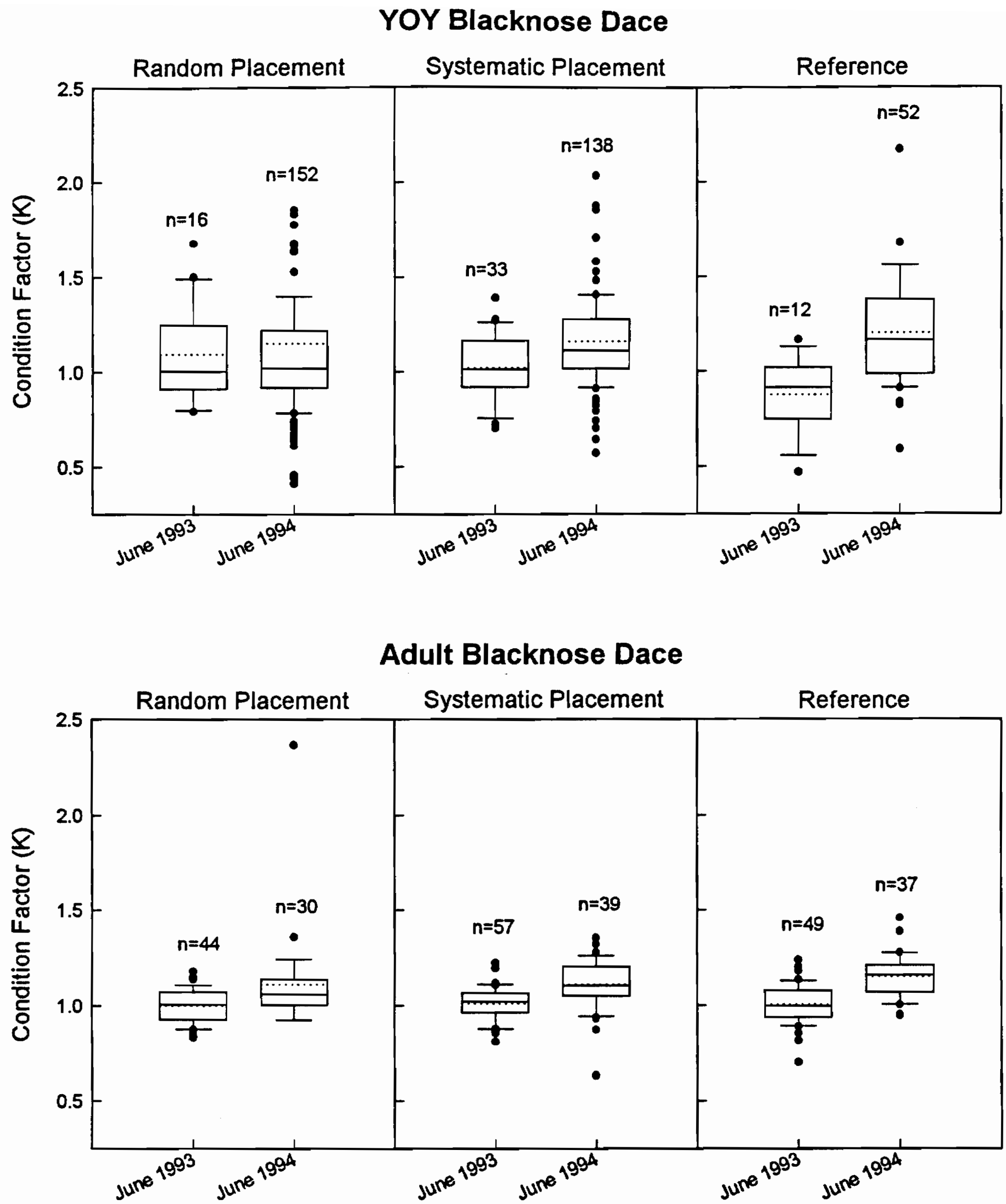



**Figure 2.8.** Boxplots showing the median, quartile distribution, and 10th and 90th percentile distribution (error bars) of condition factors for young-of-the year and adult blacknose dace in three sampled reaches of Barbours Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols. N=number of fish.

**Table 2.1** Numbers of juvenile (J) and adult (A) brook trout marked during the summer and fall of 1993 and recovered in the fall of 1993 or summer of 1994 from North Prong Barbours Creek. Those marked with two brands in the fall were recaptures having marks from the summer of 1993.

| Summer 1993 | | Fall 1993 | | | | | | Summer 1994 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number Marked | | Number Recovered | | | Number Marked | | | Number Recovered | | | |
| Brand | Tag | Brand | Tag | Tag Loss | Brand | 2 Brands | Tag | Brand | 2 Brands | Tag | Tag Loss |
| 74J 71A | 83 | 25J 25A | 2 | 33 | 146* | 54* | 73* | 50 | 4 | 1 | 30 |

* Note: 57 fish were both tagged and branded during the fall period and are included in both counts. Fifty received one brand and a tag and 7 received two brands and a tag.

**Table 2.2.** Number of brook trout in Barbours Creek recaptured in the same unit, upstream, or downstream from the original location marked. Fish marked in the summer and fall of 1993 were examined in periods following, the fall of 1993 and summer of 1994.

| | Fall 1993 Juvenile Movement | | | Fall 1993 Adult Movement | | | Summer 1994 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Same Unit | Up Stream | Down Stream | Same Unit | Up Stream | Down Stream | Same Unit | Up Stream | Down Stream |
| Treatment | 18 | 15 | 0 | 8 | 11 | 2 | 15 | 14 | 4 |
| Reference | 20 | 15 | 0 | 12 | 13 | 2 | 9 | 6 | 7 |
| Total | 38 | 30 | 0 | 20 | 24 | 4 | 24 | 20 | 11 |

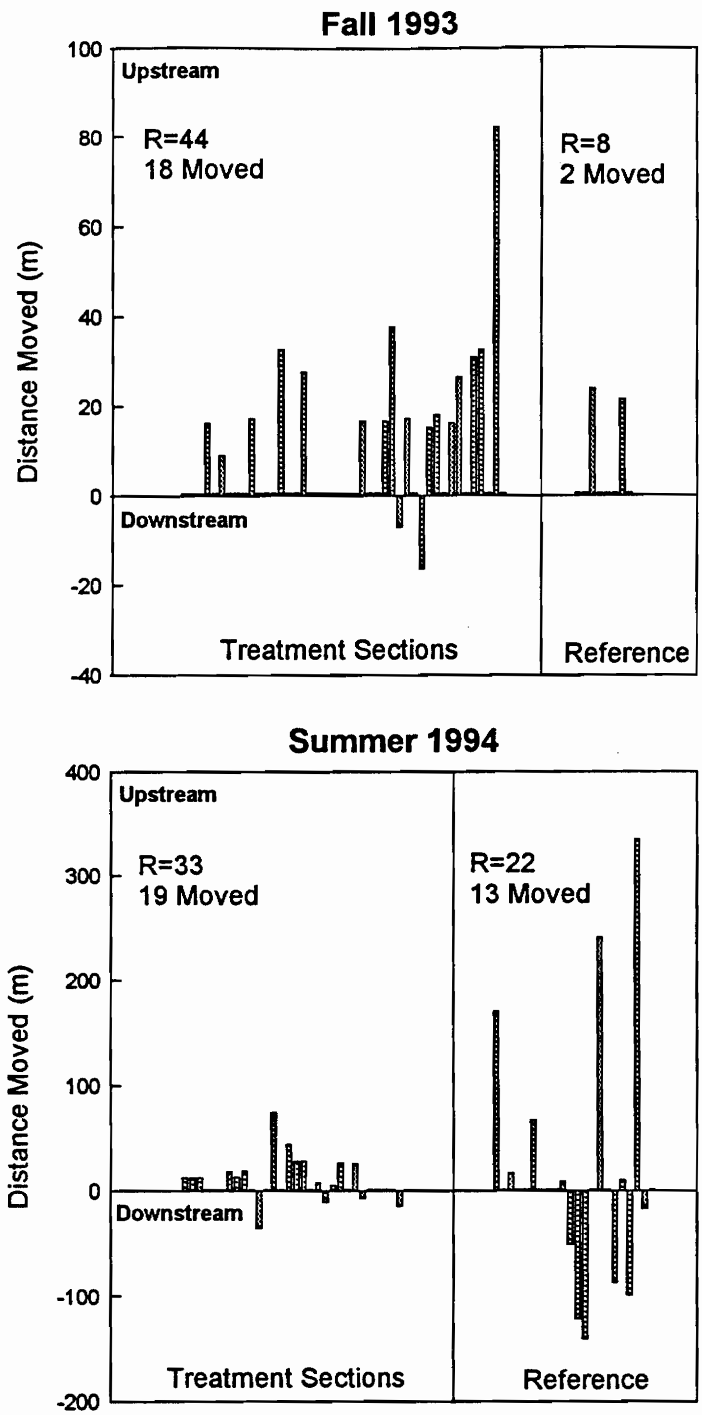



**Figure 2.9.** Distances moved by marked brook trout over two time intervals (Summer 1993-Fall 1993 and Summer 1993-Summer 1994) in North Prong Barbours Creek after the addition of LWD. R=number of recaptures.

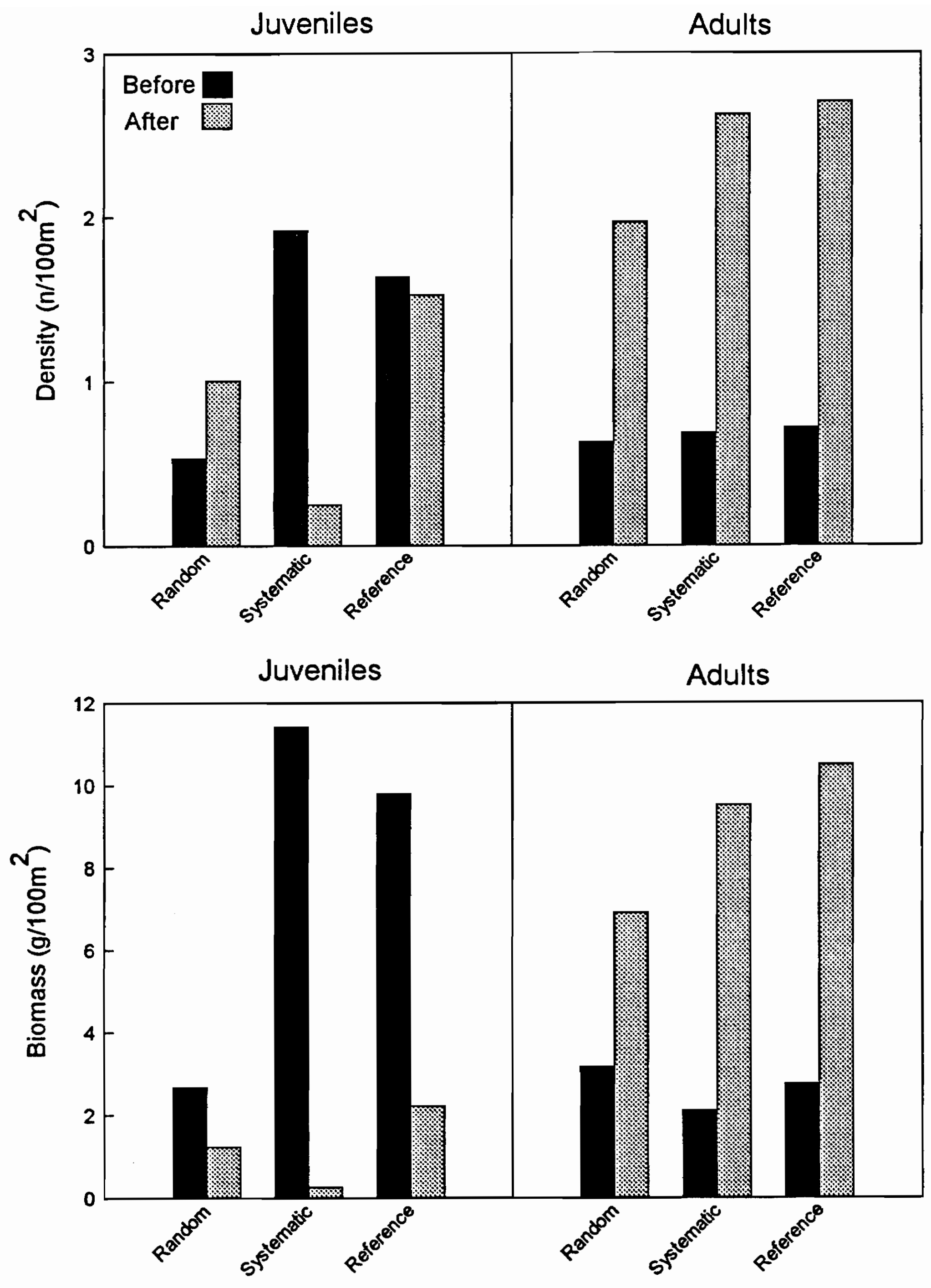



**Figure 2.10.** Total densities and biomass of juvenile and adult brook trout in three sampled reaches of North Fork Stony Creek before and after LWD additions.

