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Application of Habitat Evaluation Models in Southern Appalachian Trout Streams

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ENVIRONMENTAL SCIENCES DIVISION
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APPLICATION OF HABITAT EVALUATION MODELS IN SOUTHERN APPALACHIAN TROUT STREAMS

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ABSTRACT

LOAR, J. M. (ed.). 1984. Application of habitat evaluation models in southern Appalachian trout streams. ORNL/TM-9323. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 326 pp.

Habitat evaluation models, such as the U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM), are being widely used to identify instream flow requirements for aquatic biota at hydroelectric projects and other water resource developments. As part of the U.S. Department of Energy's effort to provide guidance to hydropower developers and regulators, a study was conducted to evaluate the validity of physical habitat indices (e.g., weighted usable area) for predicting the response of trout populations to changes in stream-flow. Because the use of habitat indices is based on the assumption that fish abundance or biomass is positively correlated with the value of the habitat index, the study focused on an analysis of fish-to-habitat relationships.

Eight study sites on cold water streams with naturally reproducing populations of brown and rainbow trout were selected. The streams were situated in the southern Appalachian Mountains of eastern Tennessee and western North Carolina. Fish biomass, abundance, and production were estimated, using electrofishing and Petersen mark-recapture techniques. Physical habitat was quantified, using the IFIM's Physical Habitat Simulation (PHABSIM) system at each site. Although previously published habitat suitability criteria were used to calculate weighted usable area (WUA), independent habitat utilization studies were also conducted for Age 0 and Age 1+ rainbow and brown trout. Water quality, water

temperature, macroinvertebrate food resources, and average monthly flow regimes were also measured at each site.

Both trout populations and physical habitat conditions varied significantly between the study sites. Mean abundance of rainbow trout (all ages combined) ranged from 66 fish/km of stream (3.1 kg/km) to 2700 fish/km (44.1 kg/km) at the eight sites. Wild brown trout populations occurred at four of the sites, with mean abundance ranging from 94 fish/km (5.1 kg/km) to 480 fish/km (28.3 kg/km). Rainbow trout abundance and biomass were significantly lower ($\alpha = 0.05$) at sites with coexisting brown trout populations compared to sites with no brown trout. Annual trout production ranged from 0.13 to 6.9 $g \bullet m^{-2} \bullet year^{-1}$ Brown trout abundance and biomass were more strongly correlated with the WUA habitat indices than were rainbow trout abundance and biomass. Significant correlations did exist between the abundance and biomass of brown trout and habitat values based on mean monthly flows over an annual cycle. Rainbow trout abundance and biomass were significantly correlated with minimum incubation habitat based on mean monthly flows, but only at sites without brown trout. Differences were observed between the habitat utilization patterns of allopatric vs sympatric rainbow trout, suggesting that interspecific interactions could be an important factor in the population dynamics of rainbow trout in streams with coexisting brown trout populations. Although the fish data set was somewhat limited because no cohort (year class) was followed over a complete life cycle, some evidence existed of an association between year-class strength and habitat stress, based on estimates of WUA from annual hydrographs for the period 1980-1983.

Based on our results, the validity of the assumption that fish abundance or biomass varies in direct proportion to physical habitat indices could not be rejected. Although physical habitat indices explained a significant proportion of the variability in brown trout populations between sites, habitat condition alone was not sufficient to explain differences in rainbow trout abundance. To predict the response of trout populations to flow alteration, it is recommended that (1) habitat variables be carefully chosen with respect to critical life stages and periods of the year, (2) site-specific interactions between target species be considered, and (3) management objectives be clearly defined. The most appropriate habitat indices are those based on minimum values calculated over the entire period that a given life stage is present. When used properly, habitat variables can be useful in assessing changes in fishery resources resulting from flow alterations.

1. INTRODUCTION

The growing recognition nationwide of the importance of protecting instream uses of water (e.g., maintenance of fish and wildlife habitats) has coincided with the recent emphasis on small hydropower development. As a result, conflicts have arisen over the use of water for hydroelectric generation and other instream uses. For example, water released below a dam to satisfy the instream flow needs of aquatic biota usually reduces reservoir storage that could otherwise be used for power production. Accurate assessment of these instream flow requirements is essential, especially in those regions of the country where water supplies are limited and where greater demands are being placed on offstream water uses (e.g., irrigation, domestic water supply). The purpose of the present study was to evaluate existing assessment methods and to provide guidance on their applicability at small hydropower sites.

1.1 HYDROPOWER DEVELOPMENT AND REGULATED FLOWS

The effects of hydroelectric operations on hydrologic patterns are generally well understood. Alterations in flow regimes below hydroelectric dams can include both spatial and temporal changes in the amount of water moving through a natural stream channel. The degree to which spatial and temporal flow patterns are altered is directly related to the design and operation of the facility. Localized spatial changes in streamflow are characteristic of many small-scale hydropower projects where water is diverted through a canal or penstock to a powerhouse at a lower elevation. The purpose of such diversions is to increase the hydrostatic head on the generator, but the result often involves the dewatering of a significant length of the original stream channel. Temporal changes in streamflow are generally short term at small hydropower sites; that is, they occur over a span of several minutes or hours. Such changes are characteristic of small hydroelectric projects that are operated in a peaking mode. Because the demand for electricity varies over a 24-h period, water is stored during off-peak hours (usually at night) for generation during the period of greatest demand. Peaking operations often result in a dramatic increase in the frequency and rate of change of major water level fluctuations and a reduction in the duration of a given water level (stage height) in the downstream channel. Long-term changes in streamflow involve the use of large reservoir storage volumes to shift peaks in the annual hydrograph to low-flow months.

Information regarding the effects on aquatic biota of such alterations in hydrologic patterns is generally descriptive in nature (e.g., Cushman 1984). In most cases, this information is inadequate for the purpose of quantifying the magnitude of biological impacts. To provide some measure of protection to downstream aquatic resources, the adverse impacts of flow regulation are mitigated by the establishment of minimum discharges at the dam. Because the water released to satisfy various instream flow needs (e.g., protection of aquatic habitats, recreation, aesthetics) often means the loss of some hydroelectric generation, instream flow needs are often perceived as being in direct conflict with the economic feasibility of small hydropower projects (IEC 1981; USDOE 1981).

1.2 STATUS OF INSTREAM FLOW ASSESSMENTS

The resolution of conflicts between hydroelectric generation and other instream uses of water (e.g., fish and wildlife habitat) requires information on the flow regimes needed to protect these uses. Assessment of the instream flow needs of aquatic biota, particularly fishes, has proven to be the most difficult and controversial aspect of the instream flow issue (Loar and Sale 1981). Over the past two decades, numerous methods have been developed to assess the effects of flow regulation on fishery resources and to provide a basis for the determination of suitable instream flow regimes that will protect these resources (see reviews by Stalnaker and Arnette 1976; Wesche and Rechard 1980; Loar and Sale 1981). These methods differ in their use of existing hydrologic records, hydraulic simulation techniques, and fish habitat preferences, and in their capability of providing seasonal and/or species-specific flow recommendations.

Many of the existing methods for assessing instream flow needs rely on historical flow records and do not consider the specific requirements of aquatic biota. Such methods are inflexible, difficult to defend in terms of aquatic ecology, and offer no opportunity for the type of trade-off analysis that is necessary in water resource development today. Even state-of-the-art methods that can quantify changes in habitat as a function of streamflow mav be inadequate because they do not consider other (biological) variables that may be significant determinants of population abundance (Patten et al. 1979).

Assessment of instream flow needs requires the evaluation of an impact chain beginning with streamflow regulation and ending with some biological response (Fig. 1-1). Habitat alteration is an intermediate step in this impact chain and is the focus of most of the assessment methods that currently exist. The linkage between habitat changes and biological response is one of the most important assumptions in instream flow assessment. Although sophisticated models such as U.S. Fish and Wildlife Service (USFWS) PHABSIM (Physical Habitat Simulation) allow quantitative analysis of the effects of flow regulation on physical habitat, these methods do not directly address other important secondary links between habitat changes and biological response. Recent guidance by the USFWS Instream Flow Group (Milhous et al. 1981; Bovee 1982) repeatedly emphasizes the influences of factors other than physical habitat on fish populations. Nevertheless, the most common applications of these methods assume a proportional relationship between habitat condition (however measured) and biological resources (e.g., fish). Therefore, it is the manner in which the methods are applied more than the methods themselves that must be more carefully evaluated.

1.3 STUDY DESIGN

The major objective of this study was to evaluate the predictive capabilities of habitat evaluation methods for assessing the instream flow needs of aquatic biota. The research focused on the following questions:

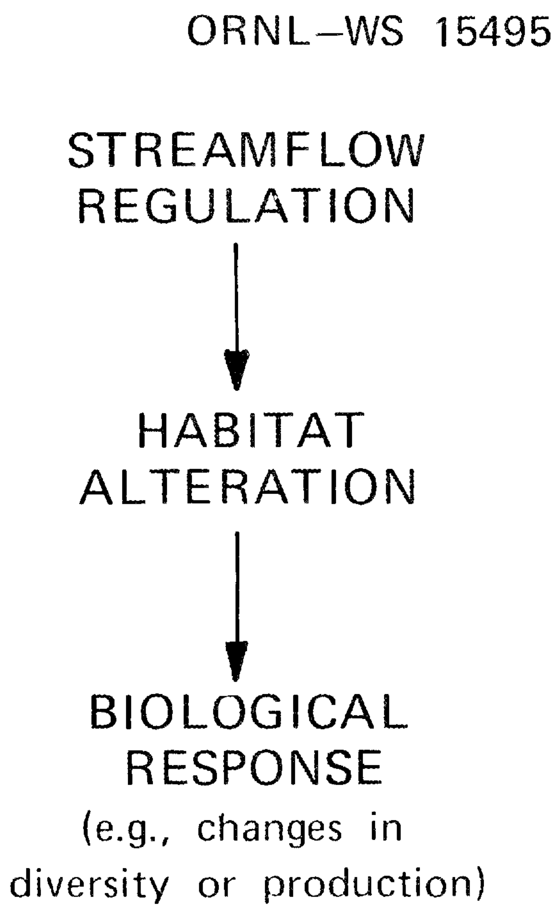

Fig. 1-1. Conceptual basis for instream flow assessment.

1. Are the biological assumptions of these methods valid?

   a. Is there a relationship between habitat availability (as estimated by each method) and habitat utilization (as determined from fish population sampling)?

   b. Can habitat availability be used to reliably predict fish population abundance?

2. Should existing methods be modified to include additional biological variables?

The methods most frequently used to assess instream flow needs for fishery resources evaluate the relationship between streamflow and available habitat and are based on the assumption that habitat availability is the factor limiting population size. These methods were developed in the West to assess the instream flow requirements of salmonid species. According to Patten et al. (1979), fish production in eastern streams is often limited by food resources; physical factors are less likely to be limiting under natural conditions. Thus, the assumption that fish populations are habitat-limited is critical.

This report examines the assumptions associated with the most commonly used method for assessing instream flow needs--the Instream Flow Incremental Methodology (Bovee 1982). Other aspects of instream flow assessment were addressed in this study but were reported separately. For example, an assumption associated with several hydraulic-rating methods (Loar and Sale 1981) is that wetted perimeter, a major flow-dependent variable used to represent habitat condition, is proportional to food production (i.e., benthic invertebrate production). In other words, benthic production is directly related to the bottom surface area. This method has been evaluated by Cada et al. (1984).

Most applications of PHABSIM, a widely used habitat modeling approach associated with the USFWS Instream Flow Incremental Methodology (IFIM), assume the existence of a direct relationship between weighted usable area (WUA) (a computed measure of habitat quality and availability) and fish abundance (Bovee 1982; Orth and Maughan 1982). That is, altering the amount of flow in the stream channel changes the amount or quality of the habitat (as measured by WUA), which, in turn, affects the size of the fish population. Results of the application of this methodology on several southern Appalachian trout streams is the subject of this report. Two null hypotheses were specifically tested in this study: (1) WUA is not correlated with trout abundance or biomass across study sites; and (2) WUA cannot be used to assess the relative effects of different flow regimes on trout populations at individual sites.

Eight study sites in four river basins in western North Carolina and eastern Tennessee were selected after an evaluation of hydrology, stream channel characteristics, accessibility, existence of previous studies, and absence of complicating factors such as high fishing pressure, stocking, or pollution. Rainbow trout (Salmo gairdneri) and brown trout (S. trutta) were selected as the target species because of the extensive data available on their habitat requirements. Wild populations of rainbow trout exist in all the streams, and wild brown trout occur in three of the four river basins. At each site, hydraulic simulation models were applied to evaluate instream habitat and to quantify the relationship between physical parameters of the stream environment (i.e., distribution of depth, velocity, bottom substrate, and cover), streamflow, and trout abundance. Concurrent investigations of the macrobenthic food resources available to trout were also conducted.

2. DESCRIPTION OF STUDY SITES

All eight study sites lie in the higher, densely forested mountains of the Blue Ridge province (Appalachian Highlands; Thornburg 1965) in eastern Tennessee and western North Carolina (Fig. 2-1). With the exception of Lost Cove Creek, all of the study streams lie in the Tennessee River drainage. Lost Cove Creek lies in the Catawba River basin, part of the Atlantic drainage. The climate is humid-temperate, but precipitation and temperature vary widely, depending on elevation and local physiographic features. Mean annual precipitation in the region ranges from <100 cm to >230 cm (Goodge 1983). July is the wettest month, and October or November are the driest (NCC 1973a,b). Annual temperatures for the region average between 12 and 14°C.

Both overland runoff (rare) and base flow in the region tend to be soft, acidic waters of very low specific conductivity. The water quality reflects the geology of the region, which is dominated by bedrock composed primarily of granites, gneisses, mica schists, and slates and low in solubility (USGS 1982). Most of the soils were formed through weathering of these rocks and decomposition of forest litter.

The following subsections describe in more detail the physical characteristics of the eight study sites and their watersheds. A summary of the general hydrologic properties and monthly flow regimes for each of the study sites is presented in Tables 2-1 and 2-2, respectively.

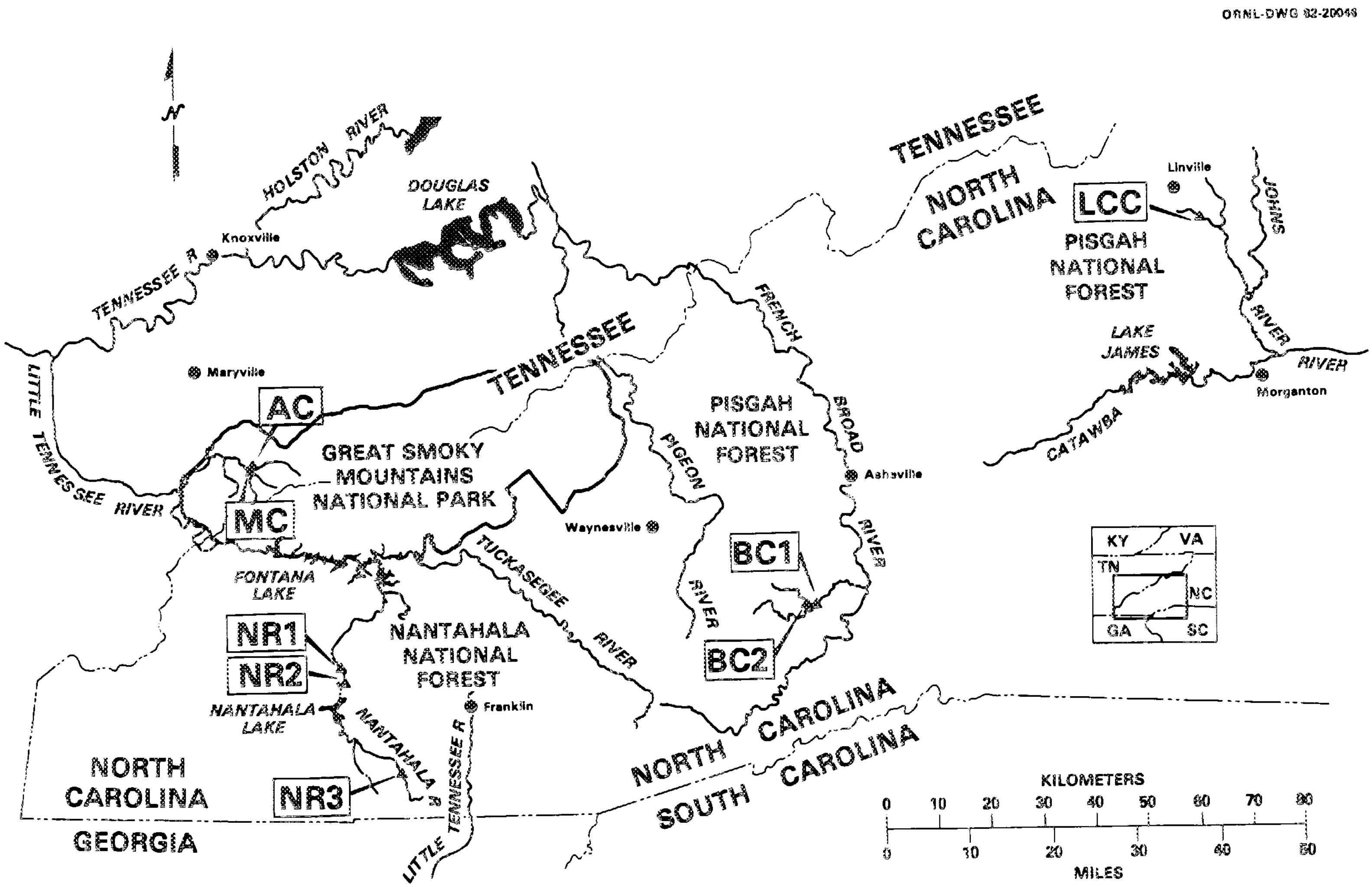

Fig. 2-1. Area map showing locations of the eight study sites.

AC = Abrams Creek; BC1, BC2 = Bradley Creek; LCC = Lost Cove Creek; MC = Mill Creek; NR1, NR2, NR3 = Nantahala River.

Table 2-1. Estimated gross hydrologic properties of the eight study sites.

Study site[a]	Unregulated watershed area (km^2)	Min/max elevation (m)	Estimated gradient[b] (m/km)	Stream order	Proportional Order[c]	Estimated mean flow[d] (m^3/s)	Maximum flow[e] (m^3/s)	Minimum flow[e] (m^3/s)	Estimated mean precipitation[f] (cm/year)
AC	48.9	522/1545	1.2	4	4.99	1.42	87	0.078	140-170
BC1, BC2	31.1	701/1550	17	4	4.99	0.99	81	0.10	140-170
LCC	17.2	597/1310	22	3	3.50	0.37	110	0.009	110-130
MC	41.8	523/1508	8.1	4	4.99	1.22	74	0.067	140-170
NR1	49.8	706/1550	30	4(5)[g]	4.07(5.01)[g]	2.01	>80[h]	0.30	150-170
NR2	14.2	808/1341	8.4	3(4)[g]	3.33(4.98)[g]	0.57	>80[h]	0.085	150-170
NR3	35.8	1042/1554	7.3	4	4.11	1.58	47	0.25	190-240

[a]AC = Abrams Creek, MC = Mill Creek, BC = Bradley Creek, LCC = Lost Cove Creek, NR = Nantahala River.

[b]Mean gradient estimated by the distance between contour lines on U.S. Geological Survey (USGS) 7.5-min quadrangles (gradients of representative reaches may differ; see Table 4-5).

[c]As calculated by the method of Stall and Fok (1968).

[d]Based on application of yield factors ($m^3 \cdot s^{-1} \cdot km^{-2}$) calculated from data for gaged streams in the vicinity of the study sites (Wiser 1981; USGS 1981a,b).

[e]Based on application of yield factors calculated from data in USGS (1981a,b).

[f]From map of precipitation isohyets developed by Goodge (1983).

[g]Historical stream order prior to construction of Nantahala dam system.

[h]Spillway releases from dams.

Table 2-2. Estimated mean monthly flows[a] (m^3/s) at the eight study sites.

	Estimated mean monthly flow (m^3/s)						
Month	AC	BC	LCC	MC	NR1[b]	NR2[b]	NR3
January	1.8	1.1	0.39	1.6	2.7	0.77	2.0
February	2.1	1.3	0.53	1.8	3.1	0.87	2.3
March	2.2	1.5	0.62	1.9	3.2	0.90	2.4
April	2.0	1.3	0.56	1.7	2.7	0.77	2.1
May	1.6	1.1	0.38	1.4	2.1	0.60	1.6
June	1.3	0.90	0.30	1.1	1.8	0.50	1.4
July	1.0	0.62	0.24	0.88	1.4	0.41	1.1
August	0.92	0.70	0.26	0.79	1.3	0.36	1.0
September	0.79	0.52	0.22	0.68	1.1	0.30	0.93
October	0.92	0.84	0.25	0.79	1.2	0.34	1.2
November	0.97	0.81	0.29	0.84	1.4	0.38	1.2
December	1.5	1.1	0.39	1.3	2.2	0.62	1.7
Annual mean	1.4	1.0	0.37	1.2	2.0	0.57	1.6

[a]Based on application of yield factors calculated from data for gaged streams in the vicinity of the study sites (Wiser 1981; USGS 1981a,b). Monthly flows at sites AC and MC are based on application of monthly distribution of flows for certain western North Carolina streams to annual yields per square kilometer for east Tennessee streams.

[b]Flow regime due to unregulated portion of watershed. Spillway releases occasionally add substantially to the listed flows in winter and fall.

2.1 ABRAMS CREEK AND MILL CREEK

These two streams originate high on the northwest slopes of Great Smoky Mountains National Park in Tennessee (Fig. 2-1). The actual study sites lie in Cades Cove, an Ordovician limestone window of remarkably low relief considering the surrounding mountains. They differ from the other study streams in that the underlying rock formations and the resulting soils of their watersheds differ substantially from the formations and soils common to the other six watersheds. The upper watersheds of Abrams Creek and Mill Creek overlie bedrock composed principally of slate, shale, sandstone, and siltstone (DeBuchananne and Richardson 1956; Elder et al. 1959); the three North Carolina streams mainly overlie granite, gneiss, or schist, or combinations of these three rock types (Goldston et al. 1955; Goldston and Gettys 1956; King et al. 1974; King 1980).

The Abrams Creek study site (AC) is a fourth-order stream draining a watershed of 48.9 km^2 (Fig. 2-2). Elevation ranges from about 520 m in Cades Cove to 1545 m on the crest of the Great Smoky Mountains. Annual precipitation averages between 140 and 170 cm/year, depending on elevation (Goodge 1983). The estimated mean flow is 1.4 m^3/s, ranging from an average monthly low flow of about 0.8 m^3/s in September to a monthly high of about 2.2 m^3/s in March. The stream gradient in the vicinity of AC is only 1.2 m/km, far lower than the gradients of the other streams in this study (Table 2-1). The study site itself consists of fairly deep pools and short riffles; exposed tree roots, logs, and brush piles provide cover (Fig. 2-3). The substrate is principally silt and mud, with some gravel, sand, and small cobble in the middle of

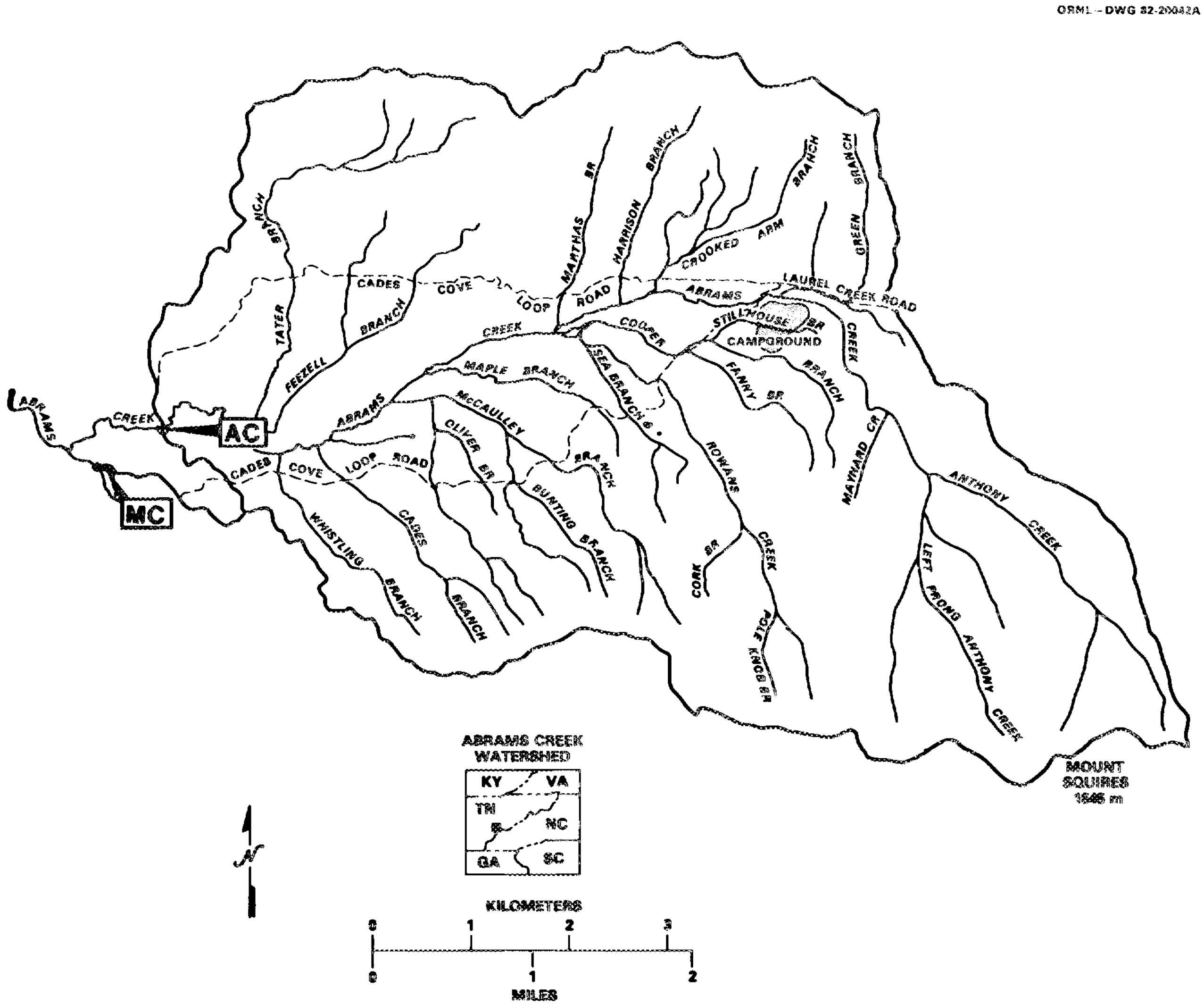

Fig. 2-2. Abrams Creek watershed.

Fig. 2-3. Abrams Creek study site, May 7, 1982. Flow was 0.62 m^3/s (44% of mean annual flow) and mean width was 7.6 m on May 6, 1982.

the channel. Riparian vegetation consists primarily of hardwoods and some shrubs (Table 2-3).

Except for the dam-regulated lower Nantahala River, Abrams Creek is the most disturbed stream system in this study. After emerging from the densely forested slopes of the Great Smoky Mountains, it meanders westward approximately 10 km across the broad, flat valley of Cades Cove. Early settlers cleared much of the Cove for pasture and crops (Mathews 1978), and the preservation of our pioneer heritage is the motivation for currently maintaining the Cove in pasture and hay crops. In the past, grazing of up to 1200-1300 head of cattle had contributed significantly to erosion of stream banks and beds, and to nutrient input, which resulted in the eutrophication and increased turbidity of the stream. More recently, fencing along the stream and reduction of the cattle herd to 500 head appear to have mitigated these adverse effects to some extent (Mathews 1978). Some reaches have been straightened and cleared of trees and brush. Other disturbances to the stream or its watershed include large numbers of people visiting the Cove by automobile, a large camping area, and possible seepage from a sewage treatment lagoon.

Natural influences on water quality include the bedrock and soils over and through which water moves. Soils of the mountainous part of the Abrams Creek watershed consist primarily of Ramsey slaty silt loam, a medium acid soil of moderate fertility derived from slate, sandstone, and quartzite bedrock (Elder et al. 1959). The broad limestone floor of the Cove itself is covered by >1.5 m of soil dominated by Sequatchie silt loam and Hayter silt loam. The former is a fertile,

Table 2-3. Checklist of riparian taxa observed at each of the eight study sites. Vegetation that occurred along the stream bank but did not intersect the plane of the water is not included.

Taxon	Great Smoky Mountains National Park		Bradley Creek		Lost Cove Creek	Nantahala River		
	AC	MC	BC1	BC2	LCC	NR1	NR2	NR3
Alder (*Alnus serrulata*)	X	X	X	X		X	X	
Birch (*Betula*)			X		X	X		
Dog hobble (*Leucothoë fontanesiana*)			X	X				
Elm (*Ulmus*)	X							
Flowering dogwood (*Cornus florida*)	X	X			X			
Hawthorn (*Crataegus*)	X							
Hemlock (*Tsuga canadensis*)		X	X	X				X
Ironwood (*Carpinus caroliniana*)	X	X	X					X
Maple (*Acer*)	X	X	X					
Mountain laurel (*Kalmia latifolia*)			X	X				
Red maple (*Acer rubrum*)	X					X		
Rhododendron (*Rhododendron*)			X	X	X	X		X
Sassafras (*Sassafras albidum*)		X						
Sedge (*Carex*)					X	X	X	
Silky dogwood (*Cornus amomum*)							X	
Silverbell (*Halesia carolina*)		X	X					
Spicebush (*Lindera benzoin*)			X					
Sweetgum (*Liquidambar styraciflua*)		X						
Sycamore (*Platanus occidentalis*)	X	X						
Willow (*Salix*)	X							
Witch hazel (*Hamamelis virginiana*)				X				X
Yellow poplar (*Liriodendron tulipifera*)		X				X		

medium acid, alluvial soil derived from the slate, sandstone, and shale of the uplands, and the latter is a fertile, medium to strongly acid, alluvial or colluvial soil of similar origin.

A portion of Abrams Creek enters the ground near the east end of the Cove, flows underground through the limestone strata, and resurfaces a short distance upstream of the study site near the west end of the Cove. This has important implications for both the hydrology and water quality of Abrams Creek (see Sect. 4.1). During summer, the creek occasionally ceases all surface flow for several kilometers between the water's entry into the ground and its emergence (south-facing tributaries may also dry up). Shifts in pH of nearly two units (Mathews 1978) have been noted between the creek's entry into the ground (pH 6.5) and its emergence (pH 8.4).

The Mill Creek watershed lies immediately to the southwest of the Abrams Creek watershed (Fig. 2-2). The Mill Creek study site (MC) shown in Fig. 2-4 is only 0.6 km from study site AC and 0.3 km upstream of the confluence of Mill Creek with Abrams Creek. A small, operating mill, pioneer cabins, and a visitors center are located about 0.7 km upstream of MC. These facilities and the small clearings surrounding them represent the only current man-made disturbances to the watershed, although some logging occurred in the past. The remainder of the Mill Creek watershed is densely forested mountains.

Mill Creek is also a fourth-order stream with a watershed area of 41.8 km^2 (Fig. 2-5), a gradient of 8.1 m/km in the vicinity of the study site, and an estimated mean flow of about 1.2 m^3/s. Minimum and maximum mean monthly flows are estimated to be 0.68 m^3/s (September)

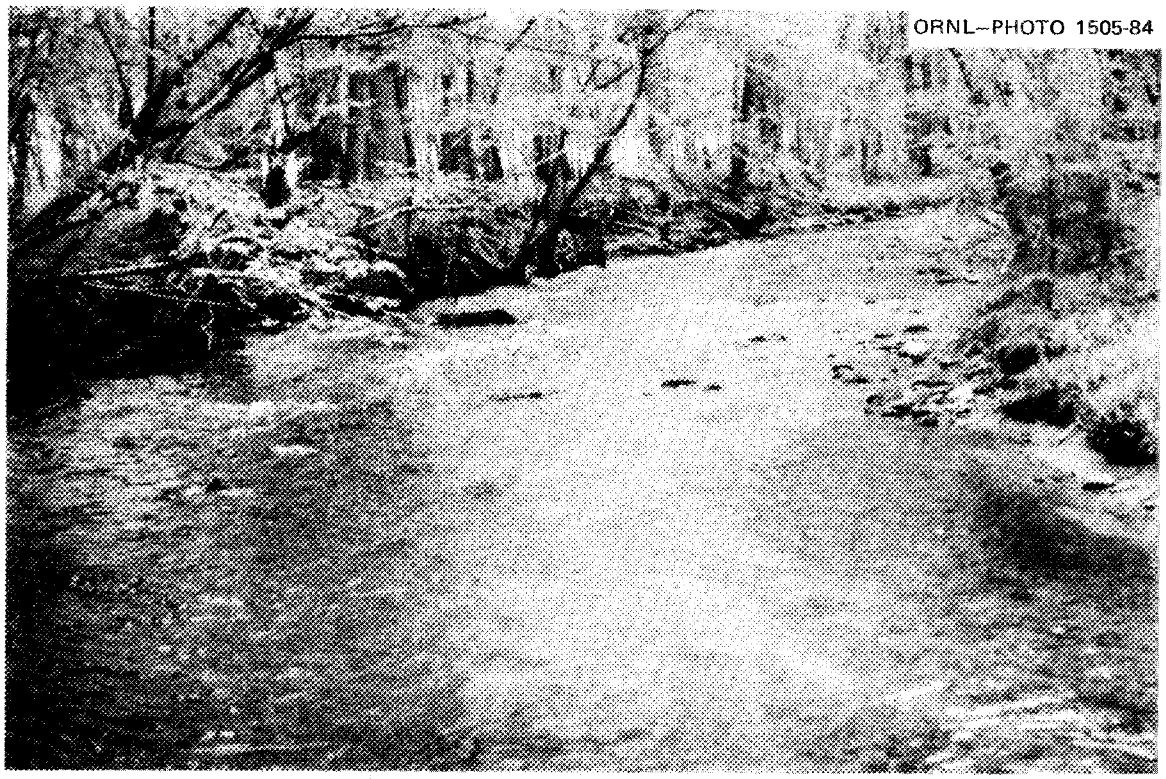

Fig. 2-4. Mill Creek study site, May 7, 1982. Flow was 0.88 m^3/s (72% of mean annual flow) and mean width was 10.4 m on May 7, 1982.

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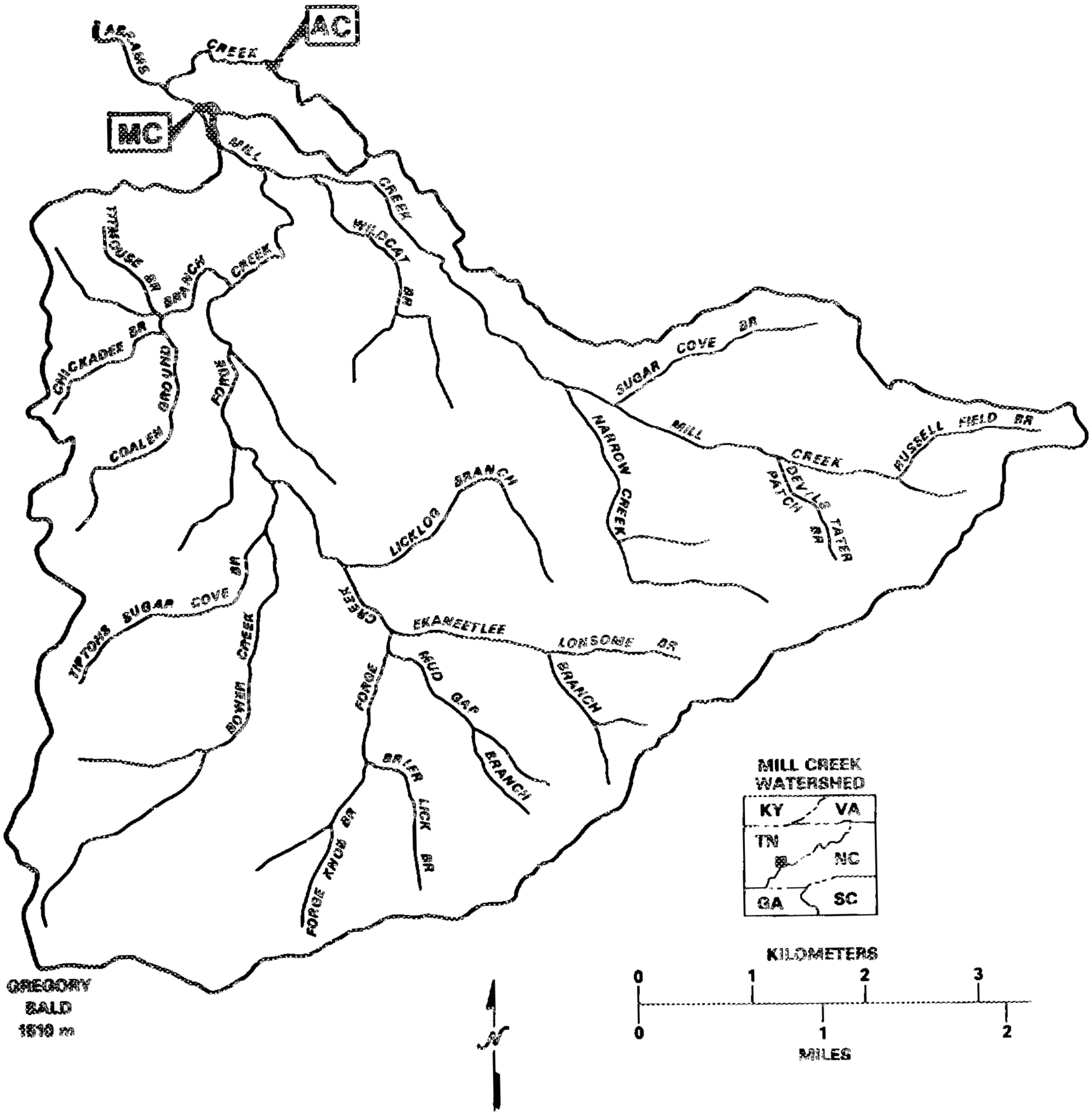

Fig. 2-5. Mill Creek watershed.

and 1.9 m^3/s (March), respectively. Elevations in the watershed range from 523 m to 1508 m. Precipitation is estimated to average between 140 and 170 cm/year (Goodge 1983). Fairly long reaches of shallow riffles and a few pools are typical of the study site (Fig. 2-4). In contrast to site AC, the substrate is mainly bedrock, cobble, clean gravel, and sand. Banks have been undercut by the stream in places. Riparian cover is dominated by a diversity of hardwood species (Table 2-3).

Except for small areas of alluvial soils (primarily Sequatchie loam and Hayter stony silt loam) in the lower watershed near site MC, the soils consist of medium acid Ramsey slaty silt loam, as does the upper watershed of site AC. This soil is derived from slate, sandstone, and quartzite bedrock.

2.2 BRADLEY CREEK

Bradley Creek, a fourth-order stream in the French Broad River basin, drains 31.1 km^2 of mountainous and densely forested land in the Pisgah National Forest (Fig. 2-6). Its watershed straddles the county line separating Henderson and Transylvania counties. Precipitation averages between 140 and 170 cm/year. Elevations range from 705 m to 1550 m. Study sites BC1 and BC2 are located approximately 200 and 350 m, respectively, upstream of the confluence of Bradley Creek with South Fork Mills River.

The stream gradient in the vicinity of the study sites is 17.4 m/km. The estimated mean annual flow at the study sites, based on yields per unit area at similar watersheds in the area, is 1.1 m^3/s.

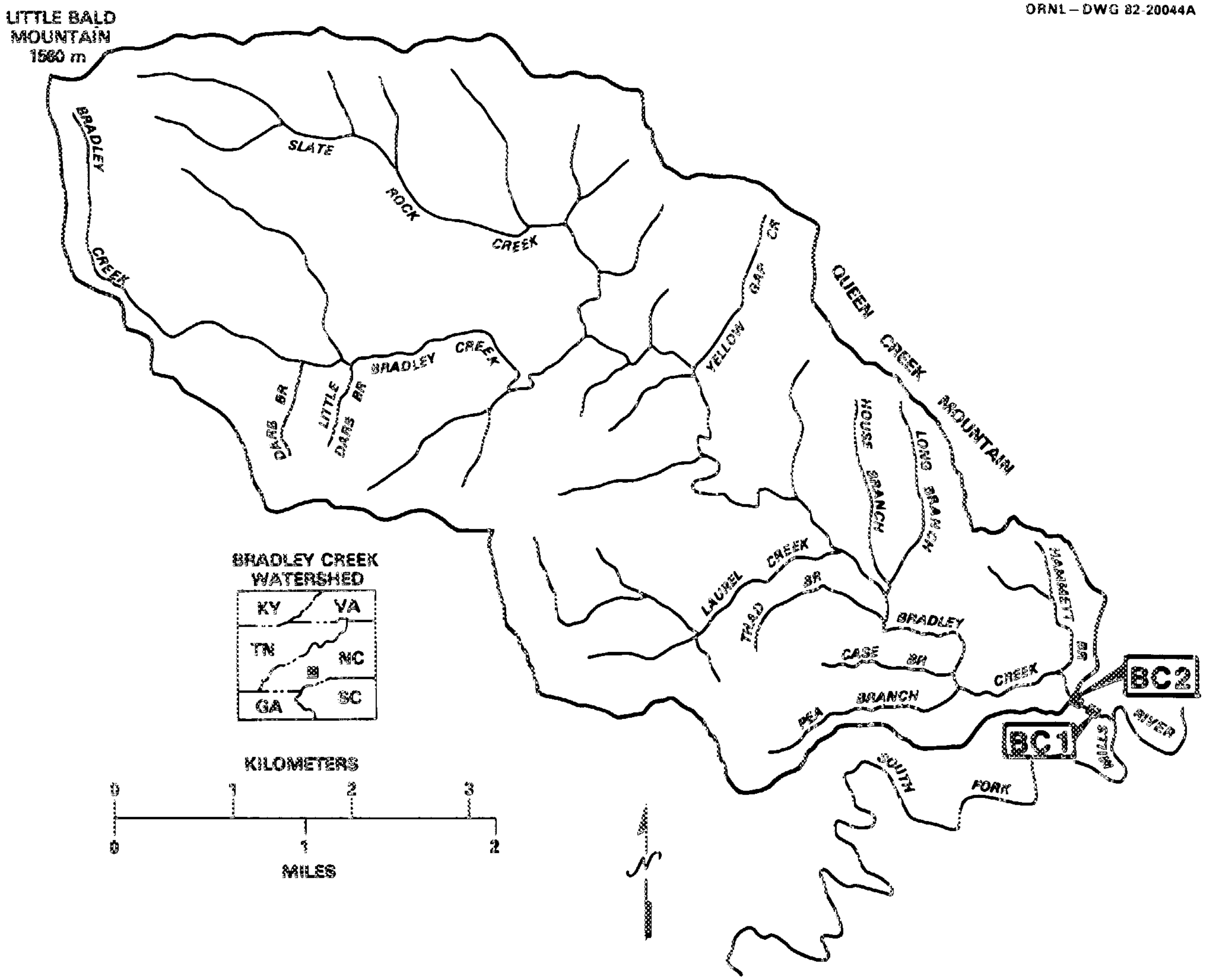

Fig. 2-6. Bradley Creek watershed.

However, the Hendersonville Water Department diverts an annual average of about 0.1 m^3/s from a small impoundment approximately 3.6 stream kilometers above the study sites (Hendersonville Water Department 1983), resulting in a net estimated annual flow of 1.0 m^3/s. The estimated mean monthly low flow is approximately 0.58 m^3/s (September), taking into account diversions by Hendersonville; mean monthly high flow is about 1.5 m^3/s (March).

The upper site, BC2, is characterized by pools, riffles, and long runs over clean gravel, cobble, sand, small boulders, and bedrock (Fig. 2-7). Dense stands of rhododendron and mountain laurel line the stream banks; other riparian species are less abundant (Table 2-3). The downstream site (BC1) has a lower gradient, with long runs and smooth gentle riffles (Fig. 2-8). Pools are limited, but backwater areas exist below the three channel constrictors that were installed by the U.S. Forest Service in a 200-m reach of lower Bradley Creek in 1976 (USFS 1982). These devices are trapezoidal in shape, with approximate areas ranging from 50 to 85 m^2. The stream bank is the base, and the three sides are constructed from large logs. Additional habitat-improvement devices in the study reach include four large logs (3.5 to 7.5 m in length and 0.25 m in diameter) that are oriented parallel to the flow. The substrate at BC1 consists of small cobble, gravel, and sand, with some detritus in small pools and backwaters. In contrast to the upper site, there are few boulders or rock ledges. The riparian vegetation also differs markedly from that found at BC2; it is more diverse and is dominated by dog hobble and several large overhanging ironwood trees (Table 2-3).

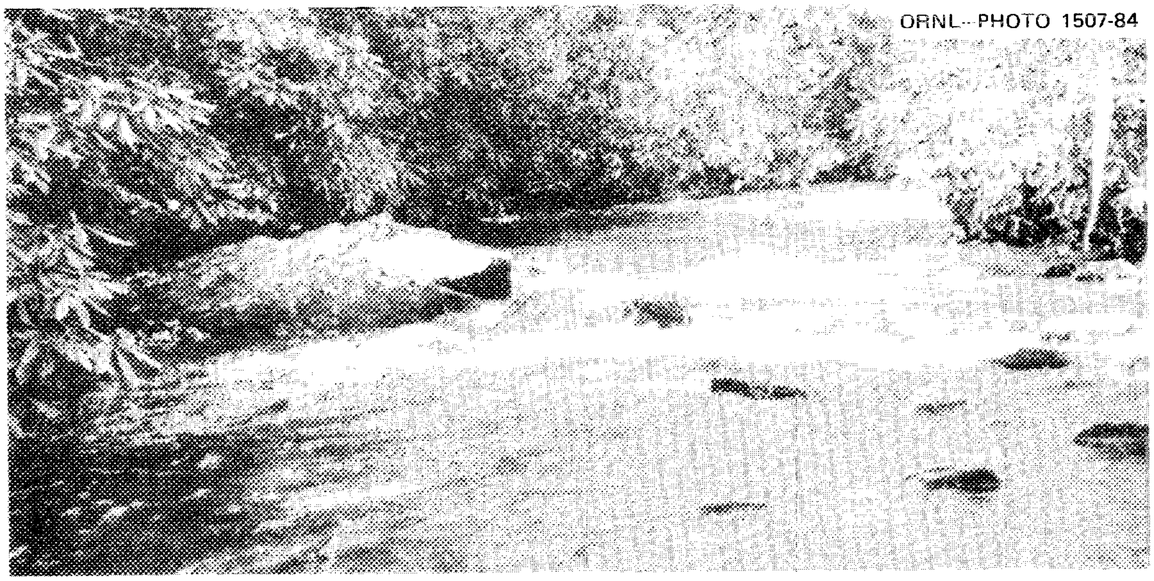

Fig. 2-7. Upper Bradley Creek study site (BC2), April 29, 1982. Flow was 1.13 m^3/s (114% of mean annual flow), and mean width was 10.1 m on April 30, 1982.

Fig. 2-8. Lower Bradley Creek study site (BC1), April 29, 1982. Flow was 1.13 m^3/s (114% of mean annual flow), and mean width was 10.4 m on April 29, 1982. Note log channel constrictor in left foreground.

Most of the soils of the watershed are stony or sandy, strongly to extremely acidic, and of low to medium fertility and organic matter (King 1980, King et al. 1974). They are derived predominately from gneiss or granite-gneiss bedrock.

2.3 LOST COVE CREEK

The Lost Cove Creek study site (LCC) lies in the Blue Ridge Mountains in southeast Avery County, North Carolina, and unlike the other study sites, its waters ultimately flow to the Atlantic Ocean via the Catawba and Santee rivers. The watershed of Lost Cove Creek is mountainous, entirely within the Pisgah National Forest, and almost completely covered in second-growth forest. Annual precipitation averages between 110 and 130 cm/year. Elevations range from 597 m at the site to 1310 m at the top of Little Bald. Most of the watershed consists of rough, stony land of low fertility derived from weathering of the granite, schist, and gneiss rocks dominant in the area (Goldston et al. 1955). Large boulders and bedrock outcrops are plentiful. The stream drops an average of about 22 m/km in the vicinity of the study site. At the site, Lost Cove Creek is a third-order stream draining an area of 17.2 km^2 (Fig. 2-9). Mean annual flow is estimated to be about 0.37 m^3/s, the lowest of the streams under investigation. Average monthly flows (estimated) range from 0.22 m^3/s in September to 0.62 m^3/s in March.

The study reach consists of alternating riffles, runs, and pools, with a substrate of clean cobble, gravel, sand, and small boulders (Fig. 2-10). Mixed hardwoods and sedges are the dominant riparian flora (Table 2-3).

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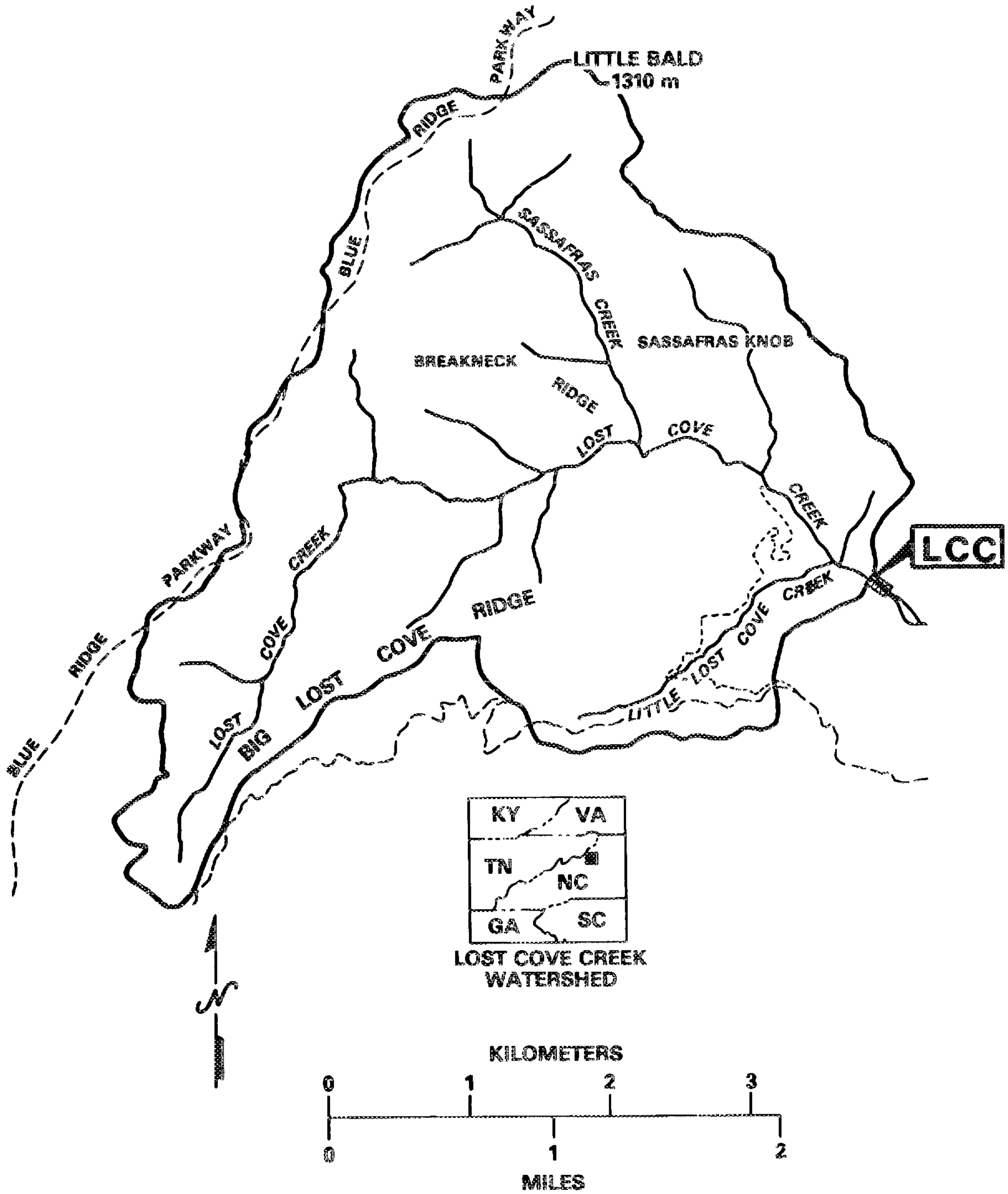

Fig. 2-9. Lost Cove Creek watershed.

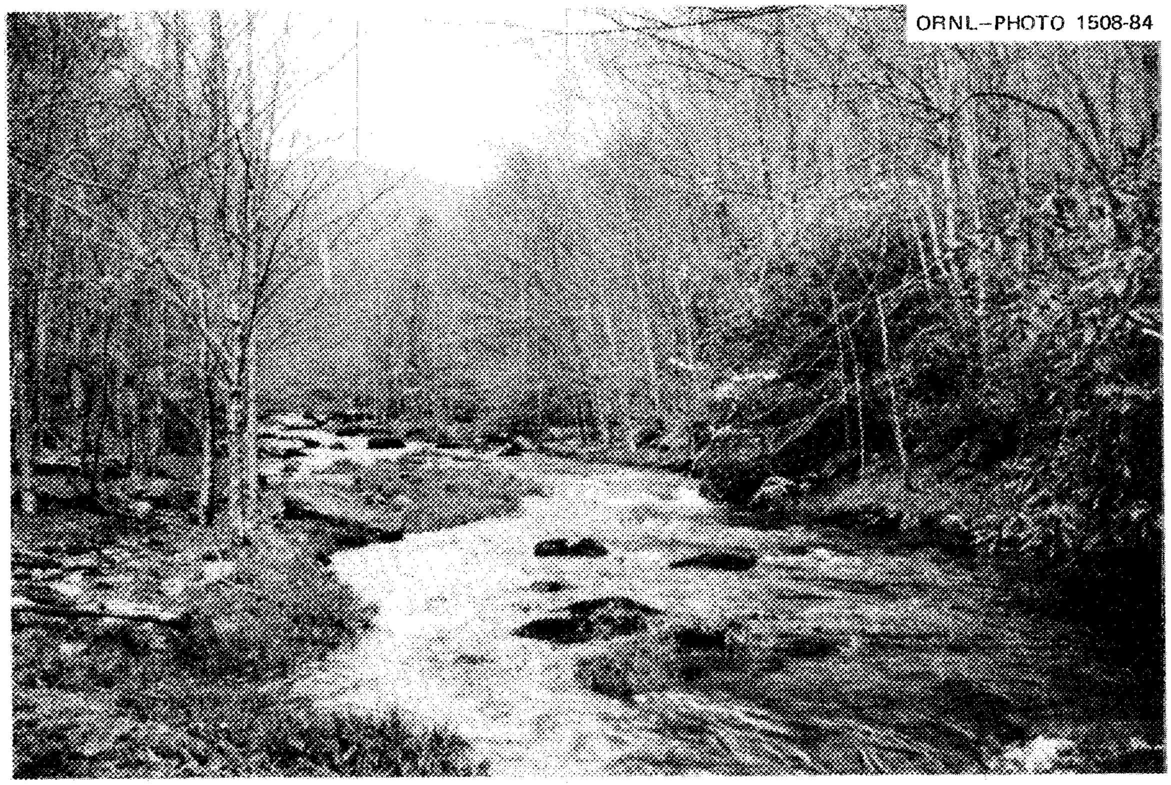

Fig. 2-10. Lost Cove Creek study site, April 27, 1982. Flow was 0.74 m^3/s (200% of mean annual flow), and mean width was 7.8 m on April 27, 1982.