### *Microhabitat Availability and Use*

North Prong Barbours Creek

*Availability of Water Column Depth*

Water column depth in the reference section was shallower than the random placement section in 1993 and shallower than the random and systematic placement sections in 1994 (Table 2.3.; Figure 2.11.). Median water column depths increased significantly in the two manipulated sections, but did not change in the reference (Figure 2.11. and Table 2.4.).

*Brook Trout Use of Water Column Depth*

Water column depths used by juvenile and adult brook trout were significantly greater than those available for every section of Barbours Creek (Figure 2.11. and Table 2.5.). Examining juvenile brook trout use of water column depths among reaches revealed similar trends to available habitat; depths selected in the reference section were significantly less than for the random placement section during both sampling periods (Figure 2.11. and Table 2.3.). Although available depths increased in the manipulated sections of Barbours Creek, use of depth by juvenile brook trout was similar after LWD was added for all sections (Figure 2.11. and Table 2.4.).

Adult brook trout used similar water column depths among sections in 1993, but greater depths were used in the random section than the other two reaches after LWD was added (Table 2.3. and Figure 2.11.). In fact, median water column depths used by adult brook trout increased significantly after LWD was added in the random placement section (Figure 2.11. and Table 2.4.).

*Blacknose Dace Use of Water Column Depth*

With the exception of adults in the random placement section in 1994, blacknose dace used significantly greater depths than were available (Figure 2.11.; Table 2.5.). Young-of-the-year (YOY) blacknose dace selected shallower depths in the reference section than in the random and systematic placement sections in 1993, but use was similar among sections in 1994 (Table 2.3. and Figure 2.11.). YOY blacknose dace were observed in greater depths in the reference section after LWD was added (Figure 2.11.; Table 2.4.).

Adult blacknose dace were also observed using significantly shallower water column depths in the reference section in 1993, although depths used in 1994 were similar among sections (Table 2.3. and Figure 2.11.). Water column depths selected by adult blacknose dace did not change after manipulations in Barbours Creek (Figure 2.11.; Table 2.4.).

*Focal Point Depths of Brook Trout*

Focal point depths selected by juvenile brook trout were significantly lower for the reference section as compared to the systematic placement section in 1993, but were similar among sections in 1994 (Table 2.3. and Figure 2.12.). Even though available depths increased in the random and systematic placement sections after LWD was added, juvenile brook trout selected significantly shallower focal point depths in these reaches in 1994 (Table 2.4. and Figure 2.12.).

Focal point elevations of adult brook trout among treatment sections were significantly lower in the reference section before and after LWD was added to Barbours Creek (Table 2.3. and Figure 2.12.). Adult brook trout were observed using significantly shallower focal point depths in the systematic placement section after manipulations (Table 2.4.; Figure 2.12.).

*Availability of Water Column Velocity*

Water column velocities were significantly different among sections of North Prong Barbours before and after the addition of LWD (Table 2.3.). Velocities observed in the reference section tended to be faster than in the placement sections; they were significantly higher than those in the systematic in 1993 and than in both of the placement sections in

1994 (Figure 2.13.). Considerable increases in velocity were observed throughout Barbours in 1994 (Table 2.4.; Figure 2.13.).

*Brook Trout Use of Water Column Velocity*

In 1993, juvenile brook trout selected greater velocities than were available in the random and systematic placement sections and adults used greater velocities than available in the random section, while velocities used and available were similar in 1994 for both age classes (Table 2.5. and Figure 2.13.). Velocities used by juvenile brook trout were similar among sections in 1993, but velocities used in the random placement section were significantly lower than in the systematic placement or reference section in 1994 (Table 2.3.; Figure 2.13.). Changes in water column velocities used by juveniles after LWD was added were not significant (Table 2.4.; Figure 2.13.).

Water column velocities selected by adult brook trout were similar among sections in both 1993 and 1994 (Table 2.3.; Figure 2.13.). Adult habitat use for water column velocity increased significantly in the systematic placement and reference sections after manipulations took place (Table 2.4.; Figure 2.13.).

*Blacknose Dace Use of Water Column Velocity*

Young-of-the-year blacknose dace used significantly lower velocities than were available in every section of Barbours Creek in 1994 (Table 2.5.; Figure 2.13.). Water column velocities used by YOY dace were similar among sampled reaches before and after LWD additions (Table 2.3.; Figure 2.13.). There were no significant changes in water column velocities used by juvenile blacknose dace after manipulations (Table 2.4.; Figure 2.13.).

Adult blacknose dace used water column velocities similar to what was available in both sampling periods (Table 2.5.; Figure 2.13.). Water column velocities used by adult blacknose dace were greater in the reference section than the two placement sections in

1993, but were similar among sections in 1994 (Table 2.3.; Figure 2.13.). Changes in water column velocities used by adult blacknose dace were not significant after LWD was added (Table 2.4.; Figure 2.13.).

*Focal Point Velocities of Brook Trout*

No significant differences were found for focal point velocities used by adult or juvenile brook trout among sections of Barbours Creek in 1993 or 1994 (Table 2.3.; Figure 2.14.). After LWD was added, the only significant change in focal point velocities used by brook trout was an increase for velocities used by adults in the systematic placement section (Table 2.4.; Figure 2.14.).

*Availability of Substrate*

Before LWD was added, the distributions of dominant substrate available in the random and systematic placement sections were significantly different from the reference (Table 2.3.). Silt was the most dominant substrate in the reference section, while the placement sections had predominantly small gravel (Figure 2.15.). After LWD was added, dominant substrates in the random placement section differed significantly from both the systematic placement and the reference sections (Table 2.3.), with boulders as the largest frequency class in the random section and large gravel in the systematic and reference sections (Figure 2.15.). Differences in dominant substrate available between years were significant for all sections of Barbours Creek (Table 2.4.), shifting toward the larger substrate classes.

The random section had a significantly greater percentage of subdominant substrates found in larger size classes than the systematic placement sections in 1993, but in 1994, there were no significant differences between any of the sampled reaches in Barbours (Table 2.3.; Figure 2.15.). Changes in subdominant substrate were not significant after LWD was added (Table 2.4.; Figure 2.15.).

*Brook Trout Use of Substrate*

Overall, juvenile brook trout predominantly used small and large gravel as dominant and subdominant substrates (Figure 2.16.). For dominant substrate, juvenile brook trout used different substrates than were available in the reference in 1993; silt was the primary available substrate (Table 2.5.; Figures 2.15. and 2.16.). Distributions of dominant and subdominant substrate for habitat use by juvenile brook trout were similar for all sections in 1993 and 1994 (Table 2.3.; Figure 2.16.). No significant differences were found in dominant substrate use by juveniles for any of the sampled reaches after LWD was added. Subdominant substrates used by juveniles in the systematic placement section changed significantly after LWD was added, primary use shifting from small gravel to large gravel (Table 2.4.; Figure 2.16.).

Adult brook trout used similar dominant substrates as available, but there were significant differences for subdominant substrate in the random placement section in 1994 (Table 2.5.; Figures 2.15. and 2.17.). The subdominant substrate most available were small gravels, while adult brook trout used cobbles. There were significant differences in dominant substrates used by adult brook trout between the random placement and the reference section in 1993, while substrate use was similar among sections in 1994 (Table 2.3.; Figure 2.17.). The most dominant substrate class used was small gravel in the random placement section, while it was organic debris in the reference (Figure 2.17.). There was a significant increase in size classes of dominant substrate used by adult brook trout in the systematic placement section and the reference in 1994 (Table 2.4.; Figure 2.17.). Subdominant substrates used by adults in the random placement section were significantly different than in the reference section in 1993, and were different than those used in both the systematic placement and reference sections in 1994 (Table 2.3.; Figure 2.17.). In both cases, the size class for the subdominant substrate was greater in the random placement section. There were no significant differences in the distributions of subdominant substrates used by adult brook trout in any section after LWD was added (Table 2.4.; Figure 2.17.).

*Blacknose Dace Use of Substrate*

In 1993, young-of-the-year blacknose dace used significantly different dominant substrates than available for all sections of Barbours (Table 2.5.; Figures 2.15. and 2.18.). In the random placement and reference sections, YOY did not use the small gravels available and YOY used a greater percentage of sand in the systematic placement section. The primary dominant substrate used by YOY in the reference section was silt in 1993, a significantly smaller size class than in the placement sections (i.e., large gravel and cobble, respectively; Figure 2.18.). Distributions of dominant substrates used were significantly different for all sections in 1994; small gravel, organic debris, and cobble representing the primary substrate of the random, systematic, and reference sections (Table 2.3.; Figure 2.18.). Dominant substrates used by YOY dace changed significantly from 1993 to 1994 (Table 2.4.); shifting toward smaller size classes in the manipulated sections and larger in the reference (Figure 2.18.).

Subdominant substrates used by YOY blacknose dace were significantly different from what was available in the random and systematic placement sections during both sampling periods (Table 2.5.; Figures 2.15. and 2.18.). It appeared that YOY did not use the smaller substrate available in 1993, while using more silt in 1994 than the small gravels that were predominantly available. In 1993, the use of silts in the random placement and large gravels in the systematic placement deemed substrate use of YOY dace significantly different among these sections (Table 2.3.; Figure 2.18.). In 1994, YOY used significantly different subdominant substrates in the systematic section; more silts and less small gravels than the other sections (Table 2.3.; Figure 2.18.). There was a significant change in the distribution on subdominant substrates from 1993 to 1994 in the systematic placement section (Table 2.4.), with subdominant substrates shifting toward smaller size classes (Figure 2.18.).

Adult blacknose dace used significantly smaller size classes of substrate (i.e, silt and organic debris) than what were available in the systematic placement section in 1994 (Table 2.5.; Figure 2.19.). Adults use of cobbles in the random placement section was significantly different than in the systematic placement or reference sections in 1993, while distributions were similar among sections in 1994 (Table 2.3.; Figure 2.19.). Size classes of dominant substrate used by adult dace decreased significantly for the systematic placement section after LWD was added (Table 2.4.; Figure 2.19.).

In 1993, adult dace were found primarily over silt in the systematic placement section, even though small gravel was the dominant and subdominant substrate available (Table 2.5.; Figures 2.15. and 2.19.). Small gravels were the most commonly used subdominant substrate in the random placement and reference sections (Figure 2.19.). There were no significant differences for distributions of subdominant substrates among sections in 1993 or 1994 (Table 2.3.; Figure 2.19.). There were no significant changes in the use of subdominant substrates by adult blacknose dace from 1993 to 1994 for any section (Table 2.4.; Figure 2.19.).

*Distance of Brook Trout to Cover and LWD*

There were no differences in distance to cover for juvenile brook trout among sampled reaches before or after LWD was added, but distance to LWD was significantly less in the systematic placement section than the random placement or reference sections in 1993 (Table 2.3. and Table 2.6). After manipulations, median distance to cover and LWD decreased significantly for the systematic placement sections and for cover in the reference section (Table 2.4 and Table 2.6.).

Distances to cover and LWD were similar among the study reaches in 1993 for adult brook trout, but the distances were significantly greater in the random placement section than in the reference in 1994 (Tables 2.3. and 2.6). Changes in the median distance to cover or LWD for adults were not significant between 1993 and 1994 for any treatment section (Tables 2.4. and 2.6.).

*Distance of Brook Trout to Nearest Conspecific and Fish*

Comparisons of distance to nearest fish for juvenile brook trout among sections revealed that the only significant difference was in 1994; the median distance was shorter in the random placement section than the other two reaches sampled (Table 2.3.; Table 2.6.). After manipulations, distance to nearest conspecific for juveniles was significantly less in the random placement section and the reference (Table 2.4.; Table 2.6.). The median distance to nearest fish in the random placement section decreased significantly after LWD additions (Tables 2.4. and 2.6.).

For adult brook trout, distances to nearest conspecific and nearest fish were similar for all three treatment sections in 1993 and 1994 (Table 2.3.; Table 2.6.). Distance to conspecific and fish did not change significantly for any section of Barbours after LWD was added (Table 2.4.; Table 2.6.).

North Fork Stony Creek

*Availability of Water Column Depth*

Water column depths available in Stony Creek were comparable among sections in 1993, but in 1994, the random placement section had significantly greater depths than the systematic placement section (Table 2.7.; Figure 2.20.). Depths did not change after LWD was added for any section of Stony (Table 2.7.; Figure 2.20.).

*Availability of Water Column Velocity*

Water column velocities were similar for all sampled reaches of Stony in 1993 and 1994, although median water column velocities increased significantly in the systematic placement section from 1993 to 1994 (Table 2.7.; Figure 2.20.).

*Availability of Dominant and Subdominant Substrate*

Dominant and subdominant substrate distributions were similar among sampled reaches of Stony in 1993 and 1994 (Table 2.7.). Dominant substrates were primarily distributed among small and large gravels and cobbles in 1993, while large gravel was the dominant substrate in each section in 1994 (Figure 2.21.). The distribution of dominant substrate changed significantly for all sections after manipulations, with more organic debris and silt and fewer cobbles available (Table 2.7.; Figure 2.21.). The distribution of subdominant substrates available changed significantly in the systematic placement section from 1993 to 1994, shifting toward smaller size classes (Table 2.7.; Figure 2.21.).

**Table 2.3.** Results from Kruskal-Wallis tests comparing eight continuous habitat variables among sampled reaches of Barbours Creek for habitat availability and habitat use for juvenile (0+) and adult (1+) brook trout and blacknose dace. Dominant and subdominant substrate distributions were compared using Kolmogorov-Smirnov tests. Blank cells represents no significance, * represents significance of 0.05<P<0.01 and ** represents significance of P<0.001. The random placement, systematic placement, and reference sections are represented by the numerals 1,2, and 3, respectively.

| | Available | | BKT (0+) | | BKT (1+) | | BND (0+) | | BND (1+) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Habitat Variable | 1993 | 1994 | 1993 | 1994 | 1993 | 1994 | 1993 | 1994 | 1993 | 1994 |
| Water Column Depth | * | ** | * | ** | | ** | ** | | ** | |
| Focal Point Depth | | | ** | | * | ** | | | | |
| Water Column Velocity | * | ** | | ** | | | | | ** | |
| Focal Point Velocity | | | | | | | | | | |
| Distance to Cover | | | | | | * | | | | |
| Distance to LWD | | | | ** | | * | | | | |
| Distance to Conspecific | | | | | | | | | | |
| Distance to Fish | | | | ** | | | | | | |
| Dominant Substrate | *1v3 2v3 | *1v2 1v3 | | | * 1v3 | | *1v3 2v3 | *all | *1v2 1v3 | |
| Subdominant Substrate | *1v2 | | | | *1v3 | *1v2 1v3 | *1v2 | *1v2 2v3 | | |

**Table 2.4.** Results from comparison testing for eight microhabitat variables measured in North Prong Barbours Creek before and after manipulations. Blank cells represents no significance, * represents significance of 0.05<P<0.01 and ** represents significance of P<0.001.

| | Available | | | Brook Trout (0+) | | | Brook Trout (1+) | | | Blacknose Dace (0+) | | | Blacknose Dace (1+) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RAN | SYS | REF | RAN | SYS | REF | RAN | SYS | REF | RAN | SYS | REF | RAN | SYS | REF |
| Water Column Depth | ** | ** | | | | | ** | | | | | ** | | | |
| Focal Point Depth | | | | ** | ** | | | * | | | | | | | |
| Water Column Velocity | ** | ** | ** | | | | | ** | * | | | | | | |
| Focal Point Velocity | | | | | | | | * | | | | | | | |
| Distance to Cover | | | | | ** | ** | | | | | | | | | |
| Distance to LWD | | | | | ** | | | | | | | | | | |
| Distance to Conspecific | | | | | | | | | | | | | | | |
| Distance to Nearest Fish | | | | ** | | | | | | | | | | | |
| Dominant Substrate | * | * | * | | | | | * | * | * | * | * | | * | |
| Subdominant Substrate | | | | | * | | | | | | * | | | | |

**Table 2.5.** Results from comparison testing of use and availability for four microhabitat variables measured in North Prong Barbours Creek. Blank cells represents no significance, * represents significance of 0.05<P<0.01 and ** represents significance of P<0.001.

| | Brook Trout (0+) | | Brook Trout (1+) | | Blacknose Dace (0+) | | Blacknose Dace (1+) | |
|---|---|---|---|---|---|---|---|---|
| | 1993 | 1994 | 1993 | 1994 | 1993 | 1994 | 1993 | 1994 |
| | Water Column Depth | | | | | | | |
| Random Placement | ** | * | ** | ** | ** | ** | ** | |
| Systematic Placement | ** | * | ** | ** | ** | ** | ** | * |
| Reference | ** | ** | ** | ** | ** | ** | ** | ** |
| | Water Column Velocity | | | | | | | |
| Random Placement | ** | | * | | | ** | | |
| Systematic Placement | ** | | | | | ** | | |
| Reference Placement | | | | | | ** | | |
| | Dominant Substrate | | | | | | | |
| Random Placement | | | | | | * | * | |
| Systematic Placement | | | | | | * | | * |
| Reference | * | | | | | * | * | |
| | Subdominant Substrate | | | | | | | |
| Random Placement | | | | * | * | * | | |
| Systematic Placement | | | | | * | * | * | |
| Reference | | | | | | | | |

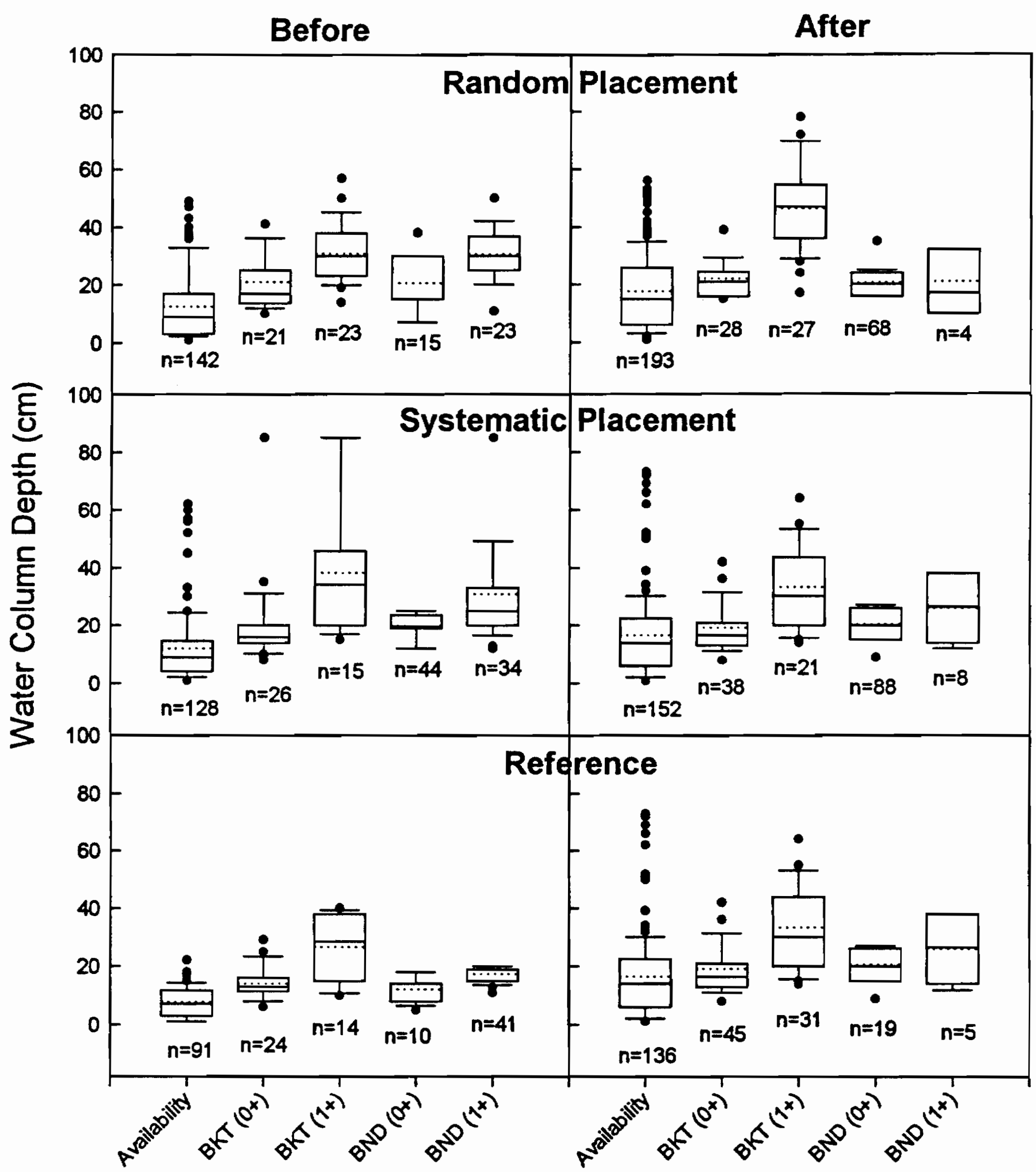



**Figure 2.11.** Boxplots showing the median, quartile distribution, and 10th and 90th percentile distribution (error bars) of water column depths available and used by brook trout (BKT) and blacknose dace (BND) in three sampled reaches of Barbours Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols.