2.4 NANTAHALA RIVER

The Nantahala River drains a portion of the Tennessee River basin in a large, mountainous, often densely forested area of Nantahala National Forest in southwestern North Carolina (Macon and Clay counties). Three study sites (NR1, NR2, and NR3) are located on the main stem of the Nantahala River (Fig. 2-1). Meteorological conditions, particularly precipitation, vary considerably within the watershed. In the vicinity of study sites NR1 and NR2, annual precipitation averages between 155 and 160 cm/year (Goodge 1983). Included within the watershed above the NR3 site is a portion of the wettest area in the United States east of the North Cascades of Washington (Geraghty et al. 1973). Annual precipitation averages about 190 cm/year near the actual study reach and as high as 236 cm/year in the vicinity of the headwaters (Goodge 1983). Interestingly, the driest area in the Southeast lies only about 80 km to the northeast in a rain shadow near Asheville where precipitation averages less than 100 cm/year.

Stony rough land and Porters loam, both derived from weathered granite, gneiss, or schist bedrock, are the dominant soil types in the watersheds of all three Nantahala River study sites (Goldston and Gettys 1956). Colluvial and alluvial deposits of Porters soils are found along either side of several stream reaches. The NR1 site also has some Ramsey stony loam, derived from the weathering of highly silicious rocks such as sandstone, slate, and shale (Goldston and Gettys 1956). All of these soils are strongly to very strongly acid.

At 1042 m, NR3 is the highest of the eight study sites. Maximum elevation in the watershed is 1554 m. The Nantahala River at this site is a fourth-order stream with a gradient of 7.3 m/km and a watershed area of 35.8 km^2 (Fig. 2-11). Mean annual flow is estimated to be 1.6 m^3/s. Estimated maximum and minimum monthly flows are 2.4 m^3/s (March) and 0.93 m^3/s (September), respectively. The NR3 site consists of several pools (one of which exceeds 1.5 m in depth), riffles, and gentle rapids (Fig. 2-12). Boulders, bedrock ledges, cobble, clean gravel, and sand dominate the stream bottom. Rhododendron, ironwood, and hemlock are the principal riparian species (Table 2-3).

Some logging occurred above NR3 during the course of this study (USFS 1984). Clearcutting in the Hurricane Creek and Curtis Creek watersheds (Fig. 2-11) was initiated in 1981 and completed, except for seeding, in 1983. Similar operations were conducted over the same period in the Long Branch watershed below NR3. Previous clearcutting operations above NR3 were limited to the Hurricane Creek and Little Indian Creek watersheds in the early 1970s. At present, timber harvest is restricted to the Kimsey Creek and Park Creek drainages below NR3, where clearcutting was initiated in spring 1983. No effects of logging on stream water quality at NR3 were observed (see Sect. 4.1).

The Nantahala River at study site NR2 is a third-order stream that drains a watershed of only 14.2 km^2 (Fig. 2-13). It has a gradient of 8.4 m/km and an estimated average flow of 0.57 m^3/s, excluding occasional releases from an upstream dam. Minimum and maximum mean monthly flows are estimated at 0.30 m^3/s in September and 0.90 m^3/s in March, respectively (see Table 2-2 for all estimated mean monthly flows). Elevations range from 808 to 1341 m. The study reach consists of several short-to-long pools interspersed with short lengths of

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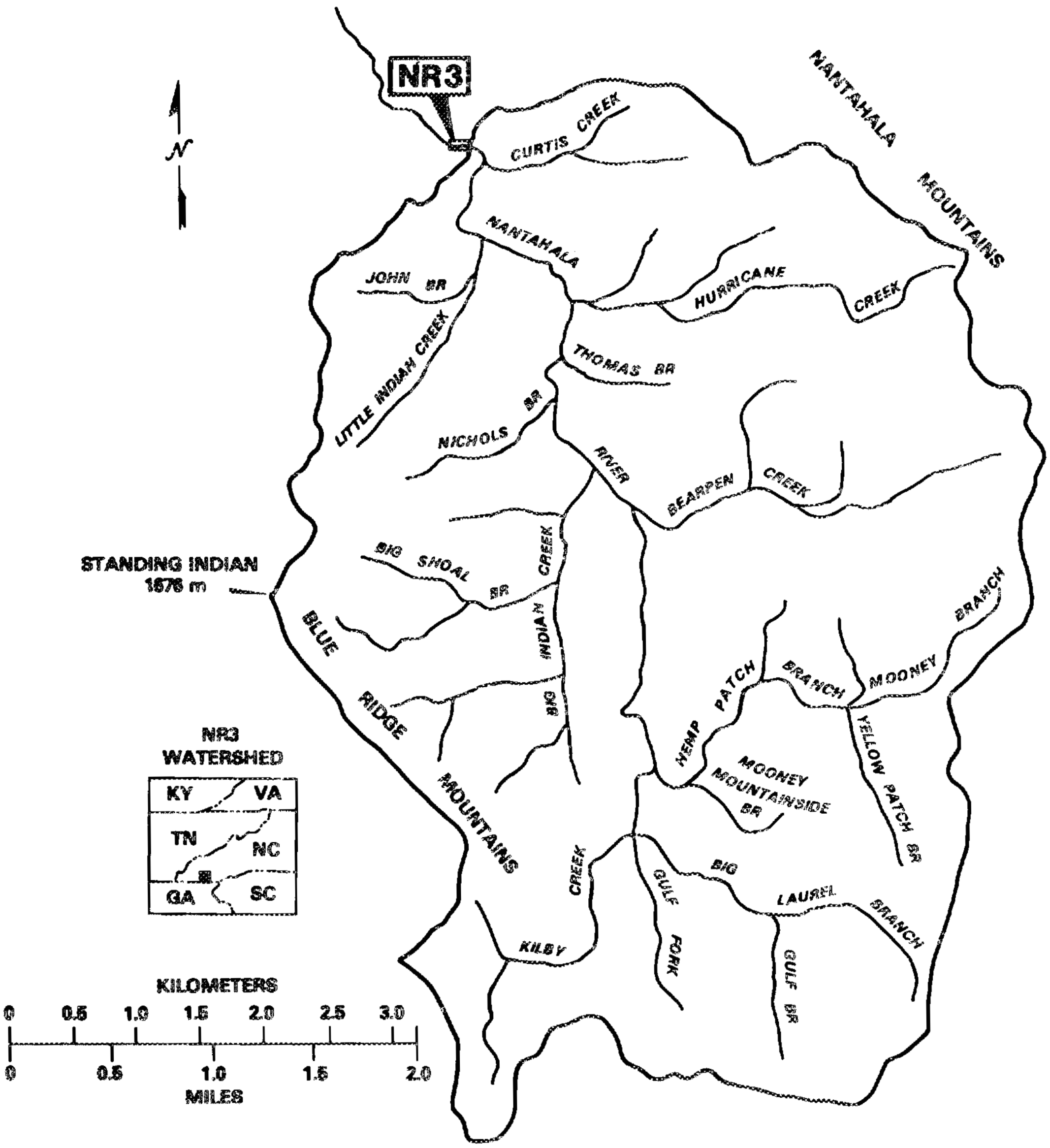

Fig. 2-11. Nantahala River watershed above NR3.

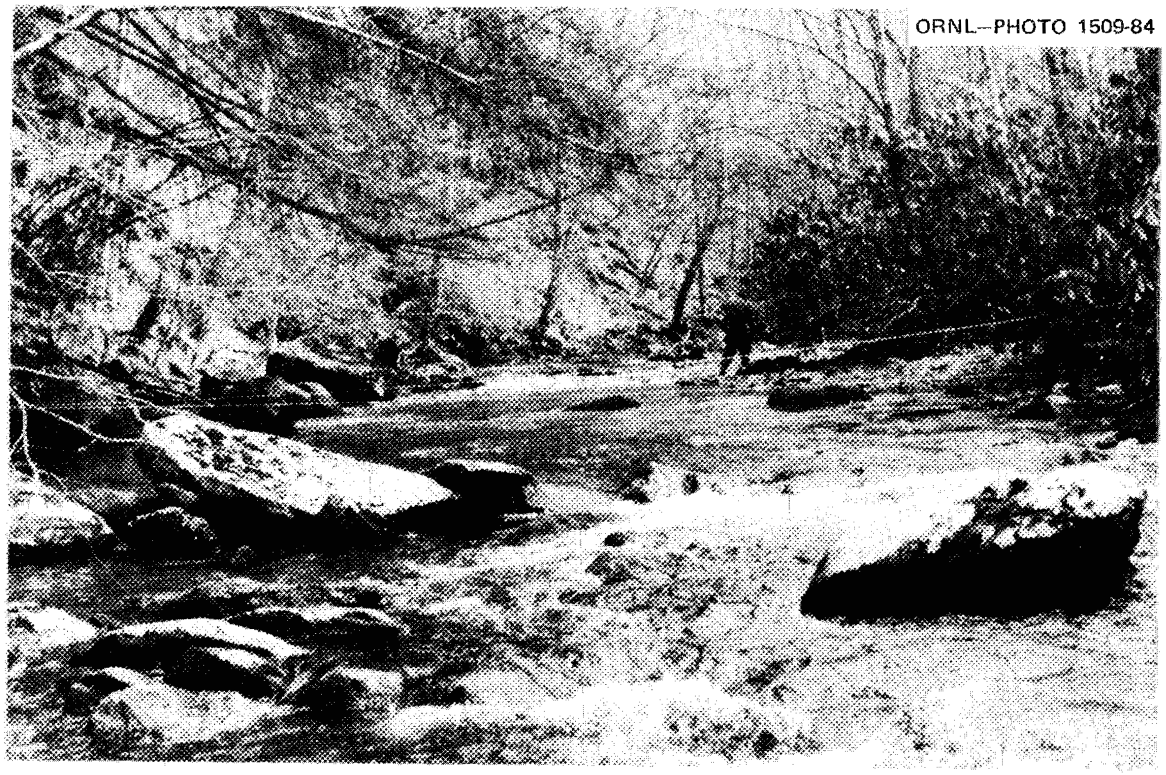

Fig. 2-12. Upper Nantahala River study site (NR3), March 25, 1982. Flow was 1.53 m^3/s (97% of mean annual flow), and mean width was 12.0 m on March 25, 1982.

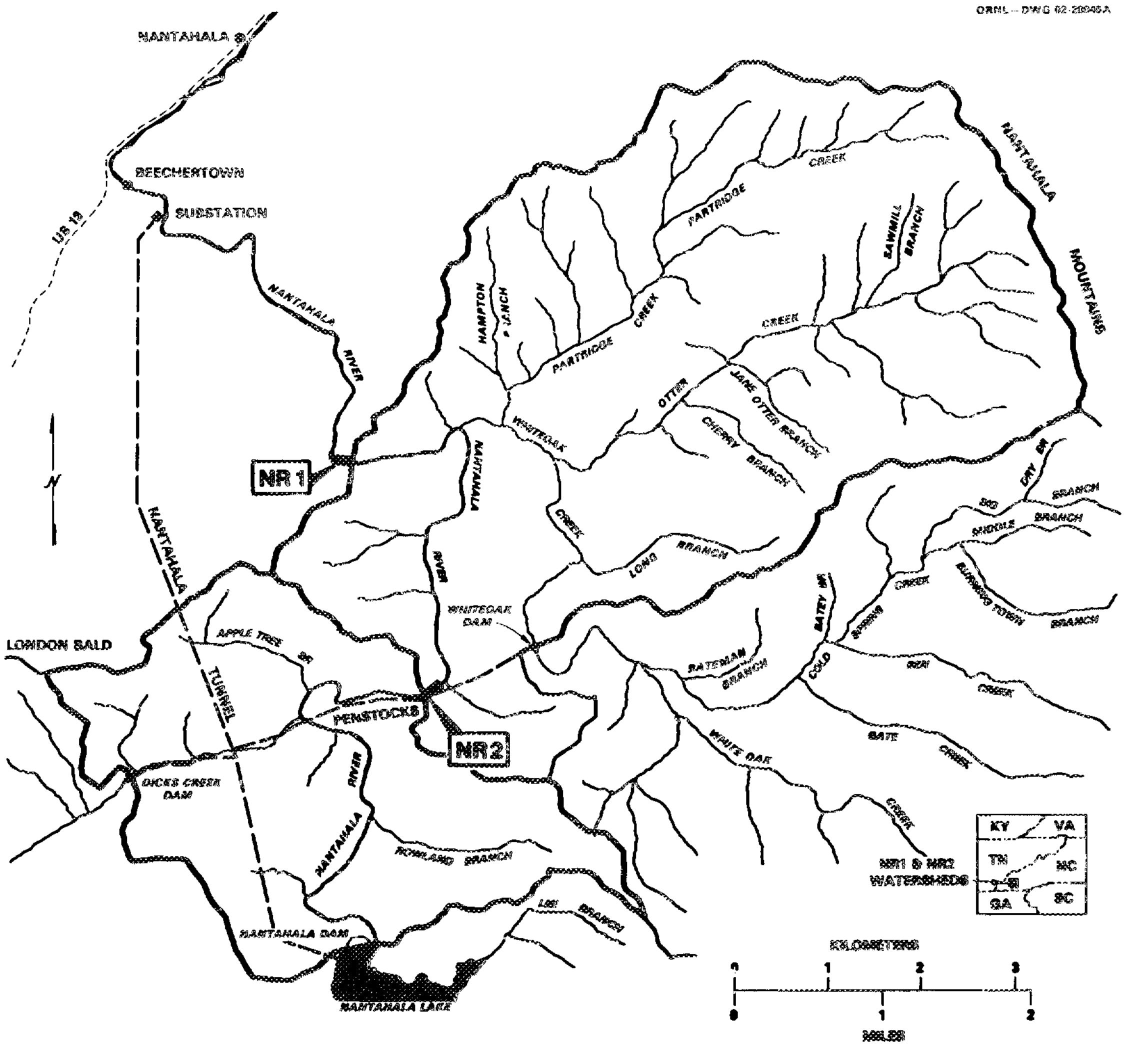

Fig. 2-13. Unregulated watersheds above the NR1 and NR2 study sites.

riffles (Fig. 2-14). The substrate consists mainly of angular bedrock, boulders, and cobble, but there is also a considerable amount of silt and detritus on the bottom of pools and backwaters. Riparian cover consists almost exclusively of alder with very few other species (Table 2-3).

At NR1, the Nantahala River is a fourth-order stream draining an unregulated watershed of 49.8 km^2 (Fig. 2-13); the regulated watershed is much larger (see discussion below). Elevations range from 706 m to 1550 m; the gradient (30 m/km) is the steepest of the eight study sites under study (Table 2-1). The estimated mean annual flow, due to the unregulated watershed, is 2.0 m^3/s, with a mean monthly maximum of 3.2 m^3/s in March and a mean monthly minimum of 1.1 m^3/s in September. The study site consists of a series of small cascades and runs interspersed with fairly deep plunge pools and still backwaters (Fig. 2-15). The substrate comprises broken and deeply creviced bedrock ledges, boulders, and cobble, with clean gravel and sand between the boulders and cobble. The riparian vegetation consists of mixed hardwoods, alder, and some sedges (Table 2-3).

In contrast to the relatively undisturbed state of the NR3 watershed, the watersheds of NR1 and NR2 are the most disturbed of the eight sites included in this study, with the possible exception of Abrams Creek. Numerous small areas have been logged or cleared for farming (Goldston and Gettys 1956), though not to the extent observed in Cades Cove above AC. More important, however, is the alteration in natural flow regimes at NR1 and NR2 that have resulted from the construction and operation of Nantahala Dam (5.8 km upstream of NR2

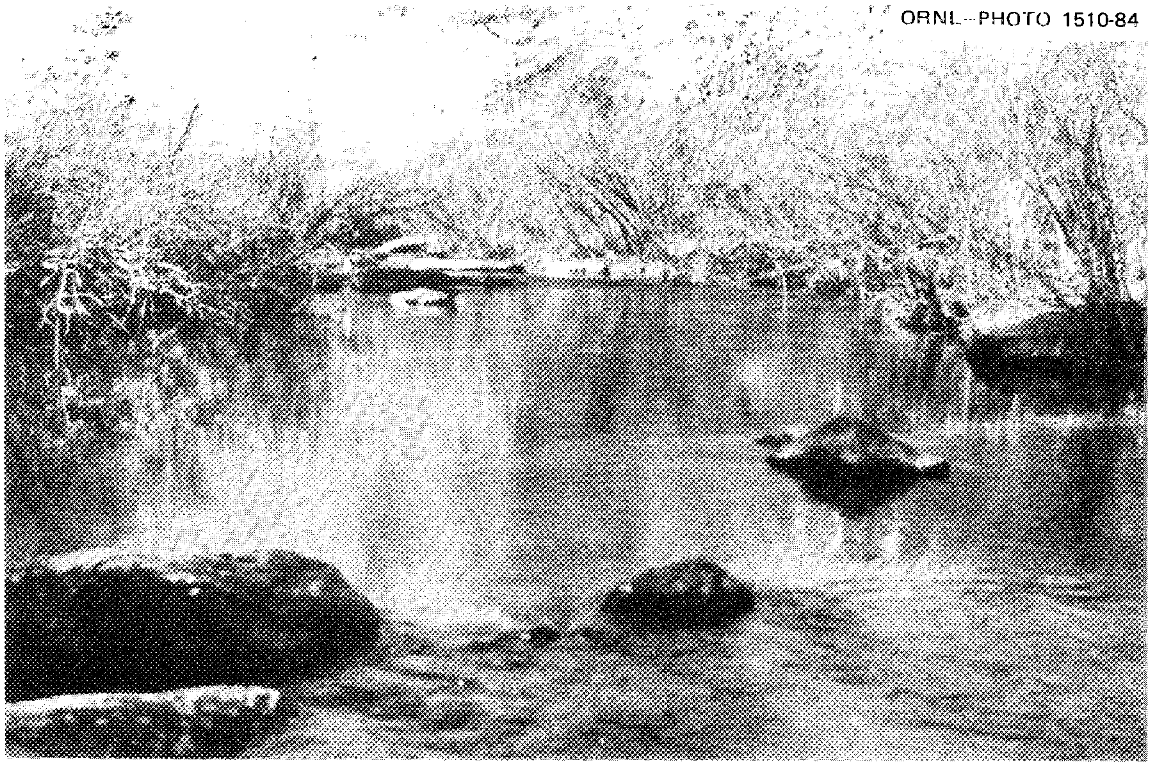

Fig. 2-14. Middle Nantahala River study site (NR2), March 23, 1982. Flow was 0.65 m^3/s (114% of mean annual flow), and mean width was 10.9 m on March 22, 1982.

Fig. 2-15. Lower Nantahala River study site (NR1), March 23, 1982. Flow was 2.89 m^3/s (144% of mean annual flow), and mean width was 18.4 m on March 24, 1982.

and 10.5 km upstream of NR1) and two smaller auxiliary dams on Dicks Creek and White Oak Creek (Fig. 2-16). These dams have converted a fourth-order stream (NR2) and fifth-order stream (NR1) into third-order and fourth-order streams, respectively, with concomitant reductions in total watershed area and flows. Total effective watershed area of NR1 was reduced from 329 km^2 to only 49.8 km^2, and that of NR2 was reduced from 258 km^2 to just 14.2 km^2.

Most of the water upstream of these dams is now diverted through penstocks and tunnels to a powerhouse located 4.2 km below NR1. The flow regimes are therefore determined primarily by precipitation and runoff from the unregulated watershed below the dams. Additional contributions to river flow, however, occur from small but unknown quantities of seepage through and under the dams and from spillway releases at Nantahala Dam during exceptionally wet periods or during maintenance on the penstocks and tunnels (NPLC 1983). During such periods, daily spillway releases have averaged as high as 76.7 m^3/s, which occurred on March 30, 1975 (TVA 1983), compared to our estimated mean flows for the unregulated watershed of 2.0 m^3/s and 0.6 m^3/s for NR1 and NR2, respectively.

These high flows were not used in developing estimates of the monthly and annual flows for NR1 and NR2. Considering the present size of the watersheds, such spillway releases are more properly considered to be abnormal events. The last large-volume releases occurred in March and April of 1980 when daily spillage averaged as high as 50.4 m^3/s. Since then, the only gate releases of any consequence have occurred during the fall when daily releases may average as much

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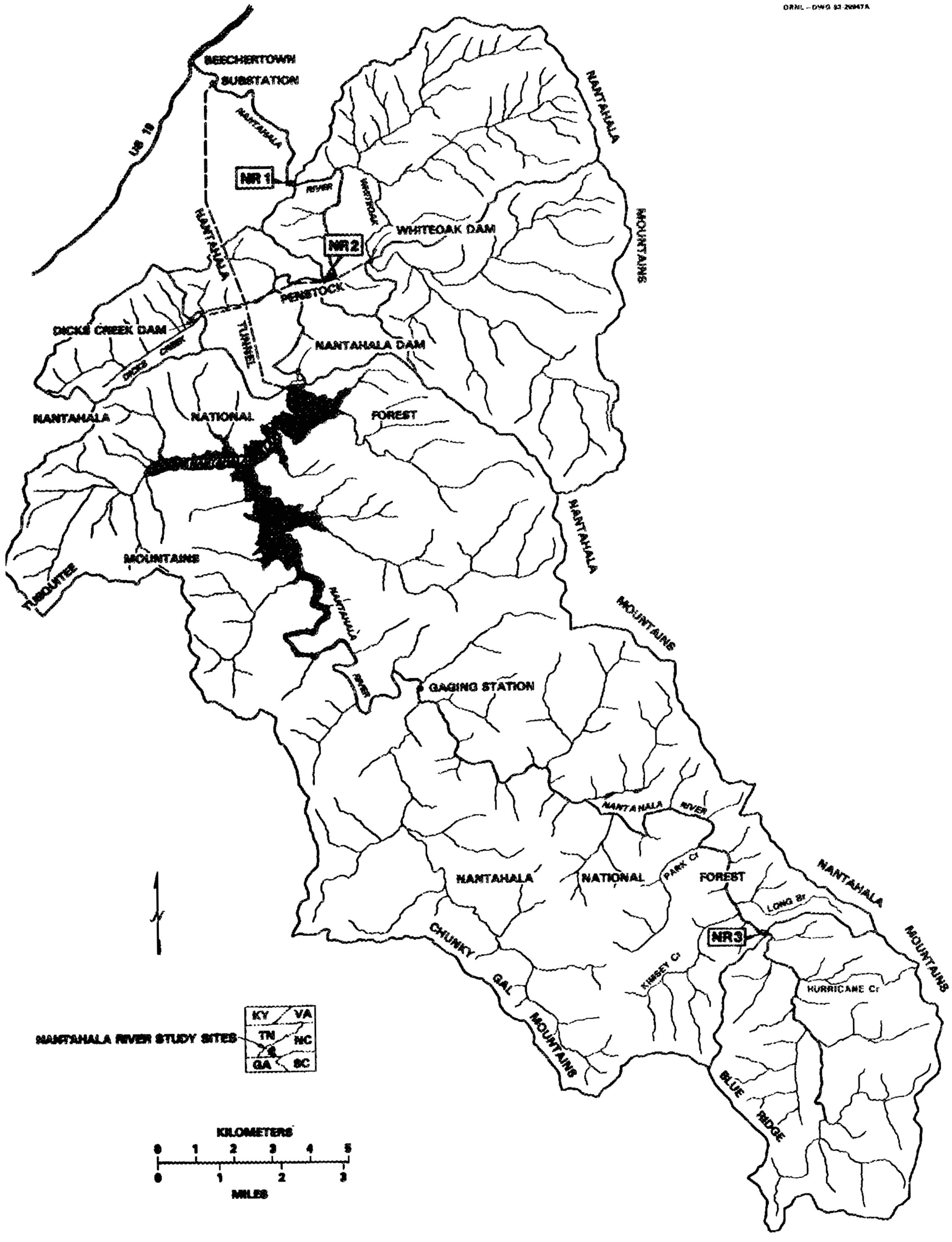

Fig. 2-16. Nantahala River watershed above NR1.

as 2.1 m^3/s. Although hardly catastrophic, even this rate of release is nearly twice the fall flow rates at NR1 (about 6 times the unregulated fall flows at NR2). On an annual basis, the total volume of spillway releases represents as much as 50% of the volume attributable to the unregulated watershed of NR1. However, these releases are concentrated in a very small percentage of the days of the year.

3. METHODS

3.1 HYDROLOGY AND PHYSICAL HABITAT

At each of the streams selected for study, representative reaches (Bovee 1982) were identified to serve as the basis of stream gaging and mapping of physical habitat variables. These reaches were selected after a careful visual survey of a longer, relatively homogeneous stream segment. Although reach selection was somewhat subjective, both fishery and hydraulic considerations were included in the evaluation to ensure that a representative reach was chosen. Along each reach a set of seven to ten permanent transects was established with headstakes on each bank. Transects were placed first at hydraulic controls (e.g., channel constrictions or riffle zones) to cover at least two complete riffle-to-pool sequences (starting and ending at controls). Additional transects were then placed to account for variation in other habitat variables, such as depth, velocity, width, cover, or substrate. All layout procedures were intended to conform as much as possible with the guidance provided by the USFWS Instream Flow Group (Bovee and Milhous 1978; Bovee 1982).

Channel cross sections, stream bank topography, water surface elevations, distances between headstakes, and headstake elevations were determined by stadia, using a Brunson transit and a leveling rod. Distances between headstakes were checked by taping. All level loops were closed to within 1.5 cm. Permanent benchmarks (e.g., crosses chiseled in boulders) were left at each study site and given relative elevations to conform roughly with U.S. Geological Survey (USGS) topographic maps of the sites.

During each visit to a study site for biological sampling, stream discharge was measured. Standard USGS procedures (e.g., Buchanan and Somers 1969) were followed in locating transects and velocity observation points for calculating total discharge. Transects used for calculating discharge were not necessarily along the habitat transects described above, but instead were located at the most uniform cross section within the reach. Discharge through partial sections was limited to 10% of total discharge.

Three types of current meters were used to measure water velocity: (1) Price AA (vertical axis, mechanical), (2) Price pygmy meter (vertical axis, mechanical), and (3) Marsh-McBirney Model 201 meter (electromagnetic). The mechanical meters were used primarily for discharge measurement or shallow water situations. The Marsh-McBirney meter was used primarily for the habitat transects to reduce sampling time. Correspondence between the two meter types was good as long as the batteries in the electromagnetic meter were kept fresh and the suggested maintenance procedures were followed. It was found that soaking the probe of the Marsh-McBirney meter in ambient stream water for approximately 60 min improved the accuracy of the velocity observations.

Depth, velocity, and substrate observations were taken across each of the habitat transects one to three times during the year, depending on the hydraulic simulation model to be applied at each site (Table A-1). Stations with lower gradients and more uniform flow regimes (e.g., AC) could be modeled with the Water Surface Profile (WSP) model in PHABSIM (Milhous et al. 1981). Other stations were surveyed three times to obtain a data set adequate for either WSP or the IFG4 model (cell-specific rating curves) in PHABSIM (Bovee and Milhous 1978; Milhous et al. 1981).

Substrate type was quantified, using the original code designations (Table 3-1) derived by the Instream Flow Group (Bovee and Cochnauer 1978). However, a three-digit code was employed which distinguished (1) dominant particle size by the value in the tens position, (2) subdominate particle size in the ones position, and (3) percent embeddedness of the dominant particles by the value in the tenth position. For example, substrate composed of small boulders that were 50% embedded in a gravel matrix would receive a composite value of 75.5. Ultimately, this three-digit code was converted back to a one-digit code in the PHABSIM application because habitat suitability data were not available in detail commensurate with the more detailed substrate code (see Sect. 3.2).

Estimates of average monthly flow regimes at each study site were calculated by first deriving a water yield (discharge per unit area; $m^3 * s^{-1} * km^{-2}$) statistic at several gaged watersheds nearby, then multiplying by the drainage area above the study site. The gaged watersheds used for each site (Table 3-2) were selected to have similar elevation, slope orientation, and physiography compared to the study site. Data for the gaged sites were obtained from Wiser (1981) and the USGS (1981a,b). Monthly flow data from gaged streams near the two Tennessee sites (AC and MC) were not available. Therefore, monthly flows at these sites were estimated by first calculating the mean percentage of annual runoff occurring in each month at two gaging

Table 3-1. Substrate codes used in the physical habitat analyses.