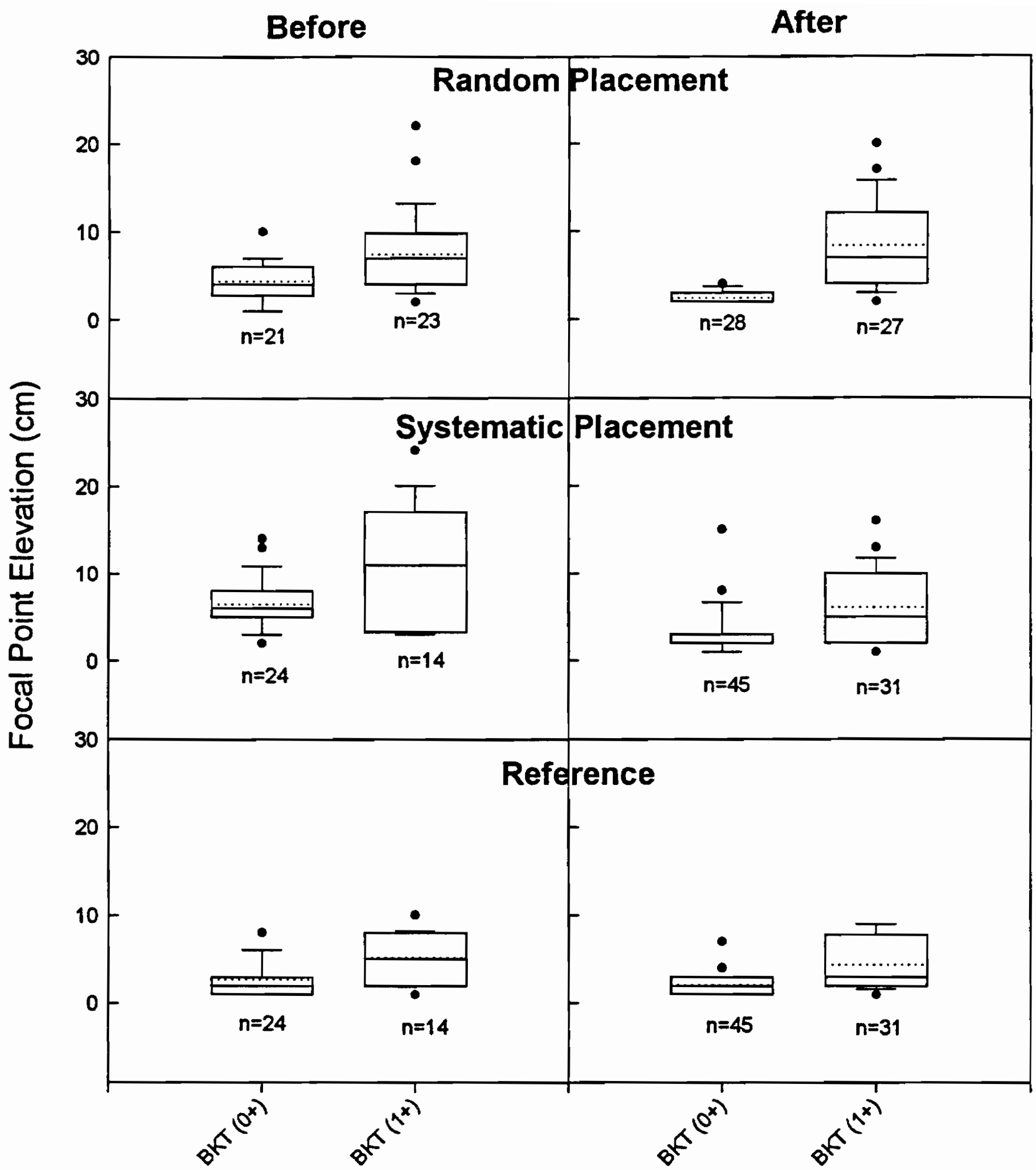



**Figure 2.12.** Boxplots showing the median, quartile distribution, and 10th and 90th percentile distribution (error bars) of focal point elevations used by brook trout (BKT) in three sampled reaches of Barbours Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols.

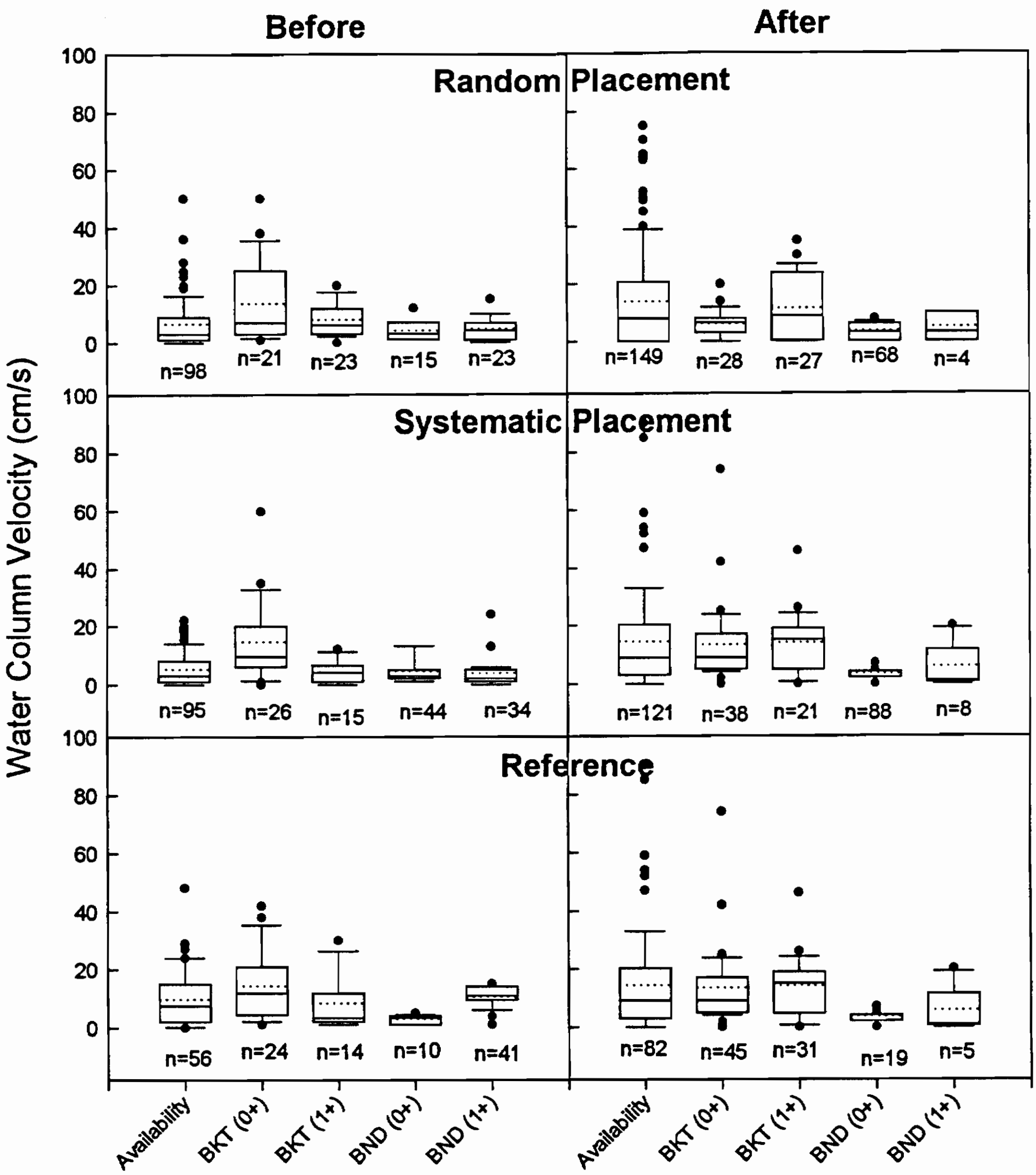



**Figure 2.13.** Boxplots showing the median, quartile distribution, and 10th and 90th percentile distribution (error bars) of water column velocities available and used by brook trout (BKT) and blacknose dace (BND) in three sampled reaches of Barbours Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols.

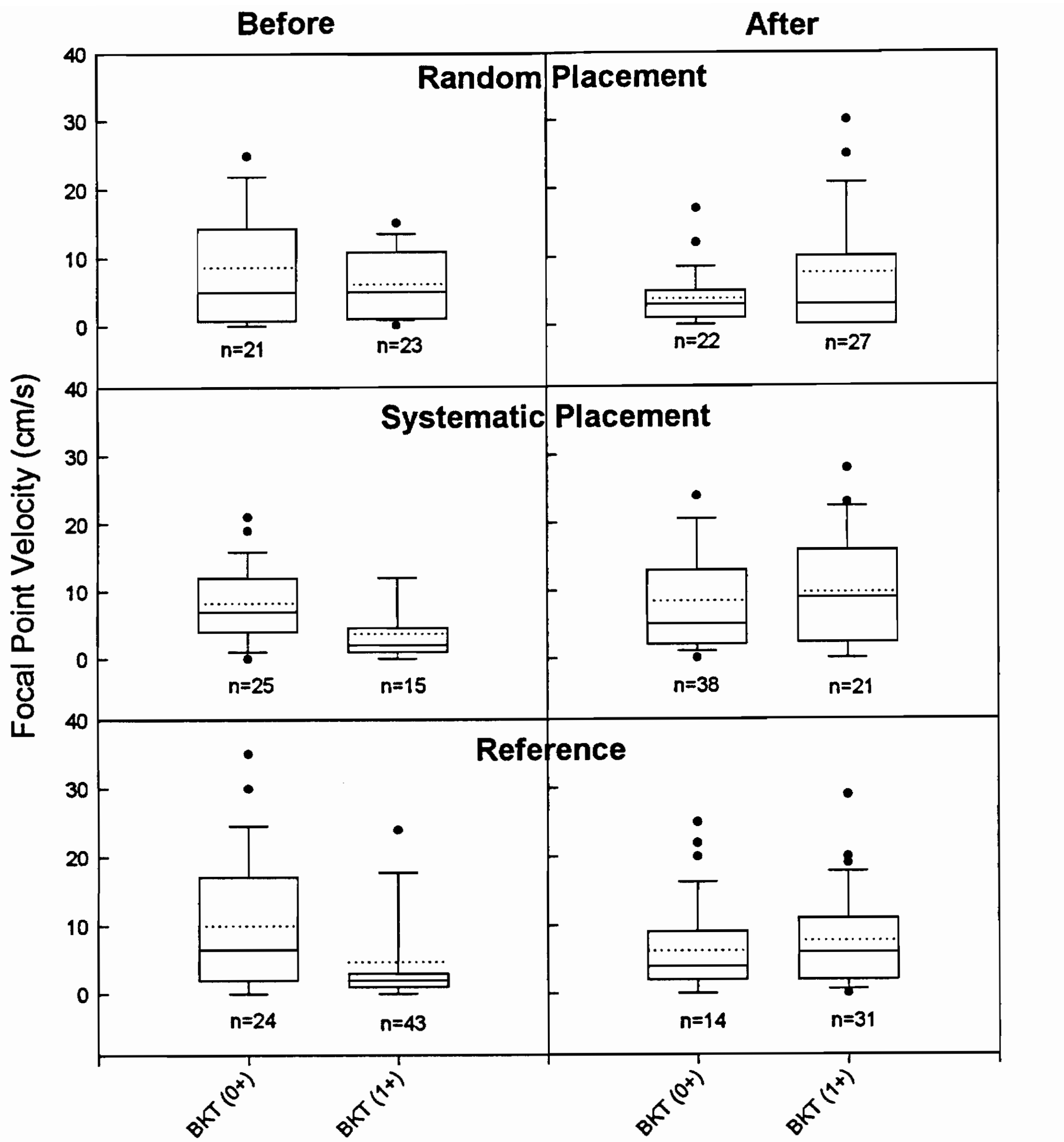



**Figure 2.14.** Boxplots showing the median, quartile distribution, and 10th and 90th percentile distribution (error bars) of focal point velocities used by brook trout (BKT) in three sampled reaches of Barbours Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols.

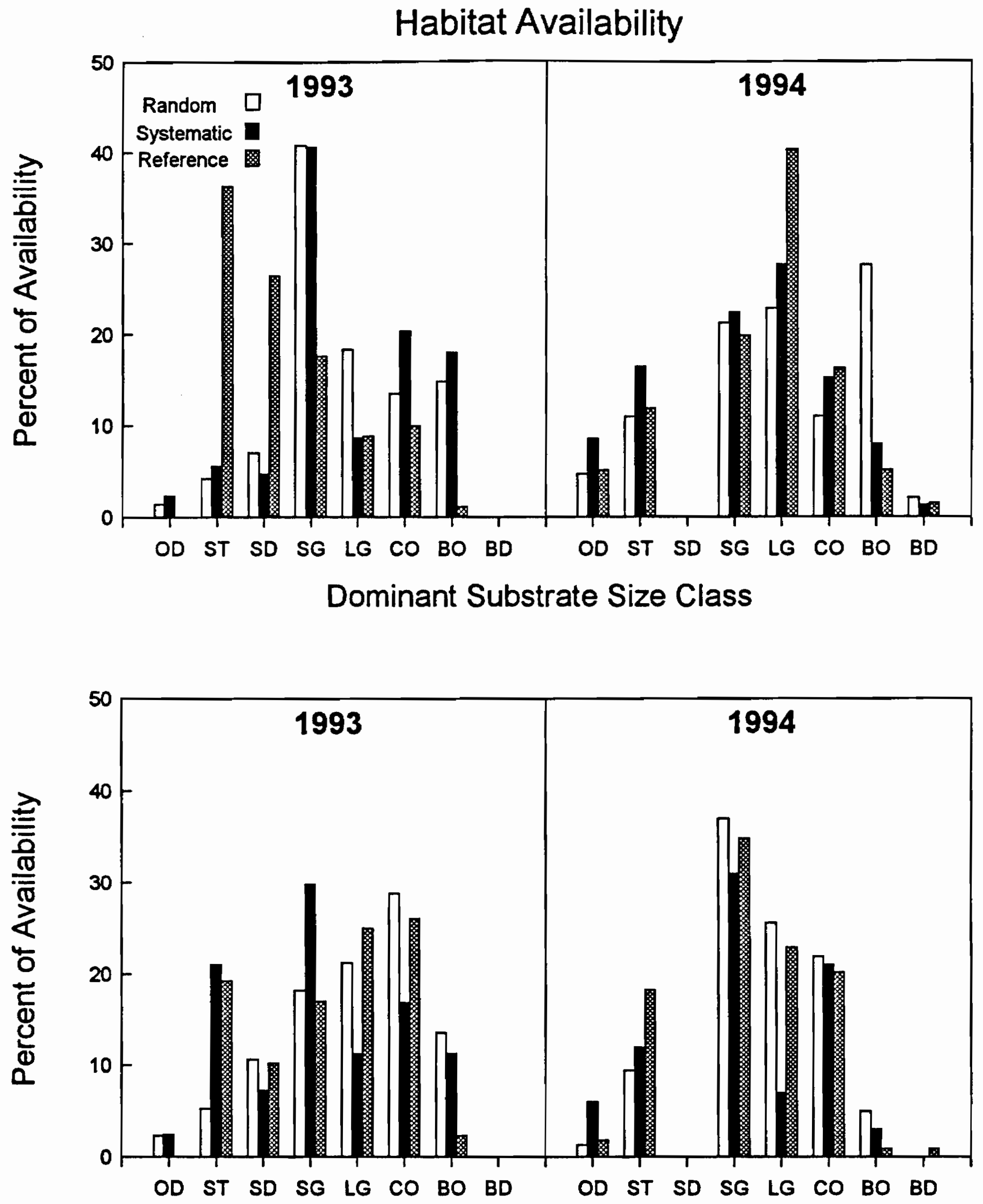



**Figure 2.15.** Dominant and subdominant substrates available in North Prong Barbours Creek before and after LWD additions. Substrate classes include: OD=organic debris, ST=silt, SD=sand, SG=small gravel, LG=large gravel, CO=cobble, BO=boulder and BD=bedrock.

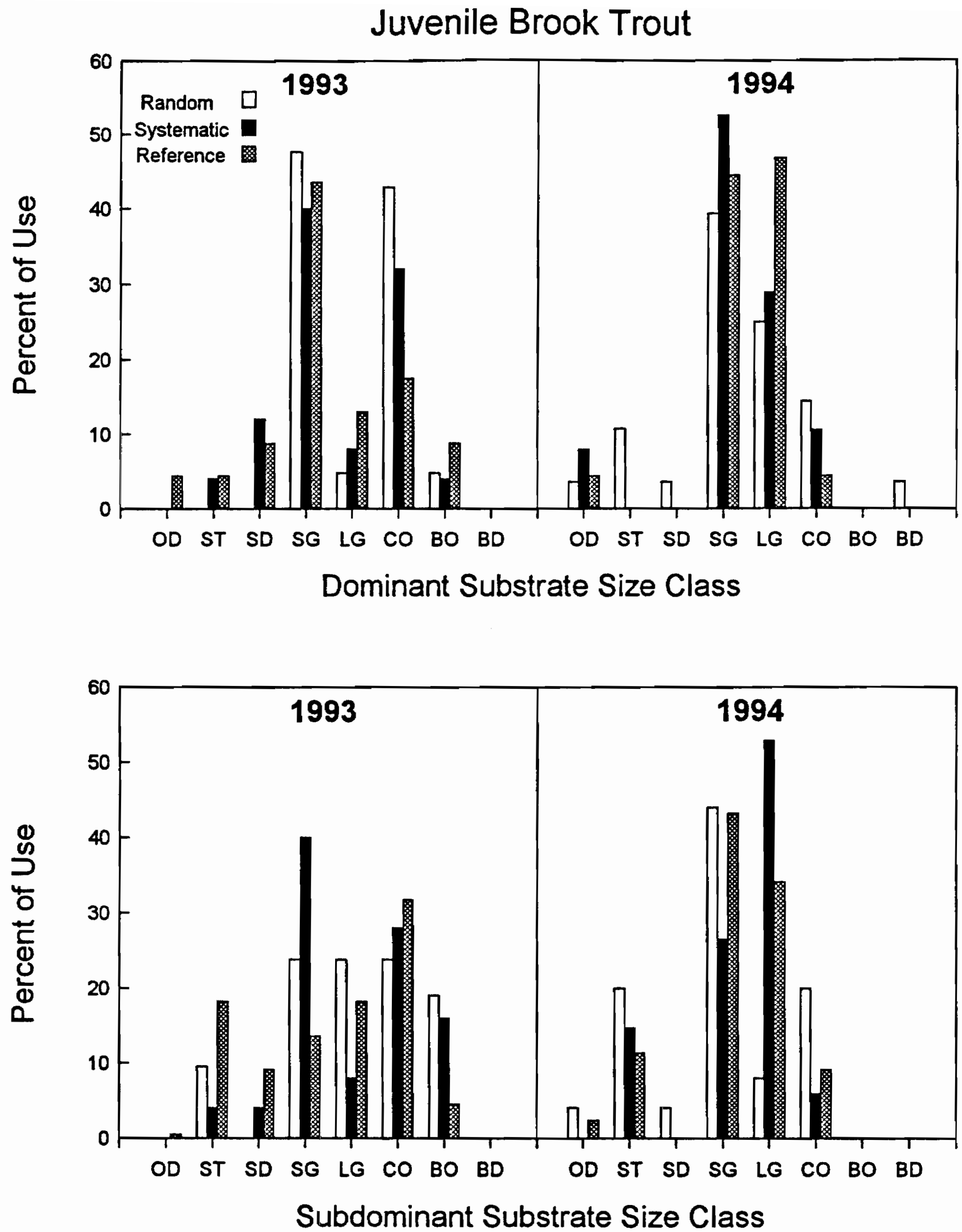



**Figure 2.16.** Dominant and subdominant substrates used by juvenile brook trout in North Prong Barbours Creek before and after LWD additions. Substrate classes include: OD=organic debris, ST=silt, SD=sand, SG=small gravel, LG=large gravel, CO=cobble, BO=boulder and BD=bedrock.

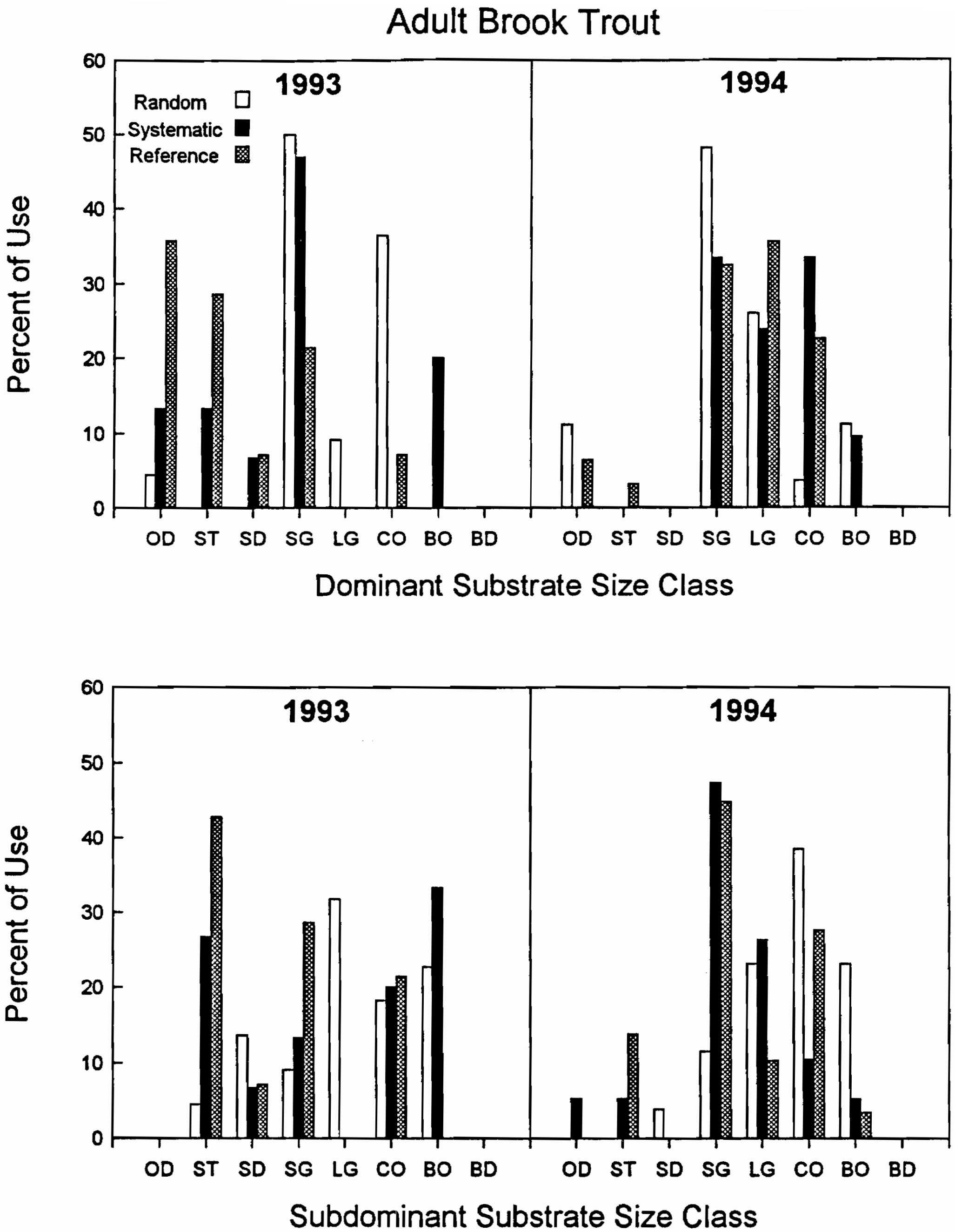



**Figure 2.17.** Dominant and subdominant substrates used by adult brook trout in North Prong Barbours Creek before and after LWD additions. Substrate classes include: OD=organic debris, ST=silt, SD=sand, SG=small gravel, LG=large gravel, CO=cobble, BO=boulder and BD=bedrock.