Code	Substrate type	Particle size range[a] (mm)
1	Plant detritus	N/A
2	Clay	<0.004
3	Silt	0.004-0.062
4	Sand	0.062-2.0
5	Gravel	2.0-64.0
6	Cobble and rubble	64.0-250.0
7	Boulders	250.0-2000.0
8	Bedrock	>2000.0
9	Logjams and/or root wads	N/A

[a]N/A = not applicable.

Table 3-2. Gaged watersheds used to estimate monthly flow regimes at the eight study sites.

Study site	Gaging station (USGS station number)	Watershed area (km^2)	Distance from study site (km, direction)
AC and MC	Cosby Creek above Cosby, Tenn. (3461200)	26	66, ENE
	Little River above Townsend, Tenn. (3497300)	275	15, ENE
	Tellico River at Tellico Plains, Tenn. (3518500)	306	47, SW
BC1 and BC2	Davidson River at Brevard, N.C. (3441000)	105	11, SW
	Mills River near Mills River, N.C. (3446000)	173	7, NE
	East Fork Pigeon River near Canton, N.C. (3456500)	133	23, NW
	West Fork Pigeon River above Lake Logan, N.C. (3455500)	71	27, W
	French Broad River at Rosman, N.C. (3439000)	176	29, SW
LCC	Linville River near near Nebo, N.C. (2138500)	173	26, S
	Yadkin River at Patterson, N.C. (2111000)	75	24, E

Table 3-2. (Continued)

Study site	Gaging station (USGS station number)	Watershed area (km^2)	Distance from study site (km, direction)
LCC	Watauga River near Sugar Grove, N.C. (3479000)	239	23, N
	South Toe River near Celo, N.C. (3463300)	112	39, SW
NR1 and NR2	Nantahala River at Nantahala, N.C. (3505500)	373	4, NW
NR3	Nantahala River near Rainbow Falls, N.C. (3504000)	143	12, NW
	Cartoogechaye Creek near Franklin, N.C. (3500240)	148	15, NE
	Little Tennessee River near Prentiss, N.C. (3500000)	363	15, NE

stations: the Nantahala River near Rainbow Springs, North Carolina, and the Little Tennessee River near Prentiss, North Carolina (Wiser 1981). These percentages were then multiplied by mean annual flow values for stations near Mill and Abrams creeks (USGS 1981b).

Estimates of watershed areas, elevations, stream gradients, and stream orders presented in Table 2-1 were determined from USGS 7.5-min topographic quadrangles. Precipitation estimates for the study sites were obtained from an unpublished isohyetal map of the region prepared by Goodge (1983), showing lines of equal mean annual precipitation based on data for the period 1935-1969. Information on operation of the Nantahala dams was provided by the Tennessee Valley Authority (1983) and Nantahala Power and Light Company (1983). The Hendersonville Water Department (1983) provided information on municipal diversions of water from Bradley Creek.

3.2 PHYSICAL HABITAT ANALYSES

3.2.1 PHABSIM Application

Physical habitat condition at all study sites was modeled, using PHABSIM, a package of computer programs developed by the Instream Flow Group (IFG) of the U. S. Fish and Wildlife Service, Ft. Collins, Colorado (Milhous et al. 1981; Bovee 1982). Access to PHABSIM was arranged through the University of Illinois at Urbana-Champaign (UIUC) where the software package was set up to teach an IFG Computer Simulation Training Course in the fall of 1981. A telecommunication link (TELENET) was utilized to provide remote access to the CDC CYBER 175 at UIUC. Input and output files were transferred between UIUC and

Oak Ridge National Laboratory (ORNL) by use of a TRS-80 Model 16 microcomputer. This strategy provided the most cost-effective access to the type of CDC machine that is compatible with the PHABSIM software.

Physical habitat modeling consisted of four phases: (1) preparation of data input files for PHABSIM, (2) hydraulic simulation modeling of depth, velocity, and substrate conditions as a function of discharge, (3) calculation of habitat response functions (habitat usability indices vs discharge), and (4) calculation of annual hydrologic and habitat regimes.

All data from discharge measurements and other depth and velocity transects were transferred from field data sheets to keypunch code sheets and stored on the IBM INTERACT system at ORNL. A SAS program was used to make unit conversions, to transform tag line distances and elevations to a uniform coordinate system for each reach, and to calculate discharge at each transect. SAS was also used to create the input files for WSP and IFG4 and to plot channel cross sections and substrate profiles. Ultimately, the hydraulic-habitat data sets were stored in a single data base.

As mentioned above, hydraulic simulation was carried out with either the WSP or IFG4 models in PHABSIM. The WSP model is a traditional "step-backwater"-type model based on the Manning equation, the Bournoulli equation, and the principle of conservation of mass and energy (Bovee and Milhous 1978; Milhous et al. 1981). The procedure used in calibrating WSP followed the guidance of Milhous et al. (1981), where the values of Manning's n are adjusted in two sets of interactions, once to predict water surface elevations at each transect and then again to predict velocities at each vertical across the transect. The second model, IFG4, uses a regression-type analysis at each point across each transect to produce depth-discharge and velocity-discharge rating curves (Milhous et al. 1981). This latter model is more suitable for the rapidly varied flow conditions but only if transect cross sections are relatively stable. The AVEDEPTH program in PHABSIM was used to calculate wetted perimeter and other hydraulic variables.

The HABTAT program of PHABSIM was used to calculate habitat response functions at each site. Habitat usability was calculated as if fish response to physical variables was independent and univariate:

$$WUA = \sum_{i=1}^{n} \hat{S}_i A_i \quad ,$$

where

WUA is weighted usable area (ft/1000 ft of stream),

$\hat{S}_i$ is a composite suitability coefficient for mapping element i,

A_i is the wetted surface area of the ith mapping element,

n is the total number of mapping elements.

Composite suitability was calculated simply as a product of individual suitability coefficients:

$$\hat{S}_i = s_v(v_i) \; s_d(d_i) \; s_s(s_i) \quad ,$$

where

$s_v(.)$, $s_d(.)$, and $s_s(.)$ are univariate suitability functions for velocity, depth, and substrate, respectively,

v_i, d_i, and s_i are mean water column velocity, mean depth, and substrate, respectively, for the ith mapping element.

Physical habitat was also quantified in terms of percent usable area (PUA) as:

$$PUA = 100\ (WUA/TSA) \quad ,$$

where

TSA is the total surface area of a study reach.

In the calculation of WUA values, physical habitat suitability data published by the U. S. Fish and Wildlife Service for the family Salmonidae (Bovee 1978) were used. These suitability curves were based on a combination of literature values (Terhune 1958; Coble 1961; Baldes and Vincent 1969; Hartman and Galbraith 1970; Stewart 1970; Hooper 1973; Reiser and Wesche 1977) and unpublished field data to which statistical analyses described in Bovee and Cochnauer (1977) could be applied. Although these habitat suitability data were not site-specific, their use in this study duplicates the most common application of PHABSIM for instream flow assessment. They were chosen as the best available first approximation of trout behavior. The development of site-specific suitability curves for use in the calculation of habitat indices (i.e., WUA or PUA) was beyond the scope of this report.

3.2.2 Habitat Availability and Utilization

Data were gathered for calculating site-specific habitat suitability curves during late summer and fall, 1983 (Table A-2).

Two study sites, NR1 and NR2, were not sampled because of difficulty in sampling (NR1) and small population size (NR2). For the other streams, collections were made both within the primary study reaches and in stream segments adjacent to these representative reaches.

A two-man crew collected fish, using a pulsed direct-current electrofisher (see Sect. 3.5). Both individuals worked slowly upstream and normally sampled a single fish at a time. Every attempt was made to identify the actual (i.e., initial) location of the fish prior to any disturbance caused by electroshocking. The location at which each fish was first observed (not necessarily where it was caught) was marked with a numbered float attached by cord to an 84-g weight. After the total length of the fish was measured and recorded along with the species, it was released downstream from the point of collection. Once the locations of 25 to 35 fish had been marked in this manner, sampling for fish stopped temporarily while habitat parameters were measured. These sampling procedures have been previously described by Bovee and Cochnauer (1977).

Depth, velocity, and substrate were determined for each float site and recorded in association with the data on species and length. Depth was read from the wading staff of a Price pygmy flow meter at the site of the float; velocity was determined at both 0.6 depth and the bottom, using the pygmy flow meter. Substrate was classified visually into a single category, using the modified Wentworth particle size scale (Sect. 3.1). For the purpose of determining habitat preferences, small boulders were included with small and large cobble in the rubble category.

Additional trips were made to each study site to measure available habitat characteristics throughout the stream reach sampled for fish. Two sampling procedures were followed: grid sampling and transect sampling (Table A-2). Grid sampling consisted of measuring depths (with a meter stick) and substrates for a 1-m grid over the entire stream reach sampled for fish (i.e., measurements were made at 1-m intervals both across the stream and along the length of the stream); no velocity data were recorded. Transect sampling entailed recording depth, velocity at 0.6 depth (using the pygmy flow meter), and substrate categories at 1-m intervals along transects spaced 5 m apart along the length of the stream. The initial transect for habitat availability was identical to the downstream transect in each representative reach. The other transects, however, did not correspond to those used to simulate hydraulics within the reach. The grid data were used, where available, to calculate the proportion of habitat in the various depth and substrate categories, and the transect data were used in a similar manner for velocities. If no grid sampling was conducted, depth and substrate were also taken from the transect data.

Habitat utilization data were used to calculate probability-of-use, or suitability, curves for three size or age classes for each species of trout, following the methods of Bovee and Cochnauer (1977). Fish were classified as fry (<11 cm), juvenile (11.0-17.9 cm), or adult (>17.9 cm). In addition, the data were analyzed for patterns of habitat use relative both to what habitat was available at a given site and to what other species of trout were present. Contingency tables were used for some of these analyses; sample sizes necessitated combining juvenile and adult fish to produce an Age 1+ category. The fry were all Age 0.

3.2.3 Cover Mapping

The type and quantity of instream and riparian cover available to trout were mapped at each of the sites in 1983. Cover items that were mapped included (1) emergent or submerged rocks, (2) overhanging riparian vegetation, (3) debris or brush piles, (4) root wads, (5) logs or fallen trees, (6) undercut banks, (7) cobble fields, and (8) large pools. In order for a cover object such as a rock, root wad, or debris pile to be included on the map, it had to be at least 0.5 m in either length or width. Clusters of smaller boulders that had an effect on water currents similar to that of a large boulder were also mapped. Overhanging vegetation was mapped separately, depending on whether it was less than or greater than 1 m from the water surface.

All cover mapping was done by setting up a tag line along each transect of the study section. A particular cover object was identified, and the perpendicular distance from the object to a point on the tag line was measured with a tape measure. Thus, two measurements were used to locate a cover object: (1) distance of the object from a headstake (i.e., distance along the tag line), and (2) distance of the object from the transect connecting the headstakes (i.e., perpendicular distance from the tag line). These two measurements represented coordinates by which the locations of cover objects and shorelines were plotted in the field on standard graph paper. The size of a cover object was also drawn to scale by means of length and width measurements. The height of an instream cover object both above and below the water surface was measured with a meter stick. The height (above and below the water surface), length, and depth of undercuts in banks, boulders, and other objects were also measured. The result was a sheet of graph paper (1 square = 0.2 m) containing the location and size of all the cover objects described above, including extent of undercutting, on either side of a given transect.

Undercut banks and boulders, instream object cover, and overhanging vegetation within 1 m of the water surface were quantified from the detailed cover maps. The length and area of undercuts with a width greater than 0.1 m were calculated for each of two categories: (1) undercut banks and (2) undercut boulders and logs which also provided overhead cover. Estimates of the number of objects and the area of instream object cover were also obtained. The zone of influence downstream from the object was also estimated by multiplying the water depth behind the object by half the width of the object perpendicular to the flow. The area of overhanging vegetation and the total area of the study reach were determined by planimetry. The total length and area for each of the three cover categories were computed and expressed as a percentage of the total area of the reach.

Incorporation of the cover data into the calculation of weighted usable area was beyond the scope of this report. However, these data were analyzed to evaluate the importance of cover as a determinant of trout abundance in our study streams (Sect. 4.5.4).

3.3 WATER CHEMISTRY

Selected physical and chemical parameters were periodically measured at all sites for the purpose of developing background information on the water quality of the study streams. With the exception of Bradley Creek, water samples were collected on each sampling trip from March through November 1982 at each site. A single water sample on each trip was used to characterize the two Bradley Creek sites because of their proximity to each other (Sect. 2.2) and the absence of tributaries entering Bradley Creek between the two sites.

Water samples were collected from fast-moving riffle areas away from the stream bank. The water was stored in glass bottles, and analyses were generally begun within 1 h (never more than 5 h) of collection. On the rare occasions when analyses were delayed, the water samples were stored on ice.

Water temperatures were measured in two ways. Continuous water temperature readings were made from late April 1982 through September 1983 by anchoring a Peabody Ryan Model J90 thermograph at each site. The submerged thermographs recorded temperatures on a continuously moving strip chart. Thermographs were positioned in deep water near riffles so that water surrounding the temperature probe was constantly exchanged and the thermograph was never exposed by falling water levels.

Water temperature was also periodically measured (e.g., during fish sampling trips) with a Hydrolab Digital 4041. The submersible probe of the Hydrolab was placed in a riffle and, in addition to temperature, provided measurements of conductivity, pH, and dissolved oxygen.

Dissolved oxygen was measured at each site on each trip (April to early September 1982) by the Winkler procedure with the azide modification (APHA-AWWA-WPCF 1975). Water samples for dissolved oxygen analysis were collected in glass-stoppered bottles and either tested immediately or, if analysis was delayed a few hours, fixed immediately and stored on ice. Dissolved oxygen was measured with the Hydrolab after mid-September 1982.

A Hach DR-EL/2 portable water test kit was used during 1982 to make field measurements of alkalinity, total hardness, calcium hardness, nitrate, and orthophosphate. Because of the extremely low values of these parameters, modifications to the basic procedures were made according to Hach recommendations. Larger water volumes (50 mL instead of 10 mL) and correspondingly larger reagent volumes were used in the alkalinity, total hardness, and calcium hardness tests. Nitrate and orthophosphate analyses were performed, using distilled water-reagent blanks to correct for reagent-caused turbidity. This was done by obtaining a nitrate or phosphate concentration reading from a distilled water-reagent mixture and subtracting that value from the concentration value for the river water-reagent mixture. Because of variations observed within the same lot of reagents, distilled water-reagent blanks were run on each date that nitrate and phosphate were analyzed.

Turbidity was periodically measured at streamside, using an H.F. Instruments Model DRT-15 portable turbidimeter. A water sample was taken from a riffle and used to determine the turbidity of the stream prior to electroshocking.

3.4 MACROBENTHOS SAMPLING

Benthic macroinvertebrates were sampled from April through September 1982 to assess the instream food resources available to fish populations and to relate the fluctuations in these resources to discharge-bottom habitat dynamics. Each site was sampled on three dates, approximately 2 months apart (Table A-1). Benthic organisms were collected along transects used to obtain habitat information (Sect. 3.1), and the same transects were used each time a site was sampled. Generally, three transects were sampled at a site. The transects were selected based on the shape of the channel: (1) one transect in which substantial areas of substrate were inundated during winter and spring flows but were dry during low summer flows, (2) another transect in which most of the bottom area was expected to remain inundated even during low flows, and (3) a third transect which was intermediate between the two extremes in terms of bottom habitat loss under low flows. Depending on the width and heterogeneity of the wetted substrate, four to seven evenly spaced bottom samples were taken from the riffle areas of each transect.

Benthic organisms were collected with Hess stream bottom samplers. Two Hess samplers with different collection net mesh sizes were used interchangeably: one (designated the blue sampler) had 263-µm-mesh netting, and the other (the silver sampler) had 363-µm-mesh netting. In other regards the two Hess samplers were the same; i.e., they had the same design and both sampled a circular area of 0.1 m^2. Collection efficiencies of the two samplers were compared by analysis of variance. The total number of organisms, total weight of organisms, and total number of chironomids were all used as dependent variables in separate analyses. Variations due to site, season, and site-season interaction were removed by including them as factors in each analysis for sampler differences. No significant differences (α = 0.05) were found for total numbers (P = 0.54), total weight (P = 0.58), and total number of chironomids (P = 0.08).

The sampler was placed on the substrate along a transect line, and rocks within the sampler were stirred and rubbed to dislodge the benthic organisms and sweep them into the collection net. For each sample, records were made of the time of day, water depth, distance from a permanent headstake, and the type of substrate being sampled. All samples were placed in plastic jars and field-preserved in 10% Formalin.

Drift samples were also collected on a limited basis in 1982. The primary goals of this study were to evaluate the contribution of terrestrial input to the overall macroinvertebrate drift in the study streams and to evaluate the degree to which trout utilized the drift. Consequently, stream drift was sampled from midmorning to early afternoon on the dates of fish recapture efforts (Table A-1). These samples were used to assess the type and quantity of drift available just prior to and during collection of fish for diet analyses (see Sect. 3.5).

Two rectangular drift nets (30 x 46 cm), made of 363-μm-mesh Nitex, were positioned in the water a short distance upstream of the fish-shocking section and salt blocks. In this way, fish-shocking activities did not affect the drift rates, yet representative samples of macroinvertebrate drift passing through the study section were obtained. The two nets were placed on opposite sides of the stream channel in water slightly less than 30 cm deep in order to ensure that organisms drifting either in the surface film or along the bottom would be collected. Data on the length of time the drift nets were in the water and the mean current velocity through the nets were used to calculate the volume of water filtered. Because it was recognized that nets clogged with drift and debris would affect the filtering rate, mean velocity values were obtained by averaging the current velocity readings taken in both clean nets and clogged nets (clogged nets are defined here as the state of the nets at the end of the sampling period). Current velocities were measured in the mouths of the nets with the same current meters used in the hydraulic studies (Sect. 3.1). Drift samples were placed in glass jars and field-preserved in 10% Formalin. Results of the drift studies are presented in Sect. 4.3.4.

In the laboratory, all macroinvertebrates (benthos and drift) were separated from debris in a white tray with the aid of a magnifier. Organisms were identified to the lowest practical taxon, using dissecting microscopes. Wet weights of combined aquatic taxa, combined terrestrial taxa, and large individuals (such as crayfish and mollusks) were determined to the nearest 0.001 mg, using a microprecision balance.

3.5 FISH SAMPLING

Fish populations at all eight study sites were periodically sampled between June 1982 and July 1983 (Table A-1). The goals of this study were to compare the composition and structure of the fish communities and, for rainbow and brown trout, to obtain estimates of population age structure, density, biomass, production, growth rates, and feeding relationships. The same sites that were the subject of detailed physical and macroinvertebrate studies were also sampled for fish (Fig. 2-1). In addition, lengths of stream above and adjacent to the study sections were also sampled in order to increase the number of fish collected. The lengths of these above-site sampling reaches varied between sites, ranging from 18 m at BC1 to 180 m at BC2. Information on fish collected from the above-site and within-site reaches was kept separate.

A mark-recapture technique was used to estimate the populations of rainbow and brown trout. During 1982, a single pass was made through the shocking area on the first day, and all trout collected were marked with fin clips. The same procedure was used for the recapture run (generally 2 or 3 days later; see Table A-1), and the number of marked fish in the recapture sample was noted. In 1983, two or three passes were made through the shocking area on the mark and/or recapture run to increase the sample size and thus the precision of the population estimates. Fish sampling was usually done in the late morning or early afternoon.

Fish were collected using Smith-Root Type XV backpack electrofishers, which utilize self-contained, gasoline-powered generators capable of delivering up to 1200 volts of pulsed direct current. A pulse frequency of 120 Hz was used at all times, and the output voltage was adjusted to the optimal value (generally 600 V or more) based on the water conductivity at a given site. Because of the very low conductivity at most of the sites (Sect. 4.1), the highest fish-capturing efficiency was obtained by attaching two anode poles to the electrofisher rather than one anode pole and a trailing, flat aluminum cathode, which is normally supplied with these units. Each pole had a circular ring electrode, and the anode pole was fitted with a nylon net so that the electrofisher operator could also collect stunned fish.

Depending on the stream flow at the site, from one to three 23-kg salt blocks were put in the water upstream of the fish-shocking areas in order to increase the conductivity of the water and the resultant effectiveness of the electrofishers. After the conductivity had increased (generally to above 20 µS/cm), the electrofishers were adjusted to the optimum voltage, and collection was begun immediately. Fish sampling began at the downstream end of the within-site reach and continued upstream to the top of the above-site reach. In order to restrict the movement of fish during collection, a 0.95-cm-square-mesh block net was stretched across the river at the junction of the within-site and above-site reaches, and the top of the above-site reach was frequently some natural barrier such as a waterfall or shallow riffle. Stunned fish were netted and immediately transferred to open-top, 0.64-cm-mesh holding cages, which had previously been distributed in shallow water along the fish-shocking area. Two electrofishers were used simultaneously at all sites except NR1, where three were used because of the wide stream channel.

The total length (TL) of all trout and larger nonsalmonids was measured in 1982. Individual weights were also determined for these fish by means of an OHAUS triple beam balance; smaller fishes, such as minnows and sculpins, were normally grouped by species, counted, and weighed together. Nonsalmonids were not sampled in 1983. Fish collected on the initial run were marked by clipping a portion of one of the fins (pectoral, pelvic, caudal, adipose). Different fins were used for different dates and different fish-shocking areas at a given site. All fish were allowed to recover in the holding cages before being redistributed throughout the shocking area, and any fish that appeared to be dying were preserved instead of being returned to the stream. In 1983, MS-222 (tricaine methanesulfonate) was used to anesthetize trout prior to measurement.

Larger trout (generally greater than 14 cm TL) that were collected on the recapture run had their stomachs flushed to determine feeding preferences. This was accomplished by inserting a plastic tube (0.5-cm outside diameter) into the gullet and repeatedly injecting river water into the stomach with a rubber bulb having one-way valves [similar to the procedure used by Seaburg (1956)]. Stomach contents were flushed through the mouth into a jar and were preserved in 10% Formalin. Other data that were collected as part of fish sampling efforts included percent cloud cover, conductivity (both before and after addition of the salt blocks), turbidity, water temperature, pH, and dissolved oxygen concentration.

To supplement age and growth information derived from length-frequency histograms, scales of rainbow and brown trout were collected for age determination. Scales were taken from an area above the lateral line and anterior to the insertion of the dorsal fin. Generally, scales were removed only from individuals greater than 10 cm TL; smaller fish were assumed to be Age 0.

The scales were mounted on or between pieces of transparent plastic and secured either by cellophane tape or 35-mm slide mounts. Enlarged images of the scales were projected on a screen, using an Eberbach 2700 slide projector with a 16-mm lens. Where possible, at least three scales from each fish were read; this minimum sample size has been recommended elsewhere (e.g., Moring et al. 1981). Scales identified as regenerated (latinucleate) and those that were damaged or highly irregular in shape were not read. In some cases, because of a high percentage of regenerated scales, zero, one, or two scales were read from a given fish.

For each scale read, the following data were recorded: number of annuli, total length of scale radius (distance from focus to oral margin), and length of radius to annulus I, annulus II, annulus III, etc. The annulus was considered to be the intersection of the outermost margin of closely spaced (i.e., slow-growth) circuli with the innermost margin of widely spaced (i.e., rapid-growth) circuli; "cutting over" (Bagenal and Tesch 1978) of circuli was also used to locate annuli when possible. Each unit of measurement, for our equipment, represented 0.12 mm of actual object length. In cases where age or the location of one or more annuli could not be determined with confidence, scale radius and the position of obvious annuli were recorded to provide maximum data.

3.6 DATA ANALYSES

3.6.1 Water Temperature

Temperature data were digitized on a Tektronix 4057 graphics microcomputer from the original paper strip chart records. Data points were taken every 3 h from the records and keypunched into data files on the IBM 3330 system as SAS (SAS 82.2) data sets.

Plots of temperature over time by site were generated, using the SAS procedure PROC PLOT. Summary statistics of temperature by site (mean daily temperatures, daily ranges, variances, etc.) were produced, using the PROC UNIVARIATE procedure.

3.6.2 Macrobenthos Production

Because only total wet weights of benthic samples were taken and there was no measurement of the size or biomass of any but the largest individual organisms, direct calculations of secondary production (elaboration of organic tissue) via standard methods (i.e., removal-summation, instantaneous growth, Allen curve, or Hynes-Hamilton) were not possible. To estimate the production at the various sites, we employed the relationship:

$$\text{Production} = (\text{biomass}) \bullet (\text{turnover ratio}) \quad ,$$

which is mathematically equivalent to the instantaneous-growth expression (Waters 1969).

Biomass was estimated as the total wet weight of all benthic macroinvertebrates found in a given sample. For estimating production, large, separately weighed crayfish were excluded from the samples;

consequently, mean biomass values would be less than those reported in Sect. 4.4, which are based on entire samples. The production estimates would tend to underestimate actual production because of this factor. To detect differences in biomass between the eight sites, analysis of variance [using PROC GLM of the Statistical Analysis System (SAS 1982)] was used, including season as a blocking factor. Individual samples were used as replicates in the ANOVA. Duncan's multiple range test was used to identify differences between the site means.

A mean turnover ratio (TR), weighted by numerical abundance, was calculated for each sample. The mean turnover ratio was defined as:

$$TR = \frac{\sum_{i=1}^{m} n_i r_i}{\sum_{i=1}^{m} n_i} ,$$

where

n = number of individuals of taxon i (i = 1, ..., m),

r = literature value of turnover ratio for taxon i.

The turnover ratio calculated for each sample was based on the observed species composition. All insect, oligochaete, and mollusk taxa in our samples were assigned a turnover ratio based on values in Krueger and Waters (1983) for the same or related taxa (Table C-1). Where Krueger and Waters listed several turnover ratios for a single taxon, we estimated a mean value for the taxon (favoring, if necessary, species that could occur in our study area over species occurring outside that area). While this approach suffers from the obvious limitation that the turnover ratios for given taxa may vary between our study area and

Minnesota (the study area for the literature values), we felt that it provided a more consistent data set than selected turnover ratios for individual taxa from a wide variety of published sources. This ratio gives disproportionate weight to small, abundant organisms; unfortunately, data on the size of individual organisms were not available.

The samples were treated as replicates in an analysis of variance for differences in TR between sites. Collection season was used as a blocking variable. Duncan's multiple range test was used to identify differences between the site means. The mean turnover ratio for the site was then multiplied by the mean biomass (average of all samples collected) to estimate annual production at each site.

3.6.3 Fisheries

Field data were transferred to keypunch code sheets and entered into the IBM as three major data bases: Fishery Data Base 1 (general information on site characteristics such as reach, turbidity, pH, conductivity, dissolved oxygen, and temperature); Fishery Data Base 2 (information on each trout collected); and Fishery Data Base 3 (stomach content analysis for each trout examined). Data for approximately 2700 trout reside on these SAS data bases. Fisheries data were analyzed, using standard SAS procedures and algorithms coded in the SAS language (similar to PL/I).

3.6.3.1 Mark-Recapture Population Estimation

The ratio index for population estimation from mark-recapture data proposed by Petersen in 1896 assumes the following conditions (Adams 1951):

(1) Marked animals suffer the same mortality as unmarked animals.

(2) Marked animals do not lose their marks.

(3) Marked animals are subject to the same sampling efficiency as unmarked animals.

(4) Marked animals randomly mix with unmarked animals, or the distribution of sampling effort is proportional to the number of animals in different parts of the habitat under study.

(5) All marked animals are recognized and reported on recovery.

(6) Negligible recruitment to the sampled population occurs during the sampling period.

Field procedures were designed to meet these assumptions as closely as possible. Fish that appeared to be weakened by the capture and marking process were not released or counted in the number of fish initially marked. Fin clips cannot be lost and are highly unlikely to be overlooked on recovery. Marked fish were distributed throughout the study reach except near the boundaries, and the 48- to 72-h interval between mark and recapture sampling allowed further mixing of marked and unmarked fish. This time interval should have been sufficient to allow the fish to resume their normal behavior (Peterson and Cederholm 1984) and hence be subject to the same sampling efficiency, although there is no way to easily test this assumption. Similarly, there is no way to test whether unmarked animals are recruited to or exit from the population. This latter problem was approached indirectly by examining rates of movement of marked animals between the within-site and above-site reaches over the period between mark and recapture samples. This movement averaged only 12% for all species and age classes. Such a low rate of migration, if also true for the unmarked segment of the populations, would have a minimal effect on the population estimates.