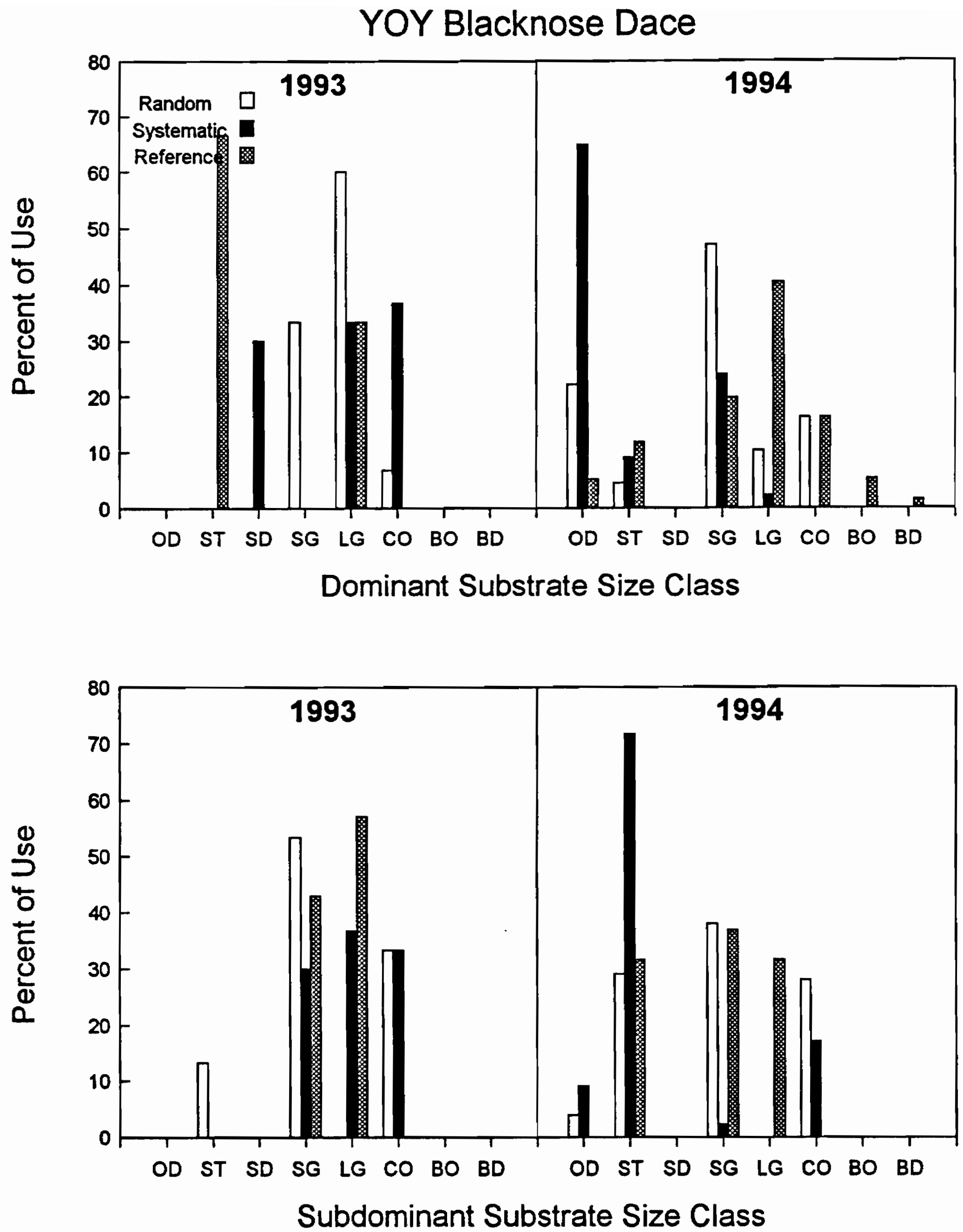



**Figure 2.18.** Dominant and subdominant substrates used by young-of-the-year blacknose dace in North Prong Barbours Creek before and after LWD additions. Substrate classes include: OD=organic debris, ST=silt, SD=sand, SG=small gravel, LG=large gravel, CO=cobble, BO=boulder and BD=bedrock.

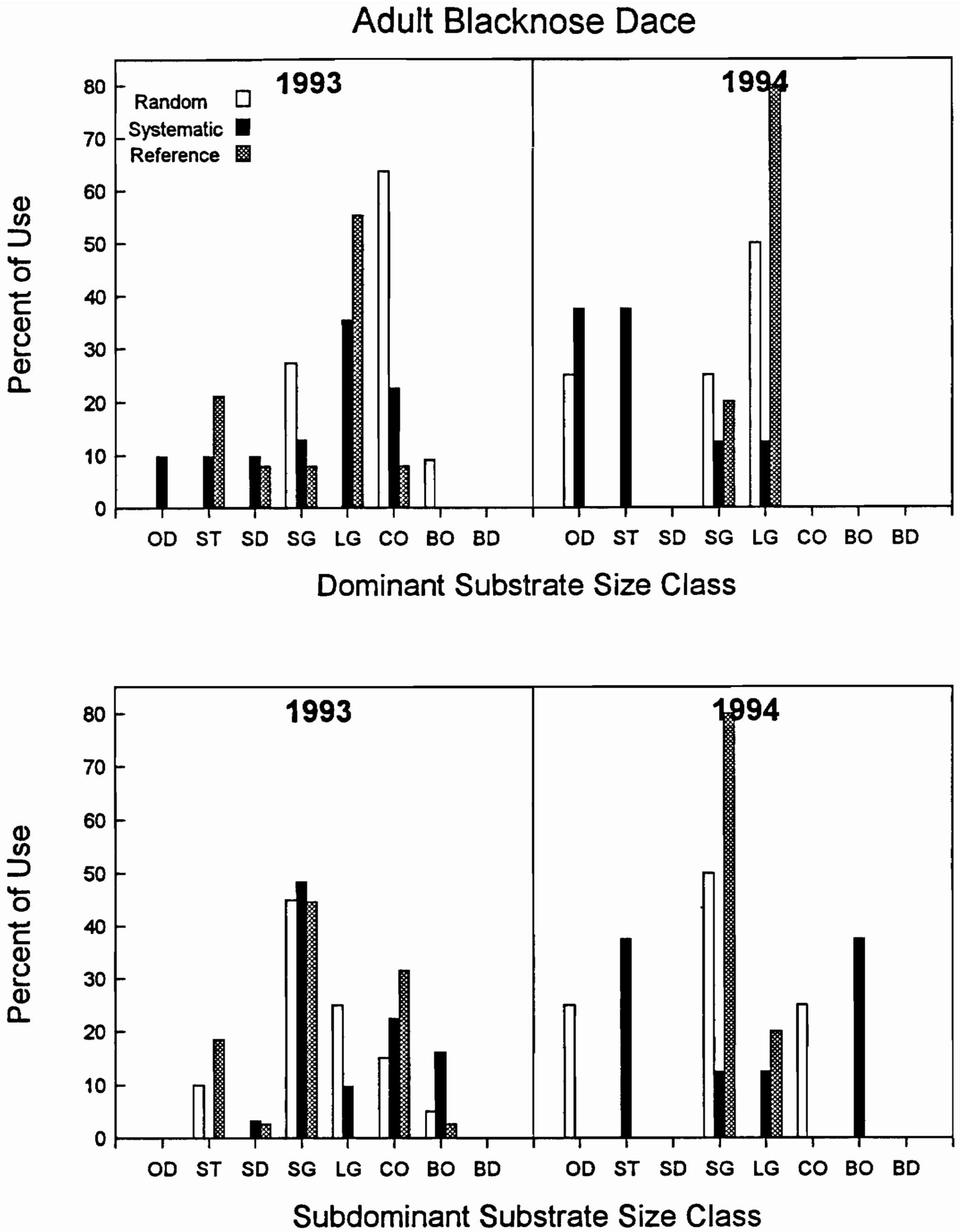



**Figure 2.19.** Dominant and subdominant substrates used by adult blacknose dace in North Prong Barbours Creek before and after LWD additions. Substrate classes include: OD=organic debris, ST=silt, SD=sand, SG=small gravel, LG=large gravel, CO=cobble, BO=boulder and BD=bedrock.

**Table 2.6.** Distances (m) for juvenile (0+) and adult (1+) brook trout to cover, LWD, nearest conspecific and nearest fish before and after LWD was added to Barbours Creek.

| | Random Placement | | | | Systematic Placement | | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | Before | n | After | n | Before | n | After | n | Before | n | After |
| | | | | | | **Distance to Cover** | | | | | | |
| 0+ | 21 | 0.61 | 28 | 0.66 | 26 | 0.94 | 38 | 0.31 | 24 | 1.69 | 45 | 0.41 |
| 1+ | 23 | 0.43 | 27 | 0.42 | 15 | 0.45 | 21 | 0.26 | 14 | 0.39 | 31 | 0.23 |
| | | | | | | **Distance to LWD** | | | | | | |
| 0+ | 21 | 2.80 | 28 | 2.37 | 26 | 3.00 | 38 | 1.68 | 24 | 2.96 | 45 | 2.69 |
| 1+ | 23 | 2.48 | 27 | 2.40 | 15 | 2.86 | 21 | 2.08 | 14 | 2.39 | 31 | 1.44 |
| | | | | | | **Distance to Nearest Conspecific** | | | | | | |
| 0+ | 21 | 2.30 | 28 | 1.49 | 26 | 1.72 | 38 | 1.89 | 24 | 2.58 | 45 | 1.3 |
| 1+ | 23 | 2.21 | 27 | 1.96 | 15 | 2.06 | 21 | 2.34 | 14 | 1.39 | 31 | 1.97 |
| | | | | | | **Distance to Nearest Fish** | | | | | | |
| 0+ | 21 | 3.02 | 28 | 1.81 | 26 | 3.06 | 38 | 3.09 | 24 | 2.80 | 45 | 3.46 |
| 1+ | 23 | 3.04 | 27 | 3.59 | 15 | 2.62 | 21 | 3.17 | 14 | 2.86 | 31 | 3.22 |