The one clear violation of an assumption was the emigration of some marked fish from the study sites (average estimated rate was 15%). Movement of this sort leads to slight overestimates of population size. Population estimates made by the three-sample removal method (Carle and Strub 1978), which is based on a substantially different set of assumptions, tended to confirm that the Petersen estimates slightly overestimated population size (A. J. Gatz, Ohio Wesleyan University, unpublished data). No attempt was made to "adjust" the Petersen estimates for the noted migration, however, because (1) there was no evidence that the bias was very great, and (2) there was no evidence that the amount of bias differed between sites. Consequently, there should be no effect on correlations between fish abundance or biomass estimates and WUA or PUA (Sect. 4.5).

The initial estimate for population size is taken from Bailey (1951, 1952):

$$x = a(n + 1)/(r + 1) \quad , \qquad (1)$$

where

$\hat{x}$ is the population estimate,

a is the number of fish initially marked, n is the total number of fish captured during the second pass,

r is the number of marked fish captured during the second pass.

The Petersen estimator (an/r) is not used, since it has infinite expectation when no marked fish are captured on the second pass (i.e., r = 0). If r = 0 is excluded, then Eq. (1) is an appropriate, but biased, estimate of the population size. Bailey (1951) shows that:

$$E(\hat{x}) = x\left\{1 - (1 - a/x)^{(n+1)}\right\} \quad . \tag{2}$$

Setting $\hat{x} = E(\hat{x})$, expression (2) can be iteratively solved for an unbiased estimate. The initial value (first iteration) for x within the brackets of expression (2) is $\hat{x}$ from Eq. (1). For subsequent iterations of expression (2), the value of x outside the brackets, which was calculated on the previous iteration, is substituted for x within the brackets. Bailey (1952) also provides an almost unbiased estimate for the variance of $\hat{x}$ [var($\hat{x}$)], but an exact value for the variance in terms of x, a, and n is not available. Bailey's (1952) estimate for variance is:

$$\text{var}(\hat{x}) = a^2(n + 1)(n - r)/(r + 1)^2(r + 2), \tag{3}$$

where the relative bias is of the order m^2e^{-m} and m = an/x.

Bailey (1952) and Seber (1973) suggest obtaining confidence intervals from the inverse of population size, $y = x^{-1}$, where

$$\hat{y} = r/an \tag{4}$$

and

$$\text{var}(\hat{y}) = y(1 - ay)/an \quad . \tag{5}$$

The 95% confidence interval about y is:

$$\hat{y} \pm 1.96 \sqrt{var(\hat{y})} \quad . \tag{6}$$

Inverting the results of expression (6) provides a 95% confidence interval about x. Equations (4) and (5) are unbiased estimates of their respective parameters.

Population estimates were calculated, using the SAS programming language according to the above algorithms, providing both biased and unbiased estimates of x and the 95% confidence intervals. Estimates were produced for each trout species, site, trip, and age category (Ages 0, 1, and 2+) and are presented in Sect. 4.3.1.1. In those instances when no marked fish were collected on the recapture run, neither an unbiased estimate of x nor the 95% confidence interval about x could be derived, and, consequently, population estimates were based on Eq. (1). Also, when the quantity calculated in expression (6) was a negative value (also because of low numbers of marked, recaptured fish), the upper confidence limit for x could not be defined.

3.6.3.2 Density and Standing Crop

Trout densities (number/100 m^2 and number/km) for each site, date, species, and age class were calculated by dividing the population estimates (number of fish in the study reach) by the flow-specific area or reach length. The area of the study reach was calculated as the product of the total reach length (within and above sections combined) and the mean width based on flow-specific PHABSIM output.

Standing crops, or biomass, of trout (g/100 m^2 and g/km) were estimated for each site, date, species, and age class by multiplying density by the mean weight of the sampled fish (g/fish).

Standing stocks of nonsalmonids were estimated in either of two ways, depending on size of the species. For larger species (suckers, rock bass, redbreast sunfish, chubs, and stonerollers), mark-recapture population estimates were calculated by Eq. 1 in Sect. 3.6.3. Separate estimates were made for different size classes (<10.0, 10.0-20.0, >20.0 cm), and mean weight per individual (g wet weight) was calculated for each size class. Total biomass was estimated by summing the products of the number and mean weight for each size group. For smaller species (all other species of minnows, darters, and sculpins), abundance was estimated by dividing the number of fish captured in a single shocking run by a capture efficiency (Seber and LeCren 1967). The efficiency used, 0.40, was an approximate empirical average probability of capture for these species groups, based on data from Mahon (1980). Total biomass of these species was calculated as the product of the estimated abundance and the mean weight per individual.

3.6.3.3 Trout Production

Production refers to the elaboration of fish tissue during any time interval Δt and can be estimated from data on growth and survivorship during this interval (Chapman 1978). To determine annual trout production at each of the eight study sites, population estimates were calculated by Eq. (1) in Sect. 3.6.3 for each of four or five sampling dates between June 1982 and July 1983. To minimize bias resulting from increased capture efficiency of larger fish (Sullivan 1956; Carline 1977; Waters 1983; this study), population estimates were computed on the basis of size classes (Elwood 1968). For rainbow trout,the size classes were <11.0 cm, 11.0-15.9 cm, 16.0-20.9 cm, and >20.9 cm. Because of the wide range in size of large brown trout (20.9-40.8 cm) in Bradley Creek and the upper Nantahala River (NR3), the largest size class (>20.9 cm) was subdivided into two size classes: 20.9-30.9 cm and >30.9 cm. The only other site with a wild brown trout population was Lost Cove Creek where, with only two exceptions, no fish >30 cm in total length were collected. Consequently, only four size classes were employed at this site.

The percent age composition was computed for each size class based on scale analyses, length-frequency histograms, and, in some cases, recapture of previously marked and aged fish. These percentages were applied to the population numbers for each size class to obtain estimates of population abundance by age class. Whenever possible, the mean weights of each age class on the date of sampling were computed from the weights of individuals of known age. Because fish collected in 1983 were not aged by scale analysis, a slightly different procedure was used to obtain age-specific mean weights. The percent age composition of each size class was estimated from both length-frequency histograms and the results obtained from the scale analyses conducted on fish collected in 1982. A mean weight was calculated for a size class and multiplied by the number of fish of a given age in that size class. The product was summed across size classes and divided by the estimated total number of fish in that age class. This estimate of the mean weight of an age class was multiplied by the population estimate for that age class to obtain total biomass (B).

Trout production was calculated by the instantaneous growth rate method (Ricker 1946):

$$P = G \, \Delta t \, \bar{B} \quad ,$$

where

P is the production in g/m^2 during the interval t_1 to t_2,

Δt is the time interval ($t_2 - t_1 = \Delta t$),

G is the instantaneous growth rate during Δt,

$\bar{B}$ is the mean biomass during Δt, estimated as $\bar{B} = \frac{B_1 + B_2}{2}$, where B_1 and B_2 represent the total biomass at the beginning and end of the interval, respectively.

Annual production was calculated as the sum of the production for each of four or five intervals between June/July 1982 and June/July 1983 (sampling dates at each site are listed in Table A-1). Estimates were obtained for the 1983, 1982, 1981, 1980, and $\leq$1979 year classes of rainbow and brown trout. Because of the uncertainty associated with age determination of larger (Age 3+) brown trout, these individuals were combined to estimate production for the $\leq$1979 year class. If a year class disappeared on a given date but reappeared later, production was calculated over the longer period (Waters 1983). Negative production values were computed for some intervals and were subtracted from total production (Chapman 1978).

At all study sites except Abrams and Mill creeks, Age 0 trout were too small on the first sampling date (June or July) to be accurately censused. To obtain estimates for these dates, an instantaneous mortality rate (Z; Chapman 1978) was computed for the interval between the two succeeding dates (e.g., between August and November 1982 in Lost Cove Creek) and was used to back-calculate an estimate of the population in June/July 1982. In two cases (1982 cohorts of rainbow trout at NR1 and brown trout at NR3), Z was calculated, using the July and September 1982 population estimates for the 1981 cohorts. Because Age 0 trout were sampled in the fall of 1983, Z for the 1982 cohort was applied to these estimates to obtain an estimate of the Age 0 population in June/July 1983. Production of the 1983 cohort from emergence to the first sampling date was estimated by assuming a mean weight of 0.04 g at emergence (Hunt 1966), an interval (Δt) of 90 and 120 d for rainbow and brown trout, respectively, and a constant mortality (estimated as Z from the 1982 cohort) over this interval. Our estimates of Age 0 production are conservative because instantaneous rates of mortality in the first several months following emergence tend to be higher and to decrease with age (Latta 1962). For example, instantaneous mortality rates of Age 0 trout ranged from 0.0073 (brown trout at NR3) to 0.0120 (rainbow trout at BC2) compared to an estimated mortality rate over a 90-d postemergence period of 0.0242 for brook trout in Michigan (Latta 1962).

3.6.3.4 Condition Factors

Condition factors (K) were calculated using the formula:

$$K = 100\ (\text{weight}/\text{length}^3) \quad ,$$

with weight in grams and total length in centimeters. Neither stocked fish nor recaptured marked fish were used in these calculations. Condition factors were calculated for fish by site, trip, taxon, and age (Ages 0, 1, and 2+). Comparisons of condition factors between groups were made, using the PROC GLM procedure on untransformed data, because the condition factors exhibited homogeneity of variance as estimated with the UNIVARIATE procedure. If the GLM procedure indicated significant differences in condition factors between groups, the Tukey option (SAS 1982) was performed segregating similar groups.

3.6.3.5 Length-Weight Regressions

Log (base 10) weight vs log length plots were produced using PROC PLOT, and individual regression parameters (slope and y intercept) were calculated using PROC GLM. Regressions were calculated by taxon and site.

3.6.3.6 Growth Rates

Instantaneous rates of growth (G) averaged over the 1-year study period (June 1982-July 1983) were calculated for each trout species, site, and age class according to Ricker (1975):

$$G = \frac{\log_e \bar{W}_2 - \log_e \bar{W}_1}{t_2 - t_1} ,$$

where

$\bar{W}_2$ is the mean weight of the members of an age class sampled at time t_2,

$\bar{W}_1$ is the mean weight of members of that same age class sampled at time t_1.

4. RESULTS AND DISCUSSION

4.1 PHYSICOCHEMICAL ANALYSES

Unlike the majority of freshwaters where relative ionic concentrations are calcium > magnesium > sodium > potassium (Hutchinson 1957), waters of Appalachian trout streams often show the trend sodium > calcium > potassium > magnesium (Johnson and Swank 1973; Swank and Douglass 1977). Although ionic levels are low and values from undisturbed watersheds fluctuate little from year to year, some seasonality has been noted. Calcium, sodium, potassium, and sulfate in the streams near Coweeta Hydrologic Laboratory in southwestern North Carolina exhibited peaks in July, August, or September, and minimum values occurred in winter. Concentrations of nitrate, ammonia nitrogen, and phosphate phosphorus are very low in undisturbed watersheds, and little seasonality has been noted (Swank and Douglass 1977).

Factors important in the regulation of ionic concentrations in mountain streams include rock weathering, rainfall chemistry and quantity, evapotranspiration, and successional status of the watershed (Vitousek 1977). Inverse correlations between elevation and concentrations of geologically derived elements in streams of the Great Smoky Mountains National Park have been explained by higher levels of rainfall and lower temperatures at the high elevations (Silsbee and Larson 1982). Concentrations of calcium, magnesium, potassium, and sodium were found to be only 2 to 4.4 times higher in streams in the Coweeta area than in precipitation, thereby suggesting the potential importance of rainwater chemistry in influencing concentrations of materials in these dilute streams (Johnson and Swank 1973). Calculations by Simmons and Heath (1982) indicate that precipitation may be the major source of dissolved material in streams in Geochemical Zone I, where the North Carolina study sites are located.

Vitousek (1977) showed that levels of chloride and sulfate in streams in the White Mountains of New Hampshire are controlled primarily by precipitation chemistry and by the concentration of these ions due to evapotranspiration. Rock weathering, however, was a more important factor in regulating levels of calcium, magnesium, sodium, and silica, although precipitation chemistry and evapotranspiration were also influential.

The successional status of the watershed may exert a strong influence on stream water chemistry. A stream draining a mature hardwood forest in the Coweeta area had higher concentrations of calcium, magnesium, sodium, and potassium than streams in white pine or coppice areas (Johnson and Swank 1973). Likewise, Vitousek (1977) found that levels of important plant nutrients (nitrate and potassium) were higher in streams draining older watersheds. The rapidly growing younger successional stages incorporate more elements into plant tissue than mature systems which are at or approaching steady state.

4.1.1 Water Quality

The water quality of the southern Appalachian trout steams included in this study is characterized by low pH, low concentrations of dissolved and suspended materials, and high levels of dissolved oxygen (Table 4-1). Because the North Carolina study streams

Table 4.1. Analyses of selected water quality parameters of the study streams. Tabular values, in mg/L, represent the mean (range in parentheses) of samples collected between April 1982 and July 1983.

Site	Alkalinity as $CaCO_3$ (mg/L)	Total hardness as $CaCO_3$ (mg/L)	Calcium hardness as $CaCO_3$ (mg/L)	Conductivity (µS/cm)	Nitrate as NO_3-N[a] (mg/L)	Phosphate as PO_4^{3-} (mg/L)	Dissolved oxygen (% saturation)	pH[b,c]	Turbidity (NTU)[d]
AC	44(12-50)	51(15-75)	38(11-55)	110(27-166)	0.45(0.10-0.80)	0.10(0.01-0.20)	85(79-91)	6.6(6.3-7.2)	4.7(1.4-21)
BC1,BC2	3(3-4)	4(3-7)	3(2-5)	5(2-7)	0.12(0.00-0.25)	0.01(ND-0.02)	99(95-107)	5.5(5.0-5.9)	3.4(2.2-5.0)
LCC	3(2-5)	4(3-5)	3(2-4)	5(4-7)	ND	0.02(0.01-0.04)	100(93-104)	5.2(4.9-5.7)	2.4(1.0-8.3)
MC	5(4-6)	5(3-9)	4(2-6)	8(5-11)	0.12(0.10-0.15)	0.06(0.04-0.08)	96(92-103)	5.9(5.6-6.2)	3.2(1.4-10)
NR1	7(4-10)	10(8-15)	7(4-10)	15(9-17)	ND	0.02(ND-0.06)	99(94-103)	6.3(5.8-7.0)	9.8(1.5-45)
NR2	8(6-10)	12(10-15)	5(4-5)	11(8-13)	ND	0.05(0.05-0.06)	96(93-104)	5.8(5.5-6.1)	5.6(1.2-31)
NR3	3(2-5)	6(4-10)	4(3-5)	4(4-5)	ND	0.02(ND-0.04)	97(95-101)	5.3(5.0-6.0)	1.8(0.4-2.8)

[a]ND = not detectable.

[b]Hydrogen ion concentrations were used to calculate mean pH.

[c]Actual pH at all sites except AC may be 0.7 to 1.1 units higher than tabular values due to errors associated with measuring pH in low-conductivity waters, and the magnitude of the error may vary as a function of conductivity. In tests conducted at Oak Ridge National Laboratory (ORNL) in May 1984 with a Hydrolab and four other electrodes (both ion and gel types), the Hydrolab gave consistently lower pH readings than the other electrodes over an actual pH range of 4.5 to 7.0 in water with a conductivity of <10 µS/cm (M. S. Adams, Environmental Sciences Division, ORNL, unpublished data).

[d]NTU = Nephelometric Turbidity Unit.

(Lost Cove Creek, Bradley Creek, and the Nantahala River) are all located in Geochemical Zone 1 (Simmons and Heath 1982), they would be expected to exhibit roughly similar water chemistries. Studies of other streams in this region have described similar physicochemical profiles (Table 4-2). Of the two Tennessee mountain streams included in this study, Mill Creek has water quality similar to the North Carolina streams, whereas Abrams Creek has considerably higher levels of dissolved and suspended materials. These differences have also been documented in previous studies of the two streams (Table 4-3).

The higher levels of dissolved materials in Abrams Creek compared to the other study streams are related to the geology of the watershed. In portions of Cades Cove above the study site, the creek flows underground where it comes in contact with limestone (Mathews 1978). Limestone is more soluble than other geological formations in the area, thus resulting in the dissolution of ions (especially calcium) and increased alkalinity, hardness, conductivity, and pH. Because the underlying formations at all other study sites are only slightly soluble (see Sect. 2), these streams have low concentrations of dissolved ions. Although Mill Creek is situated close to Abrams Creek (Sect. 2.1), the former does not flow underground or come in contact with limestone.

The agricultural nature of Cades Cove contributes to the elevated levels of phosphates, nitrates, and turbidity in Abrams Creek (Mathews 1978; Bratton et al. 1980). The low gradient and large inputs of sediment to Abrams Creek result in pockets of silt, which may be resuspended by high flows or cattle wading in the stream (Mathews 1978).

Table 4 2. Physicochemical characterization of North Carolina mountain streams. Values are in mg/L unless indicated otherwise.

Parameter	(Simmons & Heath 1982)[a]	(USGS 1981a)[b]	(Swank & Douglass 1977)[c]	(Woodall & Wallace 1972)[d]
Alkalinity (as $CaCO_3$)		5-16		10.0
Calcium	0.7-3.0		0.376-0.692	
Magnesium	0.3-0.9		0.214-0.345	
Potassium	0.3-1.9		0.235-0.524	
Sodium	0.4-2.2		0.506-1.208	
Bicarbonate	2.0-9.5			
Sulfate	0.8-5.7		0.294-1.064	
Chloride	0.0-1.9		0.495-0.679	
Silica	3.6-9.5		1.82-4.18	
Total dissolved solids	12-22			
Nitrate nitrogen	0.00-0.62	<0.05	0.002-0.016	
Ammonia nitrogen	0.00-0.01	<0.05	0.003-0.005	
Phosphorus	0.00-0.03 (total)	<0.05 (PO_4-P)	0.001-0.002 (PO_4-P)	0.001-0.003 (PO_4-P)
Dissolved oxygen		8.3-12.6		7.2-13.8
Conductivity, µS/cm		9-36		8.7-17.6
Turbidity		<1.0-4.0 (FTU)[e]		0.0-26.0 (JTU)[e]
Temperature, °C				2.0-18.5
pH		6.5-7.3	6.5-6.8	6.7-6.9
Number of streams	15	1	8	4

[a]Unpolluted streams in primarily forested watersheds in Geochemical Zone I, North Carolina.

[b]Nantahala River at Nantahala, North Carolina (approximately 8.2 and 4.0 km below NR1 and the Nantahala powerhouse, respectively).

[c]Streams in undisturbed watersheds near Coweeta Hydrologic Laboratory in southwestern North Carolina.

[d]Four watersheds (old field, hardwood, white pine, coppice) near Coweeta Hydrologic Laboratory, North Carolina.

[e]FTU = Formazin Turbidity Unit; JTU = Jackson Turbidity Unit.

Table 4-3. Physicochemical characterization of Mill Creek and Abrams Creek near study sites MC and AC, respectively, Great Smoky Mountains National Park. Values in mg/L unless indicated otherwise.

Parameter	Abrams Creek (Silsbee & Larson 1981)[a]	Abrams Creek (Mathews 1978)[b]	Mill Creek (Silsbee & Larson 1981)[c]	Mill Creek (Mathews 1978)[d]
Alkalinity (as $CaCO_3$)	48.6	1-85	4.4	1-20
Nitrate nitrogen	0.41	0.10-1.10	0.18	0.24-0.95
Phosphorus (PO_4-P)		0.02-0.04		0.01-0.04
Dissolved oxygen		7.6-11.4		8.0-12.2
Turbidity, JTU[e]		2.4-190.0[f]		0.8-3.4
Hardness (as $CaCO_3$)	52.7	16-75	5.0	4-14
Conductivity, µS/cm	69.7	30-132	10.4	10-43
pH	7.3	7.0-7.5	6.6	6.3-6.8
Temperature, °C		9-17		1-19

[a] Immediately below Cades Cove.

[b] Above confluence with Mill Creek.

[c] At confluence with Abrams Creek.

[d] Above confluence with Abrams Creek.

[e] JTU = Jackson Turbidity Unit.

[f] Isolated value attributed to cattle wading in the stream.

This could result in low turbidity most of the time with occasional high values, as demonstrated in this study and that of Mathews (1978). Higher levels of phosphates and nitrates may be due to fertilization of hay fields, cattle defecation, and possible seepage from a sewage lagoon (Mathews 1978; Bratton et al. 1980).

Turbidity fluctuations similar to those in Abrams Creek were also observed at the two Nantahala River sites located below Nantahala Dam (Table 4-1). Except for the samples collected after a period of heavy rainfall in late May 1982, turbidity was less than 6.0 NTU (Nephelometric Turbidity Unit). Because reservoirs act as sediment traps, low turbidity below dams would not be unusual. However, the significant reduction in flow that followed construction of the Nantahala Dam in 1942 (Sect. 2.4) and the low gradient above NR2 (Table 2-1) may have resulted in the accumulation of sediment that entered the river from tributaries below the dam. In free-flowing rivers, for example, silt is periodically removed (transported downstream) during high flows that normally occur during winter and early spring in this region. Dam construction, when coupled with minimal downstream releases, significantly reduces the frequency and magnitude of peak (or flushing) flows, thus reducing the sediment-transport capacity of the river. As a result, silt accumulation is enhanced in low-gradient reaches, and trout spawning and rearing habitat is degraded. Reduced flood flows decreased silt-carrying capacity, resulting in compacted spawning gravels and sediment-filled pools when more than 80% of the mean annual flow in the Trinity River was diverted to the Central Valley of California (Smith 1976).

4.1.2 Temperature

Trout populations in the southeastern United States are found only at higher elevations where water temperatures do not exceed the thermal tolerance of the species (Harshbarger 1975). Maximum summer temperatures in Mill Creek in the Great Smoky Mountains National Park (GSMNP) rarely exceeded 20°C (Fig. 4-1). Because of the subsurface diversion of flow above the Abrams Creek study site, average water temperatures were generally 3-4°C lower in summer and 4-5°C higher in winter compared with Mill Creek (Table B-1). Maximum summer temperatures of GSMNP streams are usually below 22°C; streams at higher elevations have lower summer temperatures, although this relationship between temperature and elevation does not hold in winter due to increased freezing at higher elevations (Silsbee and Larson 1982).

Maximum summer temperatures of North Carolina trout streams, on the other hand, average about 20°C, with temperatures as high as 22.2°C in some streams (Ratledge and Louder 1967, as cited in Harshbarger 1975). Streams near the Coweeta Hydrologic Laboratory have maximum temperatures of 16.0 to 18.5°C and minimum temperatures ranging from 2.0 to 6.0°C (Woodall and Wallace 1972). Temperatures in Bradley Creek and Lost Cover Creek, which have almost identical annual thermal regimes, rarely exceeded 18°C and were less than 2°C only during an extended cold period during late January 1983 (Fig. 4-2). Because of the higher elevation (Table 2-1), maximum temperatures at the upper Nantahala River site (NR3) were below 16°C (Fig. 4-3). The reduced flow and open canopy at the two lower Nantahala River sites (NR1 and NR2) probably account for the higher stream temperatures at these sites

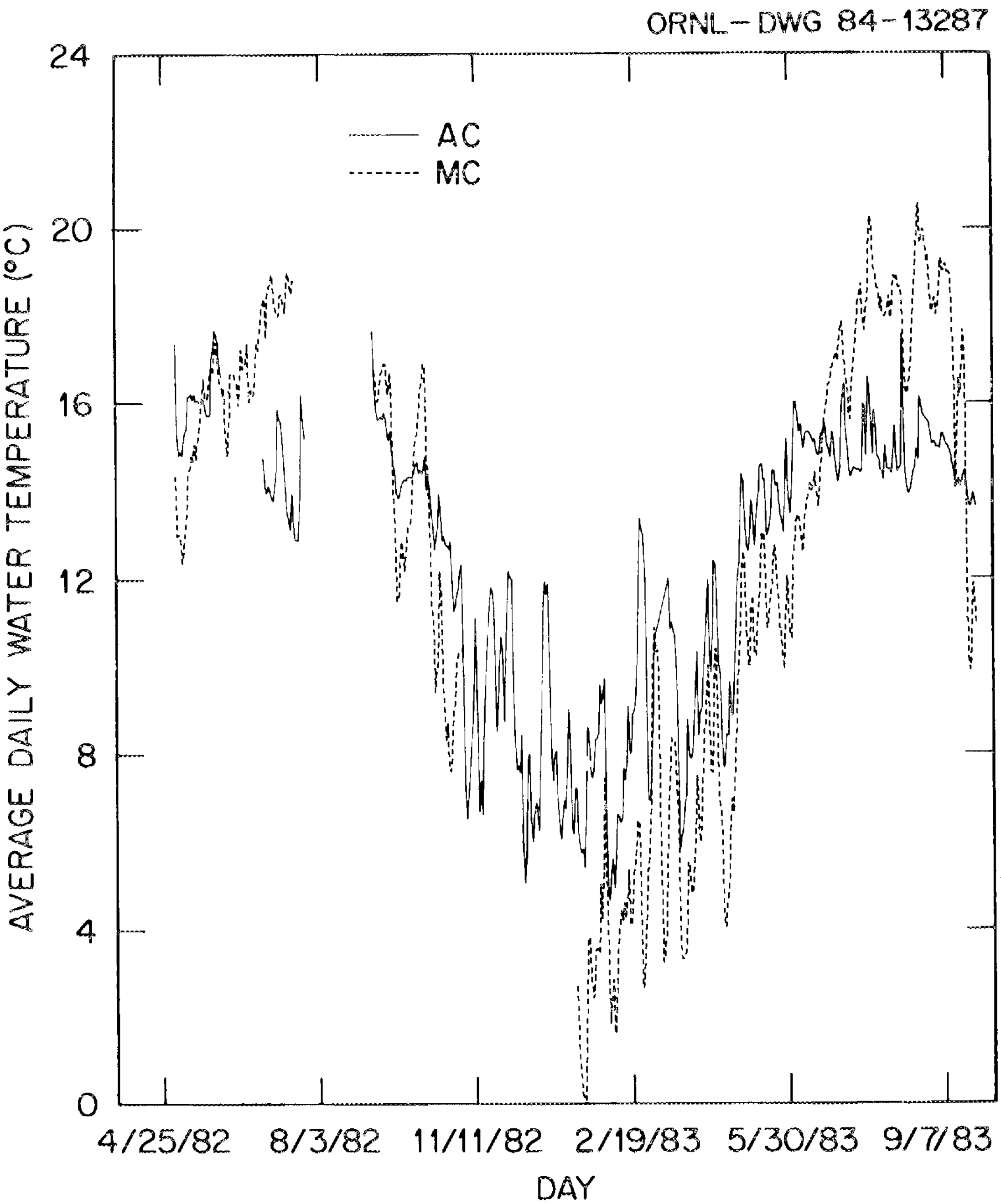

Fig. 4-1. Average daily water temperatures (°C) in Abrams Creek and Mill Creek.

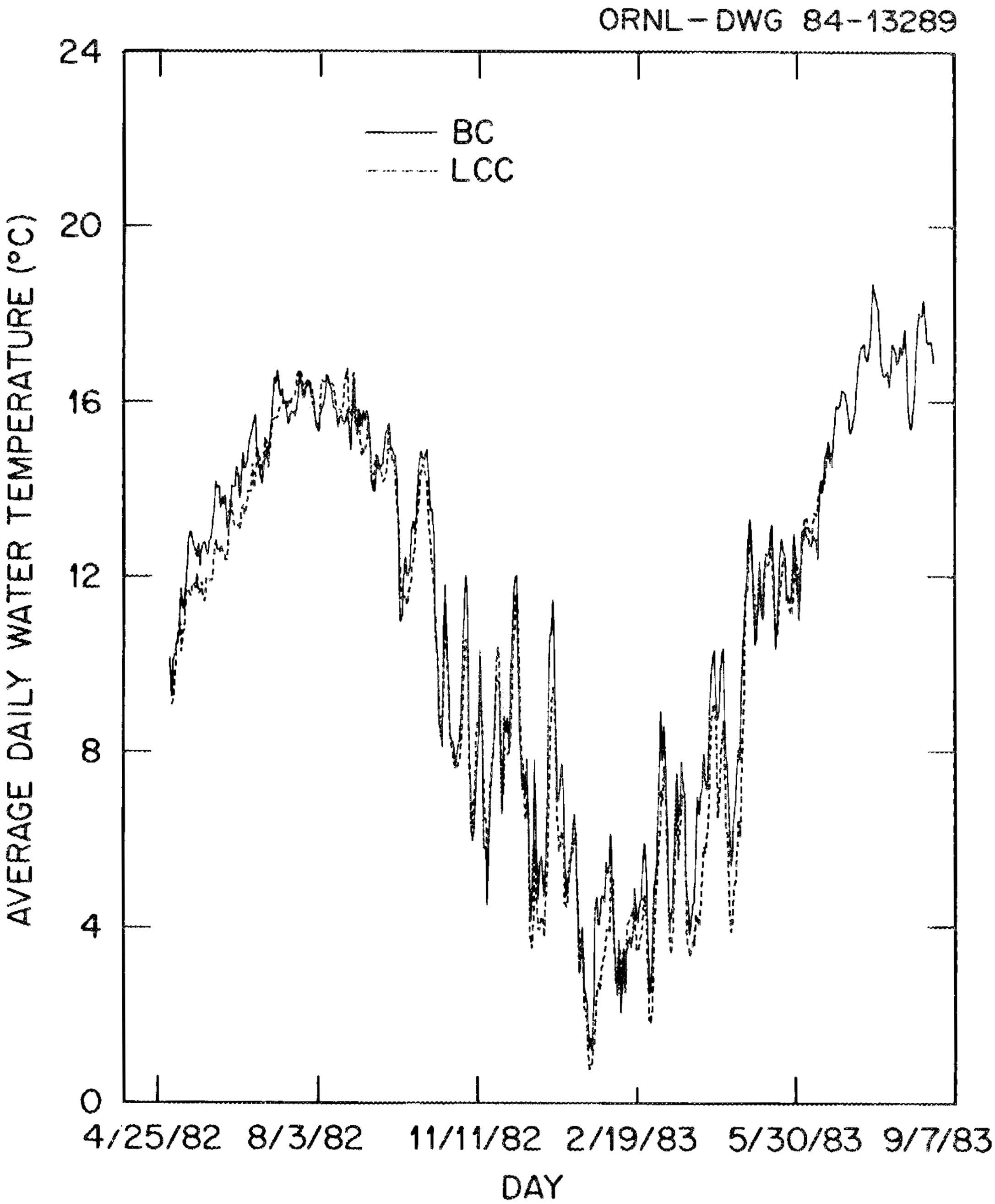

Fig. 4-2. Average daily water temperatures (°C) in Bradley Creek and Lost Cove Creek.

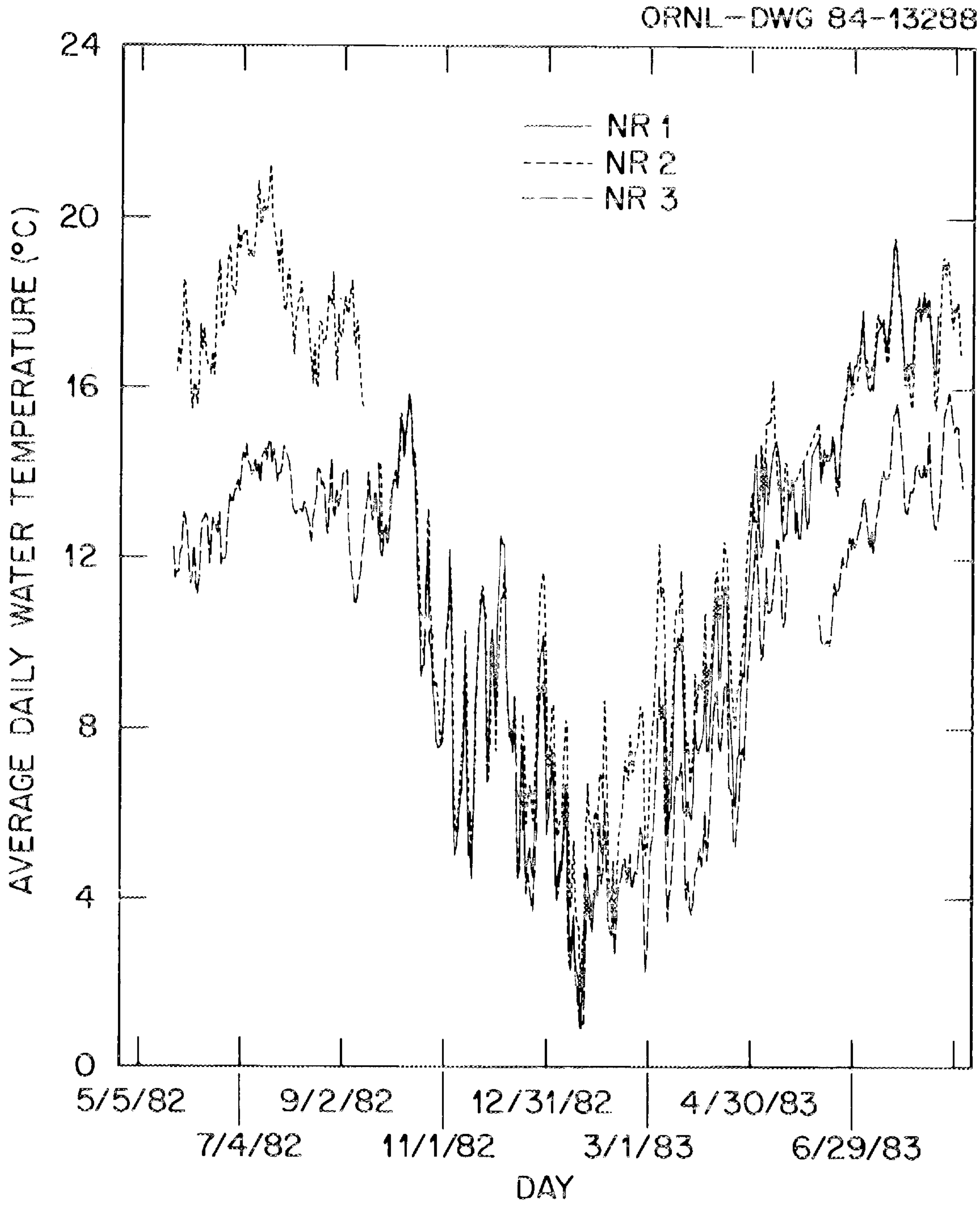

Fig. 4-3. Average daily water temperatures (°C) at three sites in the Nantahala River.

(Table B-1). Although average daily temperatures at NR2 in summer were below 22°C (Fig. 4-3), maximum temperatures exceeded 23°C in mid-July 1982. Temperatures at NR2 were generally 1-2°C higher than at NR1.

In addition to these differences in annual temperature regimes between the study sites, diel fluctuations in temperature exhibited rather well defined seasonal patterns (Table 4-4). Maximum fluctuation in temperature over a 24-h period occurred in the spring (March-May) and generally declined through the remainder of the year to a winter minimum. In Lost Cove Creek and the two GSMNP streams, however, minimum diel fluctuations occurred during summer rather than winter. Over the period of record, diel changes in stream temperature were lowest in Lost Cove Creek. The BC and NR3 sites exhibited almost identical patterns with respect to both the magnitude of the fluctuations and the seasonality. The greatest fluctuations in temperature over a 24-h period occurred at NR2 and, like the annual temperature patterns, are probably related to the low flows below Nantahala Dam and the open canopy. Riparian vegetation at NR2 consists primarily of shrubs, with no large overhanging trees (Table 2-3).

4.2 PHYSICAL HABITAT EVALUATION

4.2.1 Hydraulic Modeling

The initial approach to modeling depth and velocity distributions at the eight study sites consisted of collecting a data set containing depth/velocity/substrate transects at three flows suitable for IFG4 calibration. The selection of the most appropriate hydraulic simulation model (IFG4 or WSP) depended on local flow characteristics within the

Table 4-4. Mean daily fluctuation in water temperature (°C), by season, for the study streams. Maximum/minimum fluctuation observed over a 24-h period in parentheses.[a]

Season[b]	Abrams Creek	Mill Creek	Bradley Creek	Lost Cove Creek	Nantahala River		
					NR1	NR2	NR3
Spring 1982	2.0(<0.1-3.7)	2.0(0.8-3.3)	2.0(<0.1-3.9)	1.2(0.3-2.6)	NS	NS	NS
N	27	27	33	36			
Summer 1982	1.6(0.6-4.4)	1.6(0.6-3.2)	1.4(0.2-2.6)	0.8(<0.1-3.1)	ND	3.1(0.6-6.3)	1.4(0.3-2.9)
N	31	50	89	92		90	92
Fall 1982	1.3(<0.1-3.4)	1.5(0.4-2.7)	1.5(0.2-3.8)	1.1(0.2-2.4)	2.1(<0.1-4.0)	2.1(0.3-4.6)	1.2(0.1-1.9)
N	84	54	91	91	69	81	22
Winter 1983	1.8(0.2-3.8)	1.4(0.1-3.4)	1.2(<0.1-3.1)	1.0(0.3-2.6)	1.6(0.4-3.2)	2.0(0.2-4.5)	1.2(0.2-2.5)
N	90	47	90	86	63	90	75
Spring 1983	3.0(0.4-6.3)	1.7(0.2-4.2)	2.0(0.2-4.5)	1.5(0.2-5.0)	2.9(0.6-6.1)	3.9(0.4-7.7)	2.1(0.1-4.7)
N	84	92	92	92	84	82	81
Summer 1983	1.3(<0.1-4.4)	1.3(<0.1-2.7)	1.6(0.4-.2.7)	0.9(0.3-1.5)	2.9(<0.1-4.8)	3.3(0.9-5.8)	1.6(0.3-2.6)
N	92	88	88	24	75	85	86

[a]N = number of days of record; NS = not sampled; ND = no data available.

[b]Spring = March, April, May; Summer = June, July, August; Fall = September, October, November; Winter = December, January, February.

specific representative reach (Table 4-5). At the four sites with the steepest hydraulic slopes (BC2, LCC, NR1, and NR3), it was anticipated that the IFG4 model would be needed. However, considerable difficulty was experienced in calibrating IFG4 at these sites because of bed mobility and subsequent changes in cross-sectional profiles. For example, the profiles of transect 1 at NR1 (Fig. 4-4) show significant aggradation of the channel bed over the spring-to-fall period. The bottom substrate at this transect, and throughout NR1, is dominated by medium cobble and gravel. The changes in bed elevation at transects like this make it impossible to produce accurate stage-discharge correlations in the IFG4 model. Because of the problem of bed mobility, the WSP model was applied to all the study sites. The accuracy of these WSP calibrations at the steeper sites was checked by comparing WSP-simulated predictions at the upper and lower observed flows from the IFG4 data set. Generally, the WSP calibrations, even at the steepest site (NR1), were good or fair (Milhous et al. 1981) and much superior to those of the IFG4 hydraulic model.

4.2.2 Habitat Availability and Utilization

There are at least two general classes of habitat evaluation methods (or indices): (1) utilization indices and (2) preference indices. Habitat utilization indices are derived solely from measurements of physical habitat variables (e.g., velocity, depth, and substrate) at sites where organisms are found. The probability-of-use, or suitability, curves developed and used by the Instream Flow Group (e.g., Bovee 1978) are utilization indices. Habitat preference

Table 4-5. Representative reach characteristics at the eight study sites.

Site	Gradient (m/km)	Reach length (m)	Average width (m)	No. of transects
AC	2.0	106	8.2	10
BC1	5.4	92	10.3	10
BC2	16.5	41	10.2	7
LCC	17.5	62	6.4	8
MC	6.8	68	11.2	8
NR1	26.4	61	17.6	8
NR2	3.6	75	10.3	8
NR3	14.1	34	12.2	8

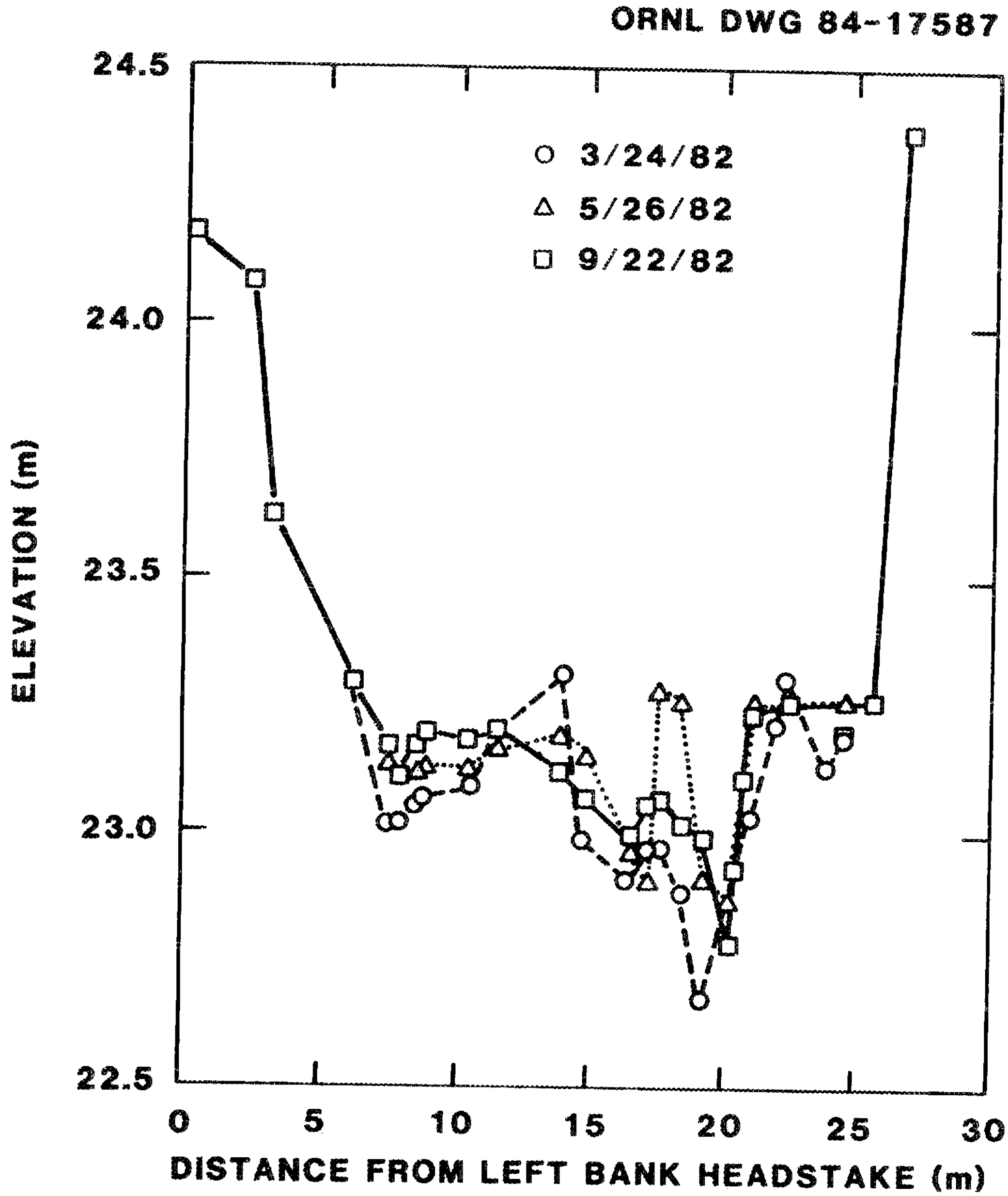

Fig. 4-4. Cross-sectional profiles of transect 1 at NR1 during periods of high flow (3/24/82; 2.92 m^3/s; water surface elevation = 23.30 m), medium flow (5/22/82; 1.5 m^3/s; water surface elevation = 23.26 m), and low flow (9/22/82; 1.03 m^3/s; water surface elevation = 23.24 m).

indices, on the other hand, include data on both physical habitat conditions where organisms are found and the relative proportions of various physical habitat conditions in the environment as a whole, i.e., data on both utilization and availability. The importance of availability to habitat selection by trout, and hence the importance of using a habitat preference index rather than a utilization index, was examined at five study sites.

Proportions of habitat available in the various depth, velocity, and substrate categories vary between most sites. Each site has its own unique configuration of depths (Table 4-6). The velocity profile at BC is intermediate between that at LCC and NR3 and not significantly different from either; all other sites, including LCC and NR3, differ significantly from each other (Table 4-7). The substrate profiles at BC and LCC also do not differ from each other, whereas all other sites differ in the proportions of substrates available in the major categories recognized (Table 4-8).

Trout of both species and age groups (Age 0 and Age 1+) tend not to use the various habitat categories in proportion to their availability at any of the sites. Specifically, Age 1+ brown trout never utilize any habitat categories in proportion to their availability. Relative to what is available, Age 1+ brown trout concentrate at depths ≥30 cm and avoid shallower water, prefer velocities <15 cm/s (especially those <5 cm/s) and avoid velocities ≥30 cm/s, and tend to favor sand and silt substrate, generally avoiding rubble, boulder, and bedrock substrates (Table 4-9). Age 0 brown trout show preferences similar to those of their older

Table 4-6. Percent habitat available in each of three depth categories at five sites, October/November 1983.

	Depth category (cm)		
Site[a]	<30	30-49	>50
AC	36.5	42.8	20.7
BC	83.3	14.2	2.5
LCC	73.2	19.1	7.6
MC	91.2	7.1	1.8
NR3	54.9	29.8	15.3

[a]Each site is significantly different from every other site (all P's < 0.005).

Table 4-7. Percent habitat available in each of four velocity categories at five sites, October/November 1983.

	Velocity category (cm/s)			
Site[a]	<5	5-14	15-29	$\geq$30
AC	74.5	20.0	3.4	2.1
BC	19.1	16.1	24.1	40.7
LCC	17.2	16.6	16.6	49.7
MC	39.2	21.5	25.3	14.0
NR3	20.6	20.6	22.5	36.3

[a]BC is not significantly different from either LCC or NR3 ($P > 0.05$); all other sites are significantly different from each other.

Table 4-8. Percent habitat available in each of four substrate categories at five sites, October/November 1983.

	Substrate category			
Site[a]	Clay, silt, and/or sand	Gravel	Rubble	Boulders and/or bedrock
AC	54.3	25.6	19.2	1.0
BC	11.3	8.2	57.2	23.3
LCC	10.2	10.8	59.2	19.7
MC	5.1	12.0	73.9	8.9
NR3	7.3	6.6	54.0	32.1

[a]All sites are significantly different from each other except BC and LCC.

Table 4-9. Habitat use by Age 1+ brown trout relative to what is available. If use is significantly different from proportions available, entries of + or ++ indicate, respectively, strong or very strong preference, and an entry of - indicates avoidance (underuse) of a given category. An entry of 0 indicates that the particular category is used in approximate proportion to its abundance. If all resources for a given resource type (i.e., depth, velocity, or substrate) are 0, the overall pattern of use of that resource is not significantly different from random (i.e., use of that resource is in proportion to availability).

	Depth (cm)			Velocity (cm/s)				Substrate			
Site	<30	30-49	≥50	<5	5-14	15-29	≥30	≤Sand	Gravel	Rubble	≥Boulders
BC	-	+	++	0	+	0	-	+	0	0	-
LCC	-	++	+	+	0	0	-	++	+	-	-
NR3	-	+	0	+	0	0	-	+	0	-	0

conspecifics in regard to depth, velocity, and substrate at BC and velocity at LCC; the small sample size at LCC precludes showing significant preference patterns for depth and substrate at that site (Table 4-10).

Age 1+ rainbow trout show nonrandom use of habitat resources at all sites for all resources except substrate at NR3 (Table 4-11). Age 1+ rainbow trout are similar to Age 1+ brown trout in their depth and substrate preferences, although their avoidance of large substrates is not as strong as that shown by brown trout. In terms of water velocity preferences, Age 1+ rainbow trout differ from similarly aged brown trout. Rainbow trout tend to prefer water velocities of 5-14 cm/s and, to a lesser extent, 15-29 cm/s; depending on the site, rainbow trout utilize both higher ($\geq$30 cm/s) and lower (<5 cm/s) velocities either in proportion to their availability or at lower frequencies than their availability in the environment. Age 0 rainbow trout show the least amount of differential habitat utilization relative to availability (Table 4-12). They use substrates in proportion to availability at all sites except NR3, where sand is overutilized and boulders and bedrock are avoided. Velocities are used in proportion to their availability at BC, MC, and NR3; at AC and LCC, Age 0 rainbow trout concentrate in areas with velocities from 15 to 29 cm/s. Age 0 rainbow trout use depths in proportion to availability at BC and MC, whereas they concentrate at 30-49 cm in LCC and NR3 and in shallow water at AC. Reiterating the main point, most species and age groups of trout do not use habitat categories in proportion to the availability of these resources in the environment -- preferences are shown.

Table 4-10. Habitat use by Age 0 brown trout relative to what is available. Symbols are defined in Table 4-9.

	Depth (cm)			Velocity (cm/s)				Substrate			
Site	<30	30-49	≥50	<5	5-14	15-29	≥30	≤Sand	Gravel	Rubble	≥Boulders
BC	-	+	0	+	0	0	-	+	0	0	-
LCC	0	0	0	+	+	+	-	0	0	0	0

Table 4-11. Habitat use by Age 1+ rainbow trout relative to what is available. Symbols are defined in Table 4-9.

	Depth (cm)			Velocity (cm/s)				Substrate			
Site	<30	30-49	≥50	<5	5-14	15-29	≥30	≤Sand	Gravel	Rubble	≥Boulders
AC	-	0	+	-	++	+	0	+	-	-	0
BC	-	+	++	-	++	+	-	+	0	0	-
LCC	-	++	0	+	0	+	-	+	+	0	-
MC	-	++	++	0	+	-	0	++	0	-	0
NR3	-	+	+	0	0	+	-	0	0	0	0

Table 4-12. Habitat use by Age 0 rainbow trout relative to what is available. Symbols are defined in Table 4-9.

	Depth (cm)			Velocity (cm/s)				Substrate			
Site	<30	30-49	≥50	<5	5-14	15-29	≥30	≤Sand	Gravel	Rubble	≥Boulders
AC	+	-	-	-	0	++	+	0	0	0	0
BC	0	0	0	0	0	0	0	0	0	0	0
LCC	-	+	0	0	0	+	-	0	0	0	0
MC	0	0	0	0	0	0	0	0	0	0	0
NR3	-	+	0	0	0	0	0	+	0	0	-

The probability-of-use, or suitability, curves show physical habitat utilization patterns without accounting for habitat availability. Curves for depth, velocity, and substrate preferences of fry, juvenile, and adult rainbow (Fig. 4-5) and brown trout (Fig. 4-6) were developed and compared with those of Bovee (1978). All the depth curves tend to have somewhat narrower optima and lower suitability values for deeper water than the corresponding curves in Bovee (1978). Similarly, the velocity curves show a lower suitability for high-velocity water than those of Bovee for both brown trout and rainbow trout as well as a higher suitability for low-velocity (including zero-velocity) water for rainbow trout than Bovee's curves. Bovee's substrate curves for all ages of brown trout show a higher suitability of use across more substrate types, especially fine substrates, than do the present curves, and the opposite is true for all ages of rainbow trout. Bovee's suitability value for sand is at or near zero for all ages of rainbow trout, whereas it varies from 0.66 to 0.38 for adult to fry, respectively, in our study. Most of the data in Bovee (1978) were collected from very high gradient, small streams with a higher availability of high-velocity water and a lower availability of fine substrates compared to our streams (USFWS 1984). Therefore, many of the differences between the two sets of suitability curves can be attributed to the differing availabilities of high-velocity water and fine substrate.

Statistical comparisons of habitat preferences exhibited by different species or age groups can be made with contingency tables. Although such tests do not take availability into account, comparisons

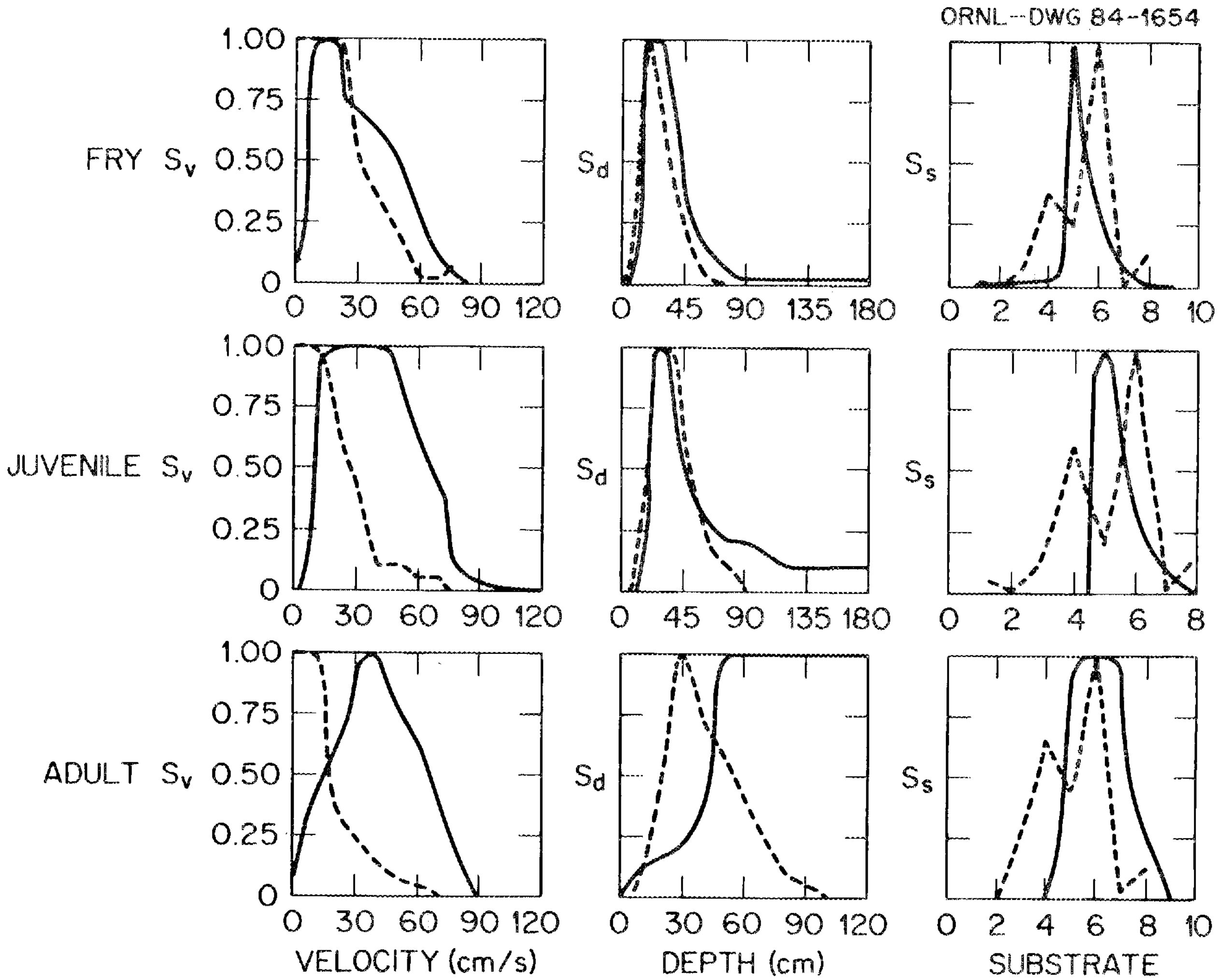

Fig. 4-5. Univariate suitability curves of velocity (S_v), depth (S_d), and substrate (S_s) for three life stages of rainbow trout. Curves are from Bovee (1978) (solid line) and from data collected in this study (broken line).