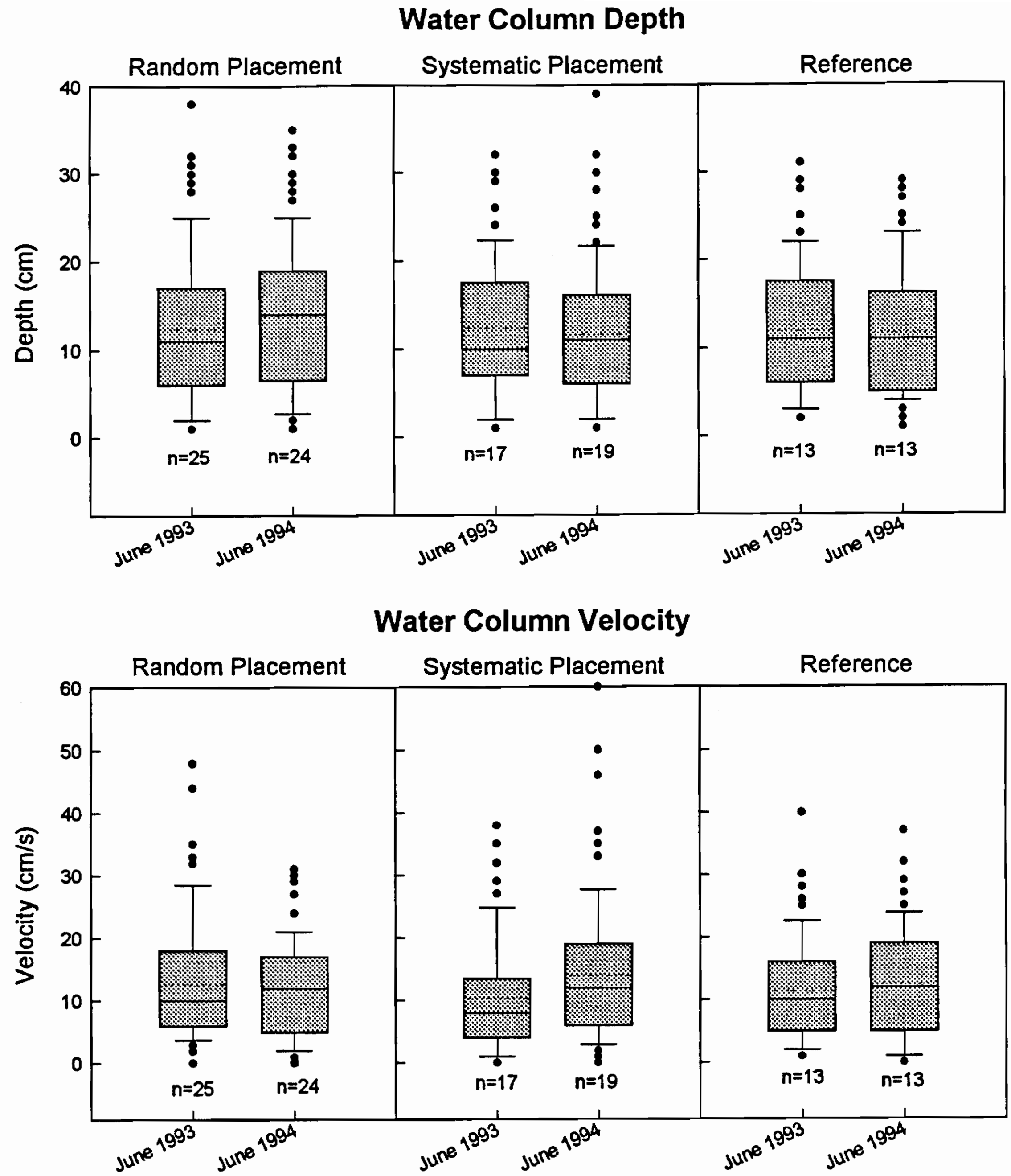



**Figure 2.20.** Boxplots showing the median, quartile distribution, and 10th and 90th percentile distribution (error bars) of water column velocities and depths available in three sampled reaches of Stony Creek in 1993 and 1994. Dotted lines indicate the means and outliers are shown by symbols.

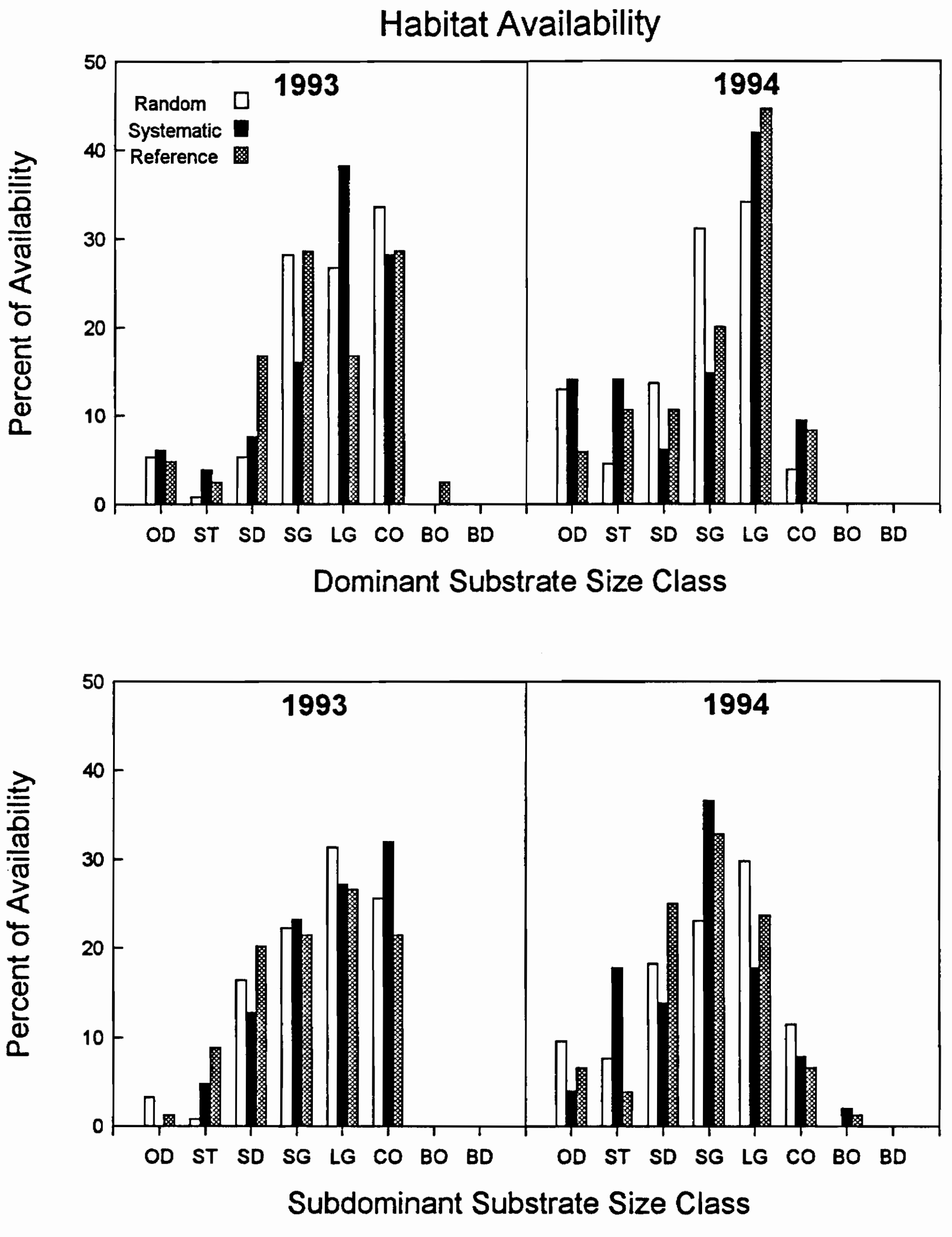



**Figure 2.21.** Dominant and subdominant substrates available in North Fork Stony Creek before and after LWD additions. Substrate classes include: OD=organic debris, ST=silt, SD=sand, SG=small gravel, LG=large gravel, CO=cobble, BO=boulder and BD=bedrock.

## Discussion

### *Effects of LWD on Population Parameters*

I had two objectives for this portion of the study: 1) to examine standard population parameters that are used to characterize fish populations and 2) to examine fish movement before and after LWD additions in North Prong Barbours Creek and North Fork Stony Creek.

<u>North Prong Barbours Creek</u>

*Brook Trout*

Densities and biomass for adult brook trout in Barbours Creek did not change significantly over the course of this study. The one year of time that elapsed after manipulations may not have been adequate to see a population response. Evaluations of stream enhancement measures indicate that populations may not respond fully for 5-7 years after treatment (Hunt 1976). But, in an evaluation of log drop structures in six Colorado streams, Riley and Fausch (1995) found rapid increases in abundance of age-2 and older trout, with numbers increasing significantly more in the treatment sections than in the control. In some cases, these changes occurred less than one month after structures were added.

Densities and biomass of juvenile brook trout were similar in the fall sampling period, but average densities and biomass of juvenile brook trout exploded in 1994 by an order of magnitude. The fact that 1994 was a good year for spawning recruitment cannot be attributed to the addition of LWD in that short time period. Recruitment success depends on spawning population size, number of eggs produced, egg and fry survival which are affected by factors such as competition, predation, availability of food, high and low flows. Gowan and Fausch (1996) found that juvenile trout did not respond to habitat manipulation when examining fish abundance and biomass.

Changes in size and condition of brook trout were evaluated in Barbours Creek with the hypothesis in mind that if LWD improves habitat by providing resting places, feeding lanes, refuge during low and high flow, rearing pools and such, condition of fish would increase. After log drop structures were installed in six Rocky Mountain streams, Riley and Fausch (1995) found no evidence that brook trout were in better condition or grew to larger sizes. In our study, median lengths of adults did not change, but the relative weights of adults over 130 mm increased significantly in the two treatment sections. Adult brook trout appeared to be very healthy before and after LWD was added. In concept, a mean $W_r$ of 100 for a broad range of size-groups may reflect ecological and physiological optimality for populations (Anderson and Neumann 1996), and those in Barbours were above 100 in all cases. Median lengths of juvenile brook trout actually decreased significantly after LWD was added, but condition of juveniles improved in the systematic placement and reference sections. Size of juveniles may have varied because of an earlier sampling period in 1994. Fry may have emerged earlier in the spring of 1994 than in 1993, but the time of spawning and survival of eggs and fry were not monitored within the course of this study.

Mechanisms that can account for all of the population characteristics above include growth, survival, and immigration/emigration or movement. It was believed that the time period of the study was insufficient to allow a significant biological response for growth and survival of fish populations, but movement of brook trout was monitored. Researchers have documented brook trout moving long distances (Gowan and Fausch 1996). The fact that fish move long distances is important when considering management strategies, but research and management of stream populations is almost always defined as those individuals inhabiting a designated stream reach. I attempted to monitor movement within the 1 km section of stream studied in Barbours Creek, hypothesizing that if LWD improved fish habitat, fish would be less likely to emigrate out of our treatment sections. In a similar study examining movement of brook trout after stream enhancement, Gowan and Fausch (1996) found that adult trout abundance increased in treatments primarily because mobile fish tended to remain in treatments after encountering them, revealing that manipulation increased the habitat available to trout; in the short run, populations responded via movement rather than increased recruitment, survival, or growth.

Numbers of brook trout moving into or out of a habitat unit based on the presence of wood could not be compared because of low sample sizes prevented this analyses. It is interesting though that no recaptured fish in the fall had moved out of its study section, and only three fish had moved out of the systematic section into the reference one year later. Most fish were recaptured within or had moved upstream from their original units and moved less than 100 m during both sampling periods, although five adults were observed moving further. Brook trout that moved into the reference section were probably exhibiting a normal trend of upstream movement that has been observed for salmonids. These results agree with those found in Colorado; researchers found that brook trout movement was predominantly upstream and that most tagged brook trout remained within 100 m of location where marked (Riley and Fausch 1994; Gowan and Fausch 1996).

Migration out of the study section is one possible explanation for low sample sizes, but an additional factor could have been the success of marking procedures. I had little success with retention of visible implant tags; 63 fish were recaptured within the sampling periods that had an adipose fin clip and no tag, indicating tag loss. Only three tags were recovered after the initial marking period. Gowan and Fausch (1996) mention but do not quantify that retention of visible implant tags in all streams where fish were tagged was poor (unpublished data). In a controlled experiment, Mourning et al.1994 found that 18% of rainbow trout lost VI tags after 120 days. On the other hand, Bryan and Ney (1994) reported a 65% retention rate for brook trout 130-160 mm in total length and 100% for brook trout 200 mm or greater over a one-year period.