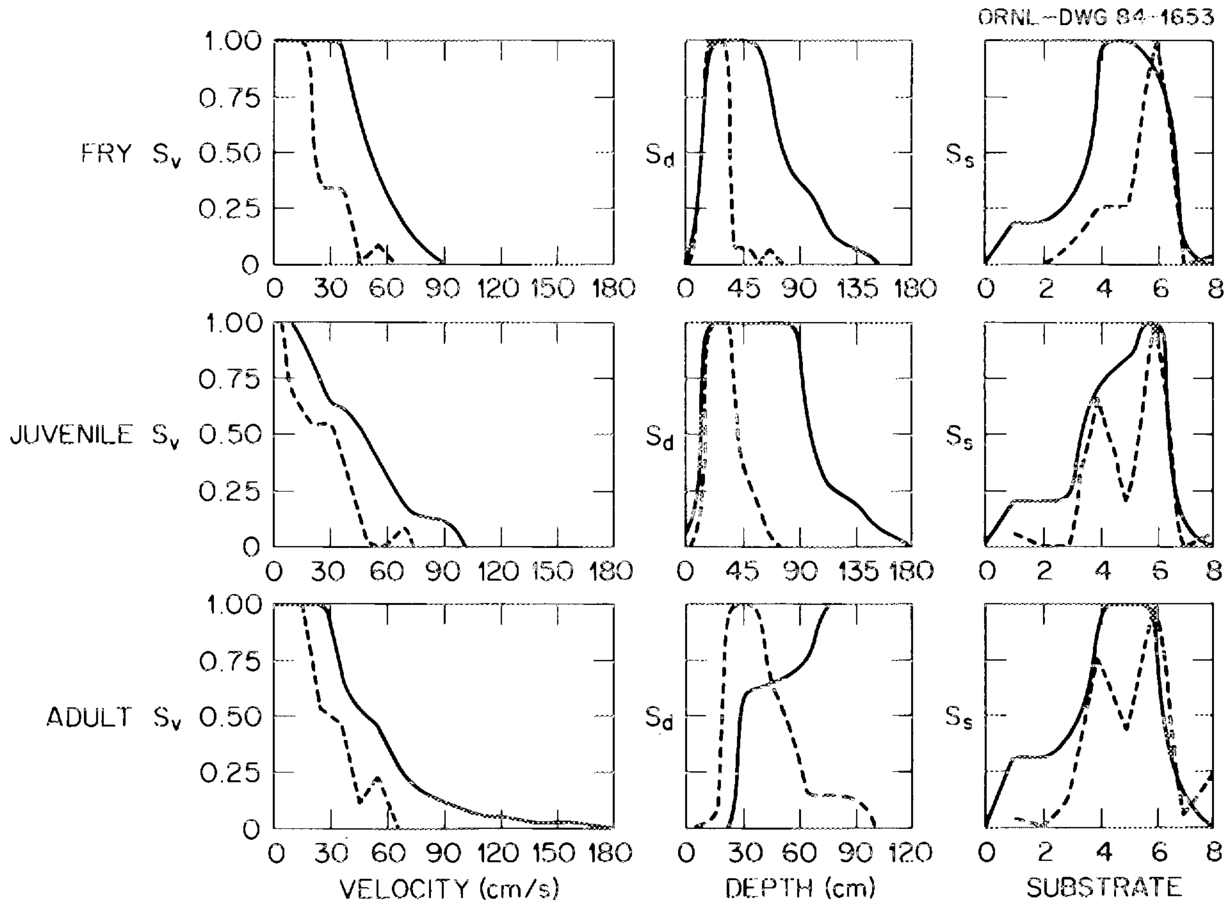

Fig. 4-6. Univariate suitability curves of velocity (S_v), depth (S_d), and substrate (S_s) for three life stages of brown trout. Curves are from Bovee (1978) (solid line) and from data collected in this study (broken line).

between brown and rainbow trout or between Age 0 and Age 1+ trout at a single site at least hold availabilities constant and hence permit statements to be made about relative preferences when availabilities do not differ between groups of fish being compared.

Age 1+ rainbow and brown trout show no significant differences in depth or velocity utilizations at any of the three sites at which they co-occur (BC, LCC, NR3) and differ in substrate use only at LCC, where brown trout tend to prefer sand and rainbow trout prefer rubble, as Bovee's (1978) suitability curves would predict. Age 0 brown and rainbow trout were collected only at BC and LCC, and no significant differences in use of depth, velocity, or substrate were documented.

As for within-species comparisons at a single site, Age 0 brown trout showed significantly higher use of water <30 cm deep and lower use of water ≥ 30 cm deep than Age 1+ brown trout at both sites at which both age groups were collected (BC and LCC). No significant differences between age groups were found for velocity or substrate use for either brown trout or rainbow trout at any site except AC. There, Age 0 rainbow trout had significantly higher frequencies in water velocities of ≥ 15 cm/s and lower frequencies in slower water, as well as higher frequencies over rubble substrate and lower frequencies over sand substrate than Age 1+ rainbow trout. At all five sites, there was a tendency for Age 0 rainbow trout to be overrepresented in water <30 cm deep; Age 1+ rainbow trout were overrepresented in water ≥ 30 cm deep. This trend was statistically significant at AC, BC, and MC.

The question of whether or not fish of a given species and age group use similar habitats despite differences in availability can be examined by using contingency tables to compare habitat use by fish from different sites. Age 1+ brown trout show no significant differences in their use of depth, substrate, or velocity at the three sites (BC, LCC, and NR3) where they occur (Table 4-13). Recall that each site has a unique depth pattern, although not all velocity and substrate patterns are different. Also, there are no significant differences in velocity and substrate utilization by Age 0 brown trout between the two sites where they were collected (Table 4-14); only depth utilization patterns differ between these sites.

In contrast to this constancy across sites exhibited by brown trout, both age classes of rainbow trout, but especially Age 1+, showed significantly different patterns of habitat use at the various sites. In comparison with the average depth utilization at all sites, Age 1+ rainbow trout at AC tended to avoid water <30 cm deep and heavily use water $\geq$50 cm deep (Table 4-15). In this case, these differences could be a direct reflection of availability (Table 4-6). Similarly, Age 1+ rainbow trout at MC tended to occur more often than average in water <30 cm deep, and MC has more water available than average in this depth category. In contrast, Age 1+ rainbow trout at BC and NR3 exhibited patterns of depth use not different from average, even though BC has more shallow water available than average and NR3 has more deep water available than average. At LCC where the availabilities are average (Table 4-6), Age 1+ rainbow trout do not exhibit average usage: they underutilize deep water (Table 4-15A).

Table 4-13. Comparison of habitat use by Age 1+ brown trout at three sites. Contingency table comparisons test the hypothesis that there is no difference in pattern of use between the three sites. This hypothesis cannot be rejected for any of the three resources. Expected values based on the null hypothesis are given in parentheses.

	Site			
	BC	LCC	NR3	Total
A. Depth category, cm				
<30	11(12.4)	24(19.7)	7(9.9)	42
30-49	13(14.8)	22(23.5)	15(11.7)	50
≥50	10(6.8)	8(10.8)	5(5.4)	23
Total	34	54	27	115
	x^2 = 5.395	df = 4	P = 0.249	
B. Velocity category, cm/s				
<5	5(11.5)	22(18.3)	12(9.2)	39
5-14	11(8.3)	12(13.1)	5(6.6)	28
15-29	9(7.4)	10(11.7)	6(5.9)	25
≥30	9(6.8)	10(10.8)	4(5.4)	23
Total	34	54	27	115
	x^2 = 8.440	df = 6	P = 0.208	
C. Substrate category				
Sand, silt, and/or clay	12(12.1)	19(19.3)	10(9.6)	41
Gravel	2(4.7)	12(7.5)	2(3.8)	16
Rubble, boulders, and/or bedrock	20(17.1)	23(27.2)	15(13.6)	58
Total	34	54	27	115
	x^2 = 6.369	df = 4	P = 0.173	

Table 4-14. Comparison of habitat use by Age 0 brown trout at two sites. Observed and expected (in parentheses) values are given for all categories, but chi-square tests were performed only after pooling groups to avoid expected values less than 5 wherever possible. Pooled values are entered between pooled categories.

	Site		
	BC	LCC	Total
A. Depth category, cm			
<30	18(20.6)	10(7.4)	28
30-49	8(5.9)	0(2.1)	8
	10(7.4)	0(2.6)	
≥50	2(1.5)	0(0.5)	2
Total	28	10	38
	x^2 = 4.755	df = 1	P < 0.05
B. Velocity category, cm/s			
<5	10(9.6)	3(3.4)	13
	15(15.5)	6(5.5)	
5-14	5(5.9)	3(2.1)	8
15-29	8(8.8)	4(3.2)	12
	13(12.5)	4(4.5)	
≥30	5(3.7)	0(1.3)	5
Total	28	10	38
	x^2 = .137	df = 1	P > 0.50
C. Substrate category			
Sand, silt, and/or clay	7(5.9)	1(2.1)	8
	10(10.3)	4(3.7)	
Gravel	3(4.4)	3(1.6)	6
Rubble	17(16.9)	6(6.1)	23
	18(17.7)	6(6.3)	
Boulders and/or bedrock	1(0.7)	0(0.3)	1
Total	28	10	38
	x^2 = 0.052	df = 1	P > 0.75

Table 4-15. Comparison of habitat use by Age 1+ rainbow trout at five sites. For all three resources (depth, velocity, and substrate), patterns of use vary significantly between sites; hence, partial x^2 values and P's are given by columns to indicate which sites are, by themselves, significantly different from the average pattern for all sites. Expected values in parentheses.

	AC	BC	LCC	MC	NR3	Total
A. Depth, cm						
<30	5(13.4)	13(12.2)	11(11.3)	32(21.7)	6(8.3)	67
30-49	22(20.0)	12(18.2)	24(16.9)	28(32.4)	14(12.4)	100
≥50	18(11.6)	16(10.6)	3(9.8)	13(18.8)	8(7.2)	58
Total	45	41	38	73	28	225
Column x^2	~9.0	~5.0	~7.7	~7.2	~1.0	
Column P	<0.025	>0.05	<0.025	<0.05	>0.50	
Total x^2 = 29.868 df = 8 P = 0.0002						
B. Velocity, cm/s						
<5	22(14.0)	2(12.8)	13(11.8)	27(22.7)	6(8.7)	70
5-14	17(14.2)	16(12.9)	6(12.0)	25(23.0)	7(8.8)	71
15-29	5(10.8)	16(9.8)	11(9.1)	12(17.5)	10(6.7)	54
≥30	1(6.0)	7(5.5)	8(5.1)	9(9.7)	5(3.7)	30
Total	45	41	38	73	28	225
Column x^2	~12.5	~14.1	~5.2	~2.8	~3.2	
Column P	<0.01	<0.005	>0.10	>0.25	>0.25	
Total x^2 = 37.709 df = 12 P = 0.0002						
C. Substrate						
Sand, silt, and/or clay	36(17.0)	10(15.5)	6(14.4)	28(27.6)	5(10.6)	85
Gravel	7(5.2)	5(4.7)	6(4.4)	6(8.4)	2(3.2)	26
Rubble	2	23	24	36	14	99
	2(22.8)	26(20.8)	26(19.3)	39(37.0)	21(14.2)	
Boulders and/or bedrock	0	3	2	3	7	15
Total	45	41	38	73	28	225
Column x^2	~40.8	~3.2	~7.9	~0.8	~6.7	
Column P	<<0.0001	>0.10	<0.025	>0.50	<0.05	
Total x^2 = 59.430 df = 8 P < 0.0001						

At these last three sites, then, differences between patterns of depth use cannot be explained by differences in availability.

A somewhat similar pattern emerges for the use of velocities by Age 1+ rainbow trout (Table 4-15B). Slowest velocities (<5 cm/s) are significantly overused compared to the overall average at AC and the next most overused (although not significantly so) at MC, and velocities in this category zone are most available at AC and second most available at MC (Table 4-7). Velocity use at BC is also significantly different from both average use and use at LCC, even though the velocities available do not differ from those at either LCC or NR3.

Some variations in substrate use between sites by Age 1+ rainbow trout (Table 4-15C) can also be explained by availability, although others cannot. At AC, sand and finer substrates are used far more than average, and these substrates are far more available at this site than the others (Table 4-8). At NR3, boulder and bedrock substrates are more abundant than anywhere else and are used the most. Besides these two sites, only LCC has a pattern of substrate use significantly different from average despite availabilities not being any different there than at BC. The differences at LCC consist of an overuse of rubble substrate and underuse of sand relative to average.

Differences in patterns of habitat use between sites by Age 0 rainbow trout are less prevalent than for Age 1+ of the same species, but do exist for at least depth and substrate (Table 4-16). Depth use differs significantly from average at both MC, where shallow depths are overutilized, and NR3, where the reverse is true (Table 4-16A). These differences may at least partially reflect availability in that MC has

Table 4-16. Comparison of habitat use by Age 0 rainbow trout at five sites. Entries and notations are the same as those in Table 4-15.

	AC	BC	LCC	MC	NR3	Total
A. Depth, cm						
<30	22(23.5)	25(21.6)	10(12.7)	40(27.9)	14(25.4)	111
30-49	11	7	10	4	22	54
	15(13.5)	9(12.4)	10(7.3)	4(16.1)	26(14.6)	
≥50	4	2	0	0	4	10
Total	37	34	20	44	40	175
Column x^2	~0.3	~1.5	~1.6	~14.3	~14.0	
Column P	>0.50	>0.10	>0.10	<<0.001	<<0.001	
Total x^2 = 31.661 df = 4 P < 0.0001						
B. Velocity, cm/s						
<5	14(8.2)	4(7.6)	3(4.5)	12(9.8)	6(8.9)	39
5-14	8(9.1)	8(8.4)	4(4.9)	12(10.8)	11(9.8)	43
15-29	11(11.8)	11(10.9)	8(6.4)	16(14.1)	10(12.8)	56
≥30	4(7.8)	11(7.2)	5(4.2)	4(9.3)	13(8.5)	37
Total	37	34	20	44	40	175
Column x^2	~6.2	~3.7	~1.2	~3.9	~4.1	
Column P	>0.10	>0.25	>0.25	>0.25	~0.25	
Total x^2 = 19.039 df = 12 P = 0.088						
C. Substrate						
Sand, silt, and/or clay	21(9.5)	4(8.7)	2(5.1)	10(11.3)	8(10.3)	45
Gravel	6(4.7)	4(4.3)	5(2.5)	3(5.5)	4(5.0)	22
Rubble, boulders, and/or bedrock	10(22.8)	26(21.0)	13(12.3)	31(27.2)	28(24.7)	108
Total	37	34	20	44	40	175
Column x^2	~21.5	~3.8	~4.4	~1.9	~1.1	
Column P	<<0.001	>0.10	>0.10	>0.25	>0.50	
Total x^2 = 32.693 df = 8 P < 0.0001						

the highest proportion of water <30 cm deep available, and NR3 has the second highest proportion of water >30 cm deep available. At no site is the pattern of use of velocities significantly different from average (Table 4-16B). Overall, however, the nonsignificant tendencies in the deviations are in the directions expected based on availabilities. For example, slow water is highly used at AC and MC, and fast water (>30 cm/s) is highly used at the other three sites (Table 4-7). Substrate use differs significantly only at AC (Table 4-16C), where sand substrates are utilized more than average, a probable reflection of their high availability at this site.

Overall, the patterns of habitat use exhibited by brown trout of either age varied only once between sites in spite of differing availabilities. The patterns of habitat use by Age 0 rainbow trout differed for a few sites and habitat features, and these differences were in directions expected based on availabilities. The patterns of habitat use by Age 1+ rainbow trout differed at two or three of the five sites for all of the resources studied. Some, but by no means all, of these differences can be attributed to differences in availability. Patterns at both AC and MC tend to deviate from average use in ways predicted by availability. This is not always true at BC, LCC, and NR3.

Besides inherent species preference and availability, the presence of a second species can also potentially affect resource use at these latter sites. Sympatric populations of wild brown and rainbow trout exist at BC, LCC, and NR3. Because of the dominance of brown trout over other salmonids (Kalleberg 1958; Nilsson 1963; Fausch and White

1981), the possibility of a habitat niche shift by rainbow trout in the presence of brown trout should be evaluated. Many analyses are required because patterns of habitat use by Age 1+ rainbow trout at the three sites where they are sympatric with brown trout vary significantly among themselves as do patterns of use for depth and substrate, but not velocity, at MC and AC where allopatric populations occur. Hence, pooled comparisons of all sympatric populations and both allopatric populations would not be meaningful. In many cases, site-by-site comparisons are necessary, although some pooling of data from sites not significantly different from each other was performed.

For depth and substrate, significant differences exist between AC and any of the individual sympatric sites. All differences are in the directions expected based on availability; i.e., Age 1+ rainbow trout use deeper water and more sand substrates at AC than at BC, LCC, or NR3. In pairwise comparisons with MC, the differences cannot always be explained in this same way. Considering depths first, the BC vs MC comparison shows significant differences in the direction expected based on availability differences, but this is not the case at LCC (Table 4-17). The significant differences at LCC include some directly opposite to availability differences. Specifically, there was an excess of Age 1+ rainbow trout in water >50 cm deep at MC in spite of its low availability at that site. Underuse of the deepest water at LCC by Age 1+ rainbow trout is consistent with the concept of competitive displacement or niche shift in that Age 1+ brown trout show preferences for deep water (Table 4-9). No significant differences exist between depth use at MC and NR3.

Table 4-17. Comparison of use of depth (cm) by Age 1+ rainbow trout at sites which differ in the presence or absence of brown trout and where significant differences occur. Expected values in parentheses.

	<30	30-49	≥50	Total
BC	13(16.2)	12(14.4)	16(10.4)	41
MC	32(28.8)	28(25.6)	13(18.6)	73
Total	45	40	29	114
	$x^2 = 6.314$ df = 2 $P < 0.05$			
LCC	11(14.7)	24(17.8)	3(5.5)	38
MC	32(28.3)	28(34.2)	13(10.5)	73
Total	43	52	16	111
	$x^2 = 6.430$ df = 2 $P < 0.05$			

Age 1+ rainbow trout at AC and MC do not differ significantly in velocity use, nor do they differ at NR3 and LCC. Hence, only two comparisons are necessary: AC + MC vs BC, which shows significant differences in the direction expected based on availability, and AC + MC vs LCC + NR3, which also shows differences in the direction expected based on availability. However, a comparison of velocity use by Age 1+ rainbow trout at MC alone vs LCC + NR3 shows significant differences, not all of which reflect availability differences (Table 4-18). Use of the slowest (<5 cm/s) and fastest (≥30 cm/s) water is highest where its availability is highest, but the use of 5- to 14-cm/s water is higher at MC despite its being no more available there than at the sympatric sites (Table 4-7). Furthermore, use of 15- to 29-cm/s velocities is higher at the sympatric sites than at MC even though velocities in this range are less available there than at MC. This difference is again consistent with a hypothesis of competition-induced niche shift in that brown trout showed preferences for water with velocities <15 cm/s (Table 4-9).

Substrate utilization patterns for Age 1+ rainbow trout at BC, LCC, and NR3 do not differ significantly, although those at AC and MC do. Age 1+ rainbow use more sand substrate at AC than at the sympatric sites, and this is consistent with its high availability at AC. However, Age 1+ rainbow trout also use more sand substrate at MC than at the sympatric sites (Table 4-19) even though it is less available at MC than at the sympatric sites (Table 4-8). Again, this difference is consistent with a hypothesis of habitat niche shift in that brown trout show a preference for sand substrate (Table 4-9).

Table 4-18. Comparison of use of velocity (cm/s) by Age 1+ rainbow trout at sites which differ in the presence or absence of brown trout and where significant differences occur. Expected values in parentheses.

	<5	5-14	15-29	≥30	Total
MC1	27(24.2)	25(20.0)	12(17.3)	9(11.6)	73
LCC+NR3	19(21.8)	13(18.0)	21(15.7)	13(10.4)	66
Total	46	38	33	22	139

$\chi^2 = 7.968$ df = 3 $P < 0.05$

Table 4-19. Comparison of use of substrate by Age 1+ rainbow trout at sites which differ in the presence or absence of brown trout and where significant differences occur. Expected values in parentheses.

	Clay, silt, and/or sand	Gravel	Rubble, boulders and/or bedrock	Total
MC	28(19.9)	6(7.7)	39(45.4)	73
BC+LCC+NR3	21(29.1)	13(11.3)	73(66.6)	107
Total	49	19	112	180

$\chi^2 = 7.700$ df = 2 $P < 0.025$

As previously indicated, the differences between habitat utilization patterns of Age 0 rainbow trout can be explained on the basis of availability. Still, for the sake of completeness, patterns of use at allopatric and sympatric sites were compared. Age 0 rainbow are sympatric with Age 0 brown trout only at BC and LCC. Habitat use associated with depth, velocity, and substrate does not vary significantly for Age 0 rainbow trout at these sites and hence can be pooled for analysis. In contrast, AC and MC differ significantly in depth and substrate use by Age 0 rainbow trout, so the allopatric populations cannot be similarly pooled. Depth use by Age 0 rainbow trout does not differ significantly between AC and the sites with sympatric populations but does differ between these sympatric sites and MC. There is greater use of water <30 cm deep at MC, which is consistent with its greater availability there (Table 4-6). Substrate use by Age 0 rainbow trout does not differ significantly between BC + LCC and MC, but does differ between these sympatric sites and AC. The difference, in this case a greater use of fine substrate at AC than at BC + LCC, is consistent with the availabilities (Table 4-8). Velocity utilization patterns for Age 0 rainbow trout do not differ between AC and MC, but do differ in the allopatric vs sympatric comparison. Again, the greater use of low-velocity water in allopatry is consistent with its greater availability there (Table 4-7). Classification of the NR3 site as either allopatric or sympatric is ambiguous, since Age 0 rainbow trout there did not coexist with Age 0 brown trout in the fall 1983 (Table A-2), although Age 1+ individuals were present and Age 0 trout were present on other sampling dates (Sect. 4.3.1.1). No significant differences in the use of any of the habitat resources occur between Age 0 rainbow trout at NR3 and the pooled BC + LCC sympatric sites.

4.2.2.1 Summary

Availability of different habitat types varies from site to site (Tables 4-6 to 4-8). Trout, especially Age 1+ trout, do not use these habitats in proportion to their abundance in the environment, but rather show preferences for certain depths, velocities, and substrates (Tables 4-9 to 4-12). These preferences vary between sites along with variations in availability; e.g., Age 1+ brown trout show a strong preference for depth >50 cm at BC where this depth is least available, moderate preference at LCC where it is somewhat less rare, and no preference at all for deep water at NR3 where it is relatively abundant (Tables 4-6 and 4-9). Not all between-site variations in habitat use by Age 1+ rainbow trout can be accounted for by variations in availability. Some between-site variations in habitat preferences seem to be the result of habitat niche shift at sites where Age 1+ rainbow trout are sympatric with Age 1+ brown trout (Tables 4-17 to 4-19). Because variations in habitat use are induced both by availability (i.e., relative distribution of habitat types in the environment) and by species interactions, no single suitability curve can be used to accurately predict habitat use in all lotic systems irrespective of the distribution of habitat types and presence or absence of other salmonids.

4.2.3 Habitat Evaluation

Physical habitat conditions at the eight study sites were evaluated in terms of weighted usable area (WUA) (m^2/km) for rainbow trout and brown trout, as described in Sect. 3.2. Univariate suitability curves were taken from Bovee (1978) (see Fig. 4-5 and Appendix E). The differences between sites can be examined in terms of (1) observed WUA values, on each sampling date, derived from the habitat response curves (WUA vs discharge for specific life stages; see Appendix F); (2) the annual regime of average habitat values produced at the historical mean monthly flows at each site; and (3) the time series of habitat values produced by average monthly flows for the period January 1980 to September 1983 (hydrographs are shown in Appendix G). Habitat values were also standardized by total wetted surface area (TSA) within a representative reach and then expressed as percent usable area (PUA): PUA = 100(WUA/TSA).

In some cases, the values of WUA calculated at observed flows at the eight study sites were strongly correlated between life stages. The highest correlation occurred between fry and juvenile WUAs, with $r = 0.92$ and $r = 0.91$ for brown trout and rainbow trout, respectively (Table 4-20). This outcome could have been expected due to the similarity in the suitability curves for these two life stages (see Figs. 4-5 and 4-6). Other WUA values that were highly correlated included incubation and fry ($r = 0.80$) and spawning and juvenile ($r = 0.79$), both for rainbow trout.

Two general shapes were observed in the habitat response curves (WUA vs flow) for trout at the eight study sites: (1) WUA increases

Table 4-20. Correlation coefficients (r) between weighted usable area (WUA) values for different life stages of rainbow and brown trout (all values of r are significant at $\alpha = 0.05$; NS = not significant).

	Adult	Juvenile	Fry	Incubation	Spawning
Brown trout					
Adult	–	0.49	NS	NS	0.51
Juvenile		–	0.92	0.47	NS
Fry			–	NS	NS
Incubation				–	NS
Spawning					–
Rainbow trout					
Adult	–	0.63	0.34	NS	0.54
Juvenile		–	0.91	0.71	0.79
Fry			–	0.80	0.64
Incubation				–	0.61
Spawning					–

asymptotically with flow, and (2) WUA increases initially and then decreases with optimum habitat values less than the average annual flow (Appendix F). Response curves of the second type (unimodal curves) are important because they predict stresses due to habitat degradation during high flow events. Unimodal curves were obtained for spawning (brown trout at AC and NR3; rainbow trout at AC and NR3), incubation (all sites and species), fry and juvenile (both species at AC and brown trout at BC2). The adult habitat response curves increased asymptotically at most sites.

Differences in physical habitat characteristics between the study sites were identified, using Duncan's multiple range test and the WUA values based on mean monthly flows. Only those months in which a life stage was present were used in this analysis (Table 4-21). The habitat values differed significantly between sites for all species and life stages (Tables 4-22 to 4-25). For rainbow trout, AC had the best habitat values for older life stages (adult and juvenile), and LCC had the best habitat for earlier life stages (incubation, and spawning). Although LCC has relatively good reproductive and rearing habitat, it appears to have the poorest adult rainbow habitat, based on WUA, of all the sites. The three Nantahala River sites consistently ranked low in terms of rainbow habitat, especially with respect to habitat for the earlier life stages.

Brown trout habitat at the four sites where this species was present was highest at LCC and lowest at NR3. The BC1 site suffered from relatively low spawning and adult habitat, and BC2 had poorer juvenile, fry, and incubation habitat. The superiority of LCC for

Table 4-21. Periodicity chart for trout life stages in southern Appalachian streams (+ = presence; 0 = absence).

Species and life stage	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Rainbow trout												
Spawning	+	+	+	0	0	0	0	0	0	0	0	0
Incubation	0	+	+	+	+	0	0	0	0	0	0	0
Fry	0	0	0	0	+	+	+	+	+	+	+	+
Juvenile	+	+	+	+	+	+	+	+	+	+	+	+
Adult	+	+	+	+	+	+	+	+	+	+	+	+
Brown trout												
Spawning	0	0	0	0	0	0	0	0	0	+	+	+
Incubation	+	+	+	+	0	0	0	0	0	0	+	+
Fry	0	0	+	+	+	+	+	+	+	+	+	+
Juvenile	+	+	+	+	+	+	+	+	+	+	+	+
Adult	+	+	+	+	+	+	+	+	+	+	+	+

Table 4-22. Comparison between sites of weighted usable area (WUA) (m^2/km) for five life stages of brown trout based on average monthly flows (see Table 2-2 for flow values).

Life stage[a]	Mean WUA (m^2/km)[b]							
Spawning	AC[c]	LCC	BC2	BC1	NR3	MC	NR1[c]	NR2[c]
n = 3	350	233	134	76	54	38	8	2
Incubation	LCC	BC1	MC	BC2	AC[c]	NR3	NR2[c]	NR1[c]
n = 6	1040	928	750	740	532	263	179	130
Fry	AC[d]	BC1	NR2[d]	BC2	MC[e]	LCC	NR1[d]	NR3
n = 10	3544	2376	1889	1779	1735	1654	1470	1299
Juvenile	AC[d]	NR2[d]	BC1	LCC	NR1[d]	BC2	MC[d]	NR3
n = 12	2967	1689	1653	1414	1237	1207	1168	961
Adult	AC[e]	NR2[e,f]	NR1[f]	LCC	NR3	BC2	BC1	MC[d]
n = 12	2532	883	828	445	405	400	344	341

[a]n = number of months that life stage is present (see Table 4-21).