*Blacknose Dace*

Few studies have measured the response of non-salmonids to habitat enhancement; response of a blacknose dace population was monitored in this study before and after LWD additions. Blacknose dace will breed in May, June and July (Schwartz 1958), so it was difficult to make conclusions about changes in parameters measured in the summers of 1993 and 1994. Densities of YOY did increase significantly in the random placement section and biomass increased for both the random and reference sections, but no changes were evident for adult density or biomass. Total lengths of adults and YOY decreased in the systematic placement section. Condition increased for juveniles in the random placement and reference sections, while condition of adults increased for all sections of Barbours. Note however, that the precision of estimates for blacknose dace condition were derived from measurements of weight accurate to 0.1 g. For YOY (1-2 g fish), measurement error was therefore 5-10% leading to 5-10% error in K. Another factor affecting changes in density and biomass is movement, but I was unsuccessful in marking blacknose dace and thus could not assess movement.

North Fork Stony Creek

I believe that water quality accounted for low sample sizes in Stony. Water quality was not adequately monitored over the course of this study, but since 1995, levels of pH have dipped as low as 3.5 after periods of high flow in Stony Creek and averages of 4.5-5 (personal communication, Holly Jennings, Forest Service Coldwater Research Fisheries Unit, Blacksburg,VA); a lethal level for brook trout fingerlings (Daye and Garside 1975). Additionally, in situ toxicity tests have revealed an 88% mortality for YOY brook trout and 90% for yearlings exposed to pH levels of 4.61 -5.07 after 336 hours (Johnson et al.1987). Thus, if hatchery trout did not migrate from the study section during low levels of pH, they most likely died. Many high elevation streams in the southern Appalachians are similarly acid-sensitive (Burton and Odum 1945; Webb et al. 1989). It is thought that blacknose dace may be even more acid-sensitive than brook char (Johnson et al. 1987). Only one adult blacknose dace was ever observed or collected in Stony.

Although water quality may be a limiting factor in North Fork Stony Creek, this stream was still considered an excellent model to examine the influence of LWD on physical habitat of a low-gradient stream in the southern Appalachians. We did find that total density of juvenile brook trout increased in the random placement and reference sections, while decreasing in the systematic placement section. This was not expected because total pool area increased dramatically in the systematic placement section and the lower velocities and greater depths found in pools are good rearing habitat for young trout. Densities of biomass of adult brook trout increased for every section of Stony Creek, including the reference section. This may have been a result of the fingerlings stocked in 1993.

### *Effects of LWD on Microhabitat Distributions*

#### North Prong Barbours Creek

We considered whether the addition of large woody debris caused shifts in available microhabitat in Barbours Creek, as described by water column depth and velocity and dominant and subdominant substratum. But if changes occurred for microhabitat availability, it was also meaningful to observe whether fish use corresponded with these shifts. Did brook trout and blacknose dace adapt to their new environment by using new habitat available, suggesting that conditions were more favorable? Or, did habitat use remain similar, suggesting that habitat was not a limiting factor in Barbours?

A comparison of microhabitat in the three sampled reaches of Barbours in 1993 and 1994 revealed that the reference section had shallower depths and higher velocities available than the random and systematic placement sections. Silts made up the greater percentage of substrate in the reference section, while small gravels were dominant in the treatment sections. This would suggest that our reference section was not an appropriate control. Regardless, the reference section was designated to observe relative changes in comparison to treated sections for microhabitat parameters after LWD additions.

LWD functions as large roughness or frictional elements, serving as controlling agents of water and sediment routing in small streams (Keller and Swanson 1979), altering depths, velocities, and substrate available within a stream. Water column depths increased significantly in the random and systematic placement sections in 1994, but were similar in the reference section. The fact that the reference section did not get deeper agrees with findings from examining cross-sectional profiles around "phantom logs", which showed a trend toward channel bed aggradation in the reference section with the placement sections being more variable (Chapter 1).

Depths are important to salmonids; Chapman (1966) asserted that space (i.e. volume of habitat) is the prime regulator of stream salmonid populations, particularly in winter, but relative differences in depth are important during any season. Median water column depths observed for brook trout and blacknose dace use typically were significantly greater than available for both years. The use of transects to collect availability data most likely generated this result; because of the nature of the channel, points measured near water's edge or over objects in the streambed (e.g., boulders) were typically shallower than places fish prefer. Juvenile brook trout used significantly shallower depths in the reference section than in the random placement section for 1993 and 1994, a trend similar to that of habitat availability. Although available depths changed significantly in the placement sections after manipulations, habitat selection by juvenile brook trout did not change markedly. Adult trout used significantly greater depths in the random placement section after manipulations, but it is difficult to determine whether this was a response to the greater depths available in this section. The fact that adult brook trout habitat use would shift toward greater depths rather than juveniles is not surprising. In a winter study, Cunjak and Power (1986) found that older trout (>age 1) occupied positions in deeper and faster water than age 0+ trout.

Results for blacknose dace were confounded by inadequate or unequal sample sizes and by the fact that dace do not hold specific focal positions, but are in constant movement within a specific area and often in groups. Water column depth was averaged for the given area a dace or an aggregation of dace was observed in. Young-of-the-year and adult blacknose dace were observed using shallower depths in the reference section as compared to the placement sections in 1993, but use was similar in 1994 among sampled reaches. YOY blacknose dace selected greater depths in the reference section in 1994.

Focal point elevation is another way to characterize use of depths for salmonids, which in flowing waters prefer to hold positions within the water column. Stream salmonids maintain relatively fixed positions with respect to the stream bed, termed focal points, and make short forays from them to feed on invertebrates drifting nearby (Fausch and White 1981). Juvenile brook trout used shallower focal point elevations in the reference in 1993, while adults were lower in the water column in this section for both years. Although water column depth increased in the placement sections, juveniles used significantly shallower focal points after LWD additions in both sections and adults used shallower depths in the systematic placement section. Lohr and West (1992) found that age 0+ rainbow and brook trout occupied focal points that were shallower and closer to the water surface than older fish.

Available water column velocities increased significantly for all sampled reaches in Barbours Creek in 1994. This suggests an increase in discharge in 1994 during the sampling period. , although logs may have provided cover for fish Another explanation could be sampling error; we were not able to use the same current meter for both sampling periods. Interestingly both juvenile and adult brook trout tended to use greater water velocities than available in the placement sections in 1993, but velocities used in the reference were comparable to the higher velocities available in this section. Observations were during daylight hours when trout are actively feeding on drifting invertebrates, which may account for the higher velocities observed for brook trout. After manipulations, no change in water column velocities used by juveniles was evident, but adults used significantly higher velocities in the systematic and reference sections. This also suggests that adults prefer to use higher velocities when available. Salmonids have been observed occupying habitat characterized by deeper and faster water than juveniles in the winter (Cunjak and Power 1986) and summer months (Chapman and Bjornn 1969). No significant trends were observed for blacknose dace, but again microhabitat data for dace was problematic.

Velocities available did not appear to affect focal point velocities of juvenile and adult brook trout; similar focal point velocities were used regardless of changes in available water column velocities. The only significant result was that adults selected higher velocities in the systematic placement section after LWD was added. That fish maintained relatively similar focal point velocities but shifted use of water column velocities, supports the hypothesis that fish should maintain positions in slowly flowing water to minimize energy expenditure, but near fast currents carrying more food per unit time to maximize energy intake (Fausch and White 1981).

Dominant substrate distributions for availability changed significantly after LWD was added for all sampled reaches, shifting toward larger size classes. Subdominant substrates remained similar. These results must be interpreted with caution. An examination of substrate frequency distributions for habitat availability (Figure 2.15.) reveals complicated trends that could be misinterpreted easily. My collection method and resulting small sample sizes make it difficult to pinpoint the influence of LWD on substrate availability. In addition, shifts in substrate availability are affected by other factors, such as discharge events over the course of the year or activities upstream from the study site. Difficulty in interpretation because of small sample sizes also holds true for use of substrates by brook trout and blacknose dace (Figures 2.16.-2.19.). Designation of what is dominant or subdominant substrate use is very subjective, especially if only one value is recorded for each availability point or each fish. The only significant trends shown for brook trout after manipulations included: increases in size classes for subdominant substrate use by juveniles in the systematic section, dominant substrate use by adults for the systematic placement and reference sections. For YOY blacknose dace, dominant substrates used shifted toward smaller size classes in they treatment sections and toward larger in the reference and subdominant use shifted toward smaller in the systematic placement section. For adult dace, dominant substrates used in the systematic section decreased in size.

Distance to cover and LWD as a specific type of cover, were observed for brook trout, to evaluate the effects of LWD additions on these associations. Cunjak and Power (1986) found the percentage of individual brook trout beneath cover in winter was high (at least 79%), and also found that association to cover was often less in summer than in winter. Median distance to cover and LWD decreased significantly for juvenile brook trout in the systematic placement section after LWD was added. This may suggest brook trout were using experimental logs as a source of cover, but this is difficult to determine. Distance to cover decreased for juveniles in the reference section. This may have also been a response to juveniles reacting to higher velocities in 1994, moving to areas where velocity was lower. Cover association is a complex phenomenon (Cunjak and Power 1986); it is difficult for a human observer to subjectively determine what cover is for a fish, especially if a fish is not observed fleeing to cover after disturbance.

I also considered associations to nearest conspecific and nearest fish (i.e. blacknose dace) in this study to determine if LWD influenced the distance fish were located from each other. Woody debris forms complex habitat matrices that visually isolate individuals, therefore partitioning more territories and reducing the frequency of aggressive encounters between competitors (Dolloff 1986; Lisle 1986). McNicol (1985) even suggests that aggressive YOY brook charr defend territories at the expense of feeding, feeding at a lower rate than nonaggressive fish. Juvenile brook trout were observed closer together in the random placement and reference sections after LWD was added, and closer to blacknose dace in the random placement. This result should be viewed with caution, because of inadequate replication and lack of recognition of other factors that may affect this association. Individual fish were not observed for long enough periods of time to address the possibility of aggressive encounters. No trends were observed for adult brook trout.

North Fork Stony Creek

Small numbers of fish in North Fork Stony limits discussion to microhabitat available before and after LWD additions. Water column depths available did not change significantly for any section of Stony Creek after LWD was added. I expected to see an increase in depths in the reference section where 92% of the cross-sectional transects showed scouring of the channel bed (Chapter 1), which in turn, should have increased available depths. The only significant result shown for water column velocities in Stony was an increase in the systematic placement section after LWD was added. The only significant change for substrate was for the distribution of subdominant substrate in the systematic section. The disparity of results for velocities and substrate may also be a result of the data collection method for microhabitat; transects for habitat availability were not concentrated in areas around logs. Again, I expected to find more significant changes for habitat available in Stony Creek because of the creation of scour and dam pools and the movement of sediments around individual logs noted for physical habitat characteristics measured in Chapter 1.

The objective of my study was to determine the influence of LWD placement on microhabitat availability, and in turn, its effect on habitat use. Although several trends were observed for availability and use for certain variables, our study was plagued by problems typical of microhabitat studies (i.e., restriction to a single season, small sample sizes) and results should be interpreted with caution.

In conclusion, I was not able to attribute significant trends observed for fish parameters in Barbours Creek to improved habitat. Large woody debris added to

Barbours Creek caused minimal changes to the stream channel. The fact that relative weights of adult brook trout increased in both our treatment sections however suggests that logs provided resting areas of lower velocities next to food pathways, leading to decreased energy expenditure. Observations of microhabitat use revealed that juvenile brook trout used a limited range of depths and velocities, but adult brook trout used a greater range of depths and velocities. Adults shifted microhabitat use in response to changes in microhabitat available.

Despite the fact that pH was most likely a limiting factor in Stony Creek, numbers of adult brook trout found in each section did increase in 1994. With improved water quality, I believe that fish abundance would increase through time because of the improvement in physical habitat (i.e. pools formed, increased complexity). Although few significant changes were observed for available microhabitat in Stony Creek, changes in physical habitat suggest that over time shifts in microhabitat would be apparent.

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## Vita

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