[b]Values connected by the same line are not significantly different (α = 0.05) based on Duncan's multiple range test.

[c]No evidence of the occurrence of this life stage at the study site (i.e., no Age 0 or sexually mature adults were collected.

[d]No individuals of this life stage were collected.

[e]Only one (MC) or two (AC, NR2) individuals of this life stage were collected.

[f]Individuals probably of hatchery origin; no evidence of wild stocks found at this site.

Table 4-23. Comparison between sites of weighted usable area (WUA) (m^2/km) for five life stages of rainbow trout based on average monthly flows (see Table 2-2 for flow values).

Life stage[a]	Mean WUA (m^2/km)[b]							
Spawning	LCC	AC	BC2	BC1	MC	NR3	NR2	NR1
n = 3	238	237	205	115	40	34	3	2
Incubation	LCC	BC1	MC	BC2	AC	NR3	NR2	NR1
n = 4	1016	886	728	723	406	236	172	115
Fry	AC	LCC	BC1	BC2	MC	NR3	NR1	NR2[c]
n = 8	445	445	434	354	242	204	196	174
Juvenile	AC	BC1	LCC	BC2	MC	NR3	NR1	NR2
n = 12	822	585	542	489	350	279	207	178
Adult	AC	NR1	NR3	BC2	MC	NR2	BC1	LCC
n = 12	2600	1308	1232	1072	984	935	929	573

[a]n = number of months that life stage is present (see Table 4-21).

[b]Values connected by the same line are not significantly different ($\alpha = 0.05$) based on Duncan's multiple range test.

[c]Only one Age 0 trout collected at this site.

Table 4-24. Comparison between sites of percent usable area (PUA) for five life stages of brown trout.

Life stage[a]	Mean PUA[b]							
Spawning n = 3	AC[c] (4.38)	LCC (4.18)	BC2 (1.36)	BC1 (0.75)	NR3 (0.46)	MC (0.35)	NR1[c] (0.05)	NR2[c] (0.02)
Incubation n = 6	LCC (16.05)	BC1 (8.89)	BC2 (7.27)	MC (6.54)	AC[c] (6.42)	NR3 (2.12)	NR2[c] (1.64)	NR1[c] (0.72)
Fry n = 10	AC[d] (45.06)	LCC (28.69)	BC1 (23.51)	NR2[d] (18.49)	BC2 (18.23)	MC[e] (15.82)	NR3 (10.94)	NR1[d] (8.48)
Juvenile n = 12	AC[d] (36.31)	LCC (23.95)	BC1 (16.23)	NR2[d] (16.19)	BC2 (12.24)	MC[d] (10.52)	NR3 (7.98)	NR1[d] (7.04)
Adult n = 12	AC[e] (30.80)	NR2[e,f] (8.41)	LCC (7.28)	NR1[f] (4.68)	BC2 (4.01)	NR3 (3.36)	BC1 (3.33)	MC[d] (3.10)

[a]n = number of months used in the analysis, based on presence of the life stage (see Table 4-21).

[b]Values connected by the same line are not significantly different ($\alpha = 0.05$) based on Duncan's multiple range test.

[c]No evidence of the occurrence of this life stage found at the study site (i.e., no Age 0 or sexually mature adults were collected).

[d]No individuals of this life stage were collected.

[e]Only one (MC) or two (AC, NR2) individuals of this life stage were collected.

[f]Individuals probably of hatchery origin; no evidence of wild stocks found at this site.

Table 4-25. Comparison between sites of percent usable area (PUA) for five life stages of rainbow trout.

Life stage[a]	Mean PUA[b]							
Spawning	LCC	AC	BC2	BC1	MC	NR3	NR2	NR1
n = 3	(3.49)	(2.75)	(1.98)	(1.08)	(0.34)	(0.27)	(0.03)	(0.01)
Incubation	LCC	BC1	BC2	MC	AC	NR3	NR2	NR1
n = 4	(14.80)	(8.37)	(6.98)	(6.18)	(4.75)	(1.86)	(1.53)	(0.63)
Fry	LCC	AC	BC1	BC2	MC	NR3	NR2[c]	NR1
n = 8	(7.93)	(5.57)	(4.35)	(3.65)	(2.25)	(1.75)	(1.73)	(1.15)
Juvenile	AC	LCC	BC1	BC2	MC	NR3	NR2	NR1
n = 12	(10.10)	(9.07)	(5.73)	(4.94)	(3.18)	(2.34)	(1.70)	(1.18)
Adult	AC	BC2	NR3	NR2	LCC	BC1	MC	NR1
n = 12	(31.53)	(10.77)	(10.22)	(9.87)	(9.55)	(9.10)	(8.88)	(7.38)

[a]n = number of months used in the analysis, based on presence of the life stage (see Table 4-21).

[b]Values connected by the same line are not significantly different ($\alpha = 0.05$) based on Duncan's multiple range test.

[c]Only one Age 0 trout collected at this site.

brown trout is especially obvious when WUA is expressed as a percent of total wetted surface area (Table 4-22).

Examination of the hydrologic record synthesized for the study sites indicates several periods of flow-related stress, which could have affected the trout populations that were observed in 1982 and 1983 (Table 4-26). The most important periods of potential habitat stress were

(1) persistent low flows from July through December 1980 at AC and MC;

(2) low flows in the late fall and winter of 1980 and 1981 at all sites;

(3) low flows in August, September, and October 1981 at LCC, Bradley Creek, and the Nantahala River basin;

(4) high flows in March and April 1980 at LCC, Bradley Creek, and the Nantahala River basin;

(5) high flows in January 1982 at AC and MC, and in February 1982 at Bradley Creek; and

(6) high flows in February, March, and April 1983 at AC, MC, LCC, and Bradley Creek.

Each of these extreme hydrologic events depressed WUA values for specific species-life stage combinations. A time series of habitat values based on average monthly flows over the last 4 years is shown in Appendix H. Because this time series is based on average monthly habitat values, the periods of flow-related habitat stress, which usually occurred over time intervals shorter than a month, are not obvious in all cases.

Table 4-26. Occurrence of high flows (>150% mean monthly flow) or low flows (<50% mean monthly flow) in five watersheds, 1980-1983. Values are percent of the average monthly flow.

Year and month	Site AC	BC	LCC	MC	NR
1980					
January	--	--	--	--	--
February	--	--	--	--	--
March	152	--	--	151	170
April	--	191	210	--	--
May	--	--	--	--	--
June	49	--	--	49	--
July	42	--	--	42	--
August	28	48	--	28	49
September	32	--	--	33	--
October	34	--	--	36	49
November	--	--	--	--	--
December	37	40	43	37	48
1981					
January	20	30	36	20	31
February	--	--	--	--	--
March	--	--	--	--	--
April	--	--	--	--	--
May	--	--	--	--	--
June	--	--	--	--	--
July	--	--	--	--	--
August		44	33		43
September	--	--	--	--	--
October	--	37	33	--	41
November	--	34	30	--	--
December	--	--	43	--	--
1982					
January	177	--	--	178	--
February	--	--	--	--	--
March	--	--	--	--	--
April	--	--	--	--	--
May	--	--	--	--	--
June	--	--	--	--	--
July	--	--	--	--	--
August	--	--	--	--	--
September	--	--	--	--	--
October	--	--	--	--	--
November	168	--	--	153	--
December	183	188	164	185	197

Table 4-26. (continued)

Year and month	Site AC	BC	LCC	MC	NR
1983					
January	--	--	--	--	--
February	--	187	205	--	--
March	--	157	227	--	--
April	188	217	230	190	169
May	--	--	185	--	--
June	--	--	154	--	--
July	--	--	--	--	--
August	38	--	--	36	--
September	42	--	--	46	--

In addition to these natural flow events that had an adverse impact on trout habitat, short-term maintenance releases from Nantahala Reservoir had an impact on NR2 and, to a lesser extent, on NR1. The most significant of these releases occurred in March 1980 when average daily flow below the dam exceeded 36 m^3/s (TVA 1983). Although flows of this magnitude are beyond the range of our WSP calibrations, habitat values at these extremely high flows can be assumed to be very low for all species and life stages.

4.3 FISH POPULATION STUDIES

The target species in this study were rainbow (*Salmo gardneri*) and brown (*S. trutta*) trout. Wild rainbow trout populations exist at all eight study sites, but wild brown trout are found only in Bradley Creek, Lost Cove Creek, and the upper Nantahala River (NR3). An insignificant population exists in Abrams and Mill creeks in the Great Smoky Mountains National Park; a single individual [total length (TL) = 8.8 cm] was collected at the Mill Creek site and only two brown trout (TL = 32.4 and 57.6 cm) were found at the Abrams Creek site. A single brook trout (TL = 16.9 cm) was also collected in Lost Cove Creek. With the exception of the WUA vs discharge curves which were computed for both rainbow and brown trout at all eight sites, these incidental catches are not considered in the analyses that follow (Sects. 4.3 and 4.5).

When this study was initiated in March 1982, only the lower Nantahala River site (NR1) was routinely stocked with hatchery-reared trout. Approximately 1200-1500 trout were stocked twice monthly from March through August in both 1982 and 1983 (NCWRC 1983). The fish were released over a 5.6-km reach of the Nantahala River from White Oak Creek downstream to the powerhouse (Fig. 2-13). Separate estimates of the density and standing crop of stocked trout were computed (Table 4-27), since most hatchery fish could be easily distinguished from wild stocks by distinct differences in the size and shape of the pectoral, pelvic, caudal, and/or dorsal fins. In the case of a few brown trout, such a determination was sometimes difficult, presumably because some individuals had spent several months (or years) in the stream. Because we found no evidence of natural reproduction of brown trout at NR1, all brown trout were considered to be of hatchery origin. A similar rationale was applied to brown trout at NR2. Unlike NR1, however, this site was not stocked in either year. Only two brown trout (TL = 20.6 and 40.0 cm) were collected during the entire study, and the larger individual was encountered on every sampling date (Table 4-27).

Evidence of stocking at NR3 was first observed in early June 1983 when several fingerling rainbow trout ($\overline{TL}$ = 11.1, n = 11) with abnormal pectoral and dorsal fins were observed. These fish, which constituted 32 and 24% of the total rainbow trout collected at this site in June and July 1983, respectively, were probably steelhead trout (<u>Salmo gairdneri</u>). Adult and fingerling steelhead were recently introduced into the Nantahala River drainage by the North Carolina Wildlife Resources Commission. In February 1983, both ripe and spent female steelhead were found in Curtis Creek, and Little Indian and Big Indian creeks (NCWRC 1983), all of which are tributaries of the Nantahala River and located just above NR3 (Fig. 2-11). In early April 1983,

Table 4-27. Population estimates ($\hat{x}$), densities (number/100 m^2), and standing crops (g/m^2) of stocked trout at the three Nantahala River sites.

Site and date	$\hat{x}^a$	Density	Standing crop	Species composition (%rainbow:%brown:%brook)
NR1				
7-22-82	7	0.26	0.20	20:80:0
9-22-82	58	2.24	2.11	0:100:0
3-31-83	152[b]	4.70	5.26	75:18:7
7-19-82	24	0.82	1.48	85:14:0
NR2				
7-22-82	1	0.13	0.74	0:100:0
9-23-82	2	0.26	0.85	0:100:0
3-31-83	1	0.12	0.73	0:100:0
7-21-83	1	0.13	0.96	0:100:0
NR3[c]				
6-8-83	12	0.57	0.08	100:0:0
7-22-83	22	1.34	0.26	100:0:0

[a]From Eq. (1) in Sect. 3.6.3.1.

[b]Season is closed during March.

[c]No stocked trout (steelhead) were identified in 1982.

hatchery-reared steelhead were stocked in the upper Nantahala River (NCWRC 1984). Although most of these fish might be expected to move downstream to Nantahala Reservoir soon after release, some may have remained in the upper reaches, thus accounting for their presence in the June and July samples collected at NR3. No hatchery-reared salmonids were found at any of the five sites outside the Nantahala River drainage.

Because of the poor survival of hatchery-reared trout following their initial release in a natural stream environment (see review by Bachman 1982), frequent stocking is required to maintain a catchable population over time. As a result of these two factors (poor survival and frequent stocking), large fluctuations were observed in the density and standing crop of the stocked trout population at NR1 (Table 4-27). After stocking is terminated, such populations may approach zero after only several months of residency in the stream. Although Bachman (1982) observed stress in wild trout from agonistic encounters with hatchery trout, such effects would occur over relatively short periods of time. We assumed that such a transitory phenomenon would not have a significant adverse effect on the wild trout population as a whole. However, because fishing pressure is usually high on stocked streams, the coexisting wild population is also exposed to short but intense periods of angling immediately following stocking. Undoubtedly some wild trout are creeled during these periods even though hatchery trout are probably much more vulnerable to angling than are wild stocks. On the other hand, anglers were never observed at AC, MC, or NR2 and were only rarely encountered at the other sites (including NR1) during the course of the study. Thus, we assumed that fishing pressure was not a significant factor in controlling wild trout abundance at NR1 or any of the other seven sites.

Consequently, the wild rainbow trout population at NR1 was included in our analysis, but the stocked population, including all brown trout, was omitted from the computations of density, standing crop, and production (Sect. 4.3.1) and the analysis of habitat vs trout (Sect. 4.5). Brown trout at NR2 were also excluded because these fish are presumably of hatchery origin and are present in very low densities (Table 4-27). The fingerling steelhead trout at NR3, on the other hand, were included in all analyses except production, where separate estimates for the two populations were made.

4.3.1 Density and Standing Crop

As noted earlier, one way in which fish populations may reflect the adequacy of their environment is by their abundance. A stream with relatively low carrying capacity (e.g., due to lack of suitable habitat or adequate food base) would be expected to have correspondingly low densities of resident fishes. On both a seasonal and longer-term basis, the dual processes of migration and mortality adjust the numbers of fish per unit area to that which can be supported by the available resources.

4.3.1.1 Salmonids

The numbers and standing crops of Age 0, 1, and 2+ rainbow and brown trout were estimated at all of the study sites for the sampling dates between June 1982 and July 1983. Estimates of rainbow trout abundance, expressed as number per kilometer and number per 100 square meters, are presented in Tables 4-28 through 4-30. Densities (no./100 m^2) of older (Age 1+) rainbow trout were similar among dates at a given site, but varied by as much as two orders of magnitude between sites. Also, considerable variation in Age 0 densities was observed among dates at a given site (Table 4-28). Densities of Age 0 rainbow trout were lowest at NR2 and NR1 and highest at MC. Densities of Age 1 and Age 2+ rainbow trout were generally lowest at NR2 and BC1 and highest at MC (Tables 4-29 and 4-30). Total rainbow trout densities (all ages combined) ranged from a low of 0.5 fish/100 m^2 at NR2 in July 1982 to a high of 71.1 fish/100 m^2 at MC in July 1983.

Statistical comparisons of mean densities of rainbow trout among the eight study sites are presented in Table 4-31. Densities of Age 0 and Age 1 trout were significantly higher at Mill Creek than at the other seven sites. Few significant differences were noted between the mean densities of rainbow trout at the other sites, despite an approximate order of magnitude range between the smallest and the largest estimates. It is likely that the wide confidence limits for many of the population estimates (Tables 4-28 through 4-30) precluded detection of significant site differences in age-class-specific rainbow trout densities.

Brown trout densities, like those of rainbow trout, were similar among different dates at a given site but varied by as much as an order of magnitude between sites (Tables 4-32 through 4-34). Densities of all age classes were relatively low (generally less than 1.0 fish/100 m^2) at BC1, BC2, and NR3, but relatively high at LCC.

Table 4-28. Population estimates of Age 0 rainbow trout at the study sites.

Site	Date	Estimated number[a] (95% confidence limits)	Number per kilometer	Number per 100 m^2
AC	7-14-82	64 (38, b)	432.2	6.4
	9-8-82[c]	33	221.5	2.8
	10-28-82	41 (25, 584)	273.2	4.0
	7-14-83	124 (77, 1122)	830.1	12.3
BC1	6-23-82	--	--	--
	8-25-82[c]	24	222.2	2.4
	11-12-82[c]	99	655.6	7.5
	6-22-83[c]	3	19.9	0.2
BC2	6-23-82[c]	2	21.1	0.2
	8-26-82	177 (96, b)	790.3	9.0
	11-11-82	72 (44, 780)	319.6	3.7
	6-22-83[c]	11	49.1	0.5
LCC	6-25-82[c]	8	74.8	1.3
	8-27-82	34 (24, 75)	315.7	7.6
	11-10-82	19 (9, b)	175.2	3.9
	6-24-83[c]	2	18.7	0.3
MC	7-1-82	254 (138, b)	2173.7	30.5
	9-9-82[c]	165	1410.3	12.9
	10-29-82	157 (85, b)	1342.7	17.6
	7-14-83	322 (150, b)	2754.7	43.2
NR1	7-22-82[c]	7	38.7	0.4
	9-22-82	68 (37, b)	374.5	2.7
	7-19-83[c]	27	149.2	1.0
NR2	7-23-82	--	--	--
	9-23-82[c]	2	9.2	0.1
	7-21-83	--	--	--
NR3	7-21-82[c]	78	481.5	4.3
	9-24-82[c]	255	1574.1	14.4
	6-8-83[c]	1	6.2	0.1
	7-22-83[c]	78	481.5	5.0

[a]Dashes indicate that an insufficient number of fish were collected to derive a population estimate.

[b]Upper confidence limit is undefined.

[c]Population estimate is based on Eq. (1) (Sect. 3.6.3).

Table 4-29. Population estimates of Age 1 rainbow trout at the study sites.

Site	Date	Estimated number[a] (95% confidence limits)	Number per kilometer	Number per 100 m^2
AC	7-14-82	24 (15, 260)	160.2	2.4
	9-8-82[c]	15	100.7	1.3
	10-28-82	24 (13, b)	161.8	2.4
	3-17-83	27 (13, b)	178.3	2.3
	7-14-83	65 (40, 798)	436.2	6.5
BC1	6-23-82[c]	8	53.0	0.6
	8-25-82[c]	3	27.8	0.3
	11-12-82	3 (3, 3)	19.9	0.2
	3-30-83[c]	24	158.9	1.5
	6-22-83	8 (4, b)	52.2	0.5
BC2	6-23-82[c]	8	84.2	1.0
	8-26-82[c]	45	200.9	2.3
	11-11-82	7 (3, b)	29.3	0.3
	6-22-83	78 (43, b)	348.0	3.7
LCC	6-25-82	11 (7, 58)	98.4	1.7
	8-27-82	24 (16, 120)	226.5	5.5
	11-10-82	28 (13, b)	262.8	5.9
	4-29-83	10 (6, 322)	94.5	1.2
	6-24-83	19 (13, 43)	176.2	2.6
MC	7-1-82	63 (42, 194)	539.8	7.6
	9-9-82	82 (45, b)	697.3	6.4
	10-29-82	49 (31, 327)	423.0	5.6
	3-17-83	133 (93, 292)	1136.8	10.9
	7-14-83	172 (119, 412)	1468.5	23.0
NR1	7-22-82[c]	88	486.2	5.6
	9-22-82	45 (27, b)	251.1	1.8
	3-31-83	109 (51, b)	601.6	3.4
	7-19-83	114 (66, b)	627.7	4.3
NR2	7-23-82	2 (1, b)	10.1	0.1
	9-23-82[c]	10	45.9	0.5
	3-31-83[c]	3	13.8	0.1
	7-21-83	18 (11, 88)	80.8	0.9
NR3	7-21-82[c]	6	37.0	0.3
	9-24-82[c]	30	185.2	1.7
	6-8-83	49 (29, b)	299.5	2.4
	7-22-83[c]	78	481.5	5.0

[a]Dashes indicate that an insufficient number of fish were collected to derive a population estimate.

[b]Upper confidence limit is undefined.

[c]Population estimate is based on Eq. (1) (Sect. 3.6.3).

Table 4-30. Population estimates of Age 2+ rainbow trout at the study sites.

Site	Date	Estimated number[a] (95% confidence limits)	Number per kilometer	Number per 100 m^2
AC	7-14-82	32 (15, b)	214.0	3.2
	9-8-82	5 (5, 5)	33.6	0.4
	10-28-82	14 (8, b)	95.6	1.4
	3-17-83	20 (12, b)	136.6	1.8
	7-14-83	28 (20, 59)	187.9	2.8
BC1	6-23-82	3 (2, b)	20.9	0.2
	8-25-82	4 (3, 17)	37.2	0.4
	11-12-82	4 (4, 4)	26.5	0.3
	3-30-83	3 (3, 3)	19.9	0.2
	6-22-83	8 (4, b)	55.9	0.6
BC2	6-23-82[c]	20	210.5	2.4
	8-26-82[c]	100	446.4	5.1
	11-11-82	9 (6, 40)	41.8	0.5
	6-22-83[c]	42	187.5	2.0
LCC	6-25-82	18 (11, b)	171.2	3.0
	8-27-82	9 (7, 17)	84.1	2.0
	11-10-82	10 (7, 17)	89.7	2.0
	4-29-83	12 (7, 376)	110.3	1.4
	6-24-83	19 (14, 30)	174.5	2.6
MC	7-1-82	42 (25, b)	356.2	5.0
	9-9-82	9 (4, b)	74.9	0.7
	10-29-82	22 (14, 77)	184.7	2.4
	3-17-83	66 (40, 9994)	566.7	5.4
	7-14-83	36 (27, 65)	311.3	4.9
NR1	7-22-82[c]	35	193.4	2.2
	9-22-82[c]	12	66.3	0.5
	3-31-83	28 (13, b)	155.4	0.9
	7-19-83	82 (38, b)	451.2	3.1
NR2	7-23-82	7 (3, b)	30.2	0.3
	9-23-82	-	-	-
	3-31-83	8 (5, b)	37.3	0.4
	7-21-83	8 (5, 34)	36.8	0.4
NR3	7-21-82	7 (3, b)	42.4	0.4
	9-24-82	33 (16, b)	202.5	1.9
	6-8-83[c]	15	92.6	0.8
	7-22-83	14 (9, 120)	86.8	0.9

[a]Dashes indicate that an insufficient number of fish were collected to derive a population estimate.

[b]Upper confidence limit is undefined.

[c]Population estimate is based on Eq. (1) (Sect. 3.6.3).

Table 4-31. Comparison between sites of the mean densities of three age classes of rainbow trout, expressed both as number per unit area and number per length of stream. Stocked trout at NR1 excluded.

Age class	Sites[a]							
	(No./100 m^2)							
Age 0[b]	MC (26.06)	AC (6.38)	NR3 (5.96)	BC1 (3.38)	BC2 (3.35)	LCC (3.28)	NR1 (1.38)	NR2 (0.10)
Age 1[c]	MC (10.69)	NR1 (3.78)	LCC (3.37)	AC (2.96)	NR3 (2.37)	BC2 (1.82)	BC1 (0.63)	NR2 (0.40)
Age 2+[c]	MC (3.69)	BC2 (2.49)	LCC (2.20)	AC (1.91)	NR1 (1.67)	NR3 (0.97)	NR2 (0.36)	BC1 (0.34)
Total[c]	MC (35.22)	AC (9.98)	NR3 (9.30)	LCC (8.19)	BC2 (7.65)	NR1 (6.49)	BC1 (2.99)	NR2 (0.70)
	(No./km)							
Age 0	MC (1920.3)	NR3 (635.8)	AC (439.3)	BC1 (299.2)	BC2 (295.0)	NR1 (187.4)	LCC (146.1)	NR2 (9.2)
Age 1[c]	MC (853.1)	NR1 (491.7)	NR3 (250.8)	AC (207.4)	LCC (171.7)	BC2 (165.6)	BC1 (62.4)	NR2 (37.6)
Age 2+[c]	MC (298.8)	BC2 (221.6)	NR1 (216.6)	AC (133.5)	LCC (130.0)	NR3 (106.1)	NR2 (34.8)	BC1 (32.1)
Total[c]	MC (2688.1)	NR3 (992.7)	NR1 (848.8)	AC (692.4)	BC2 (682.4)	LCC (414.5)	BC1 (274.0)	NR2 (66.0)

[a]Values connected by the same line are not significantly different ($\alpha = 0.05$), based on Duncan's multiple range test.

[b]N = 4 (LCC, BC2, NR3, AC, MC), N = 3 (BC1, NR1), and N = 1 (NR2), where N = no. of samples (i.e., population estimates) used to compute mean density.

[c]N = 5 (LCC, BC1, AC, MC), N = 4 (BC2, NR1, NR2, NR3), and N = 3 (NR2, adult only), where N is as defined in footnote 'b.'

Table 4-32. Population estimates of Age 0 brown trout at the study sites.

Site	Date	Estimated number[a] (95% confidence limits)	Number per kilometer	Number per 100 m^2
BC1	6-23-82[b]	2	13.2	0.2
	8-25-82	4 (2, c)	40.6	0.4
	11-12-82	11 (6, c)	74.5	0.9
	6-22-83[b]	1	6.6	0.1
BC2	6-23-82[b]	1	10.5	0.1
	8-26-82[b]	9	40.2	0.5
	11-11-82[b]	20	89.3	1.0
	6-22-83[b]	2	8.9	0.1
LCC	6-25-82[b]	4	37.4	0.7
	8-27-82	45 (28, 385)	421.5	10.2
	11-10-82	22 (12, c)	202.3	4.5
	6-24-83[b]	1	9.3	0.1
NR3	7-21-82[b]	2	12.3	0.1
	9-24-82[b]	2	12.3	0.1
	7-22-83[b]	2	12.3	0.1

[a]Dashes indicate that an insufficient number of fish were collected to derive a population estimate.

[b]Population estimate is based on Eq. (1) (Sect. 3.6.3).

[c]Upper confidence limit is undefined.

Table 4-33. Population estimates of Age 1 brown trout at the study sites.

Site	Date	Estimated number[a] (95% confidence limits)	Number per kilometer	Number per 100 m^2
BC1	6-23-82[b]	8	53.0	0.6
	8-25-82	6 (4, 21)	55.6	0.6
	11-12-82	2 (1, c)	10.4	0.1
	3-30-83	15 (9, 441)	100.0	0.9
	6-22-83	2 (2, 2)	13.2	0.1
BC2	6-23-82	3 (3, 3)	31.6	0.4
	8-26-82	4 (3, 17)	17.9	0.2
	11-11-82	8 (6, 15)	35.7	0.4
	6-22-83	4 (2, c)	18.2	0.2
LCC	6-25-82	39 (18, c)	362.7	6.3
	8-27-82	26 (20, 38)	238.3	5.7
	11-10-82	23 (16, 45)	212.6	4.8
	4-29-83	8 (5, 27)	70.2	0.9
	6-24-83	14 (8, c)	133.1	2.0
NR3	7-21-82	8 (5, c)	50.3	0.5
	9-24-82	5 (3, c)	29.2	0.3
	6-8-83	8 (4, c)	50.1	0.4
	7-22-83[b]	12	74.1	0.8

[a]Dashes indicate that an insufficient number of fish were collected to derive a population estimate.

[b]Population estimate is based on Eq. (1) (Sect. 3.6.3).

[c]Upper confidence limit is undefined.

Table 4-34. Population estimates of Age 2+ brown trout at the study sites.

Site	Date	Estimated number[a] (95% confidence limits)	Number per kilometer	Number per 100 m^2
BC1	6-23-82[b]	1	6.6	0.1
	8-25-82	2 (1, c)	14.6	0.2
	11-12-82	7 (4, 215)	44.6	0.5
	3-28-83[b]	2	13.2	0.1
	6-22-83[b]	4	26.5	0.3
BC2	6-23-82[b]	2	21.1	0.2
	8-26-82	4 (2, c)	18.2	0.2
	11-11-82	5 (3, 23)	23.9	0.3
	6-22-83	14 (8, c)	63.6	0.7
LCC	6-25-82	13 (8, 45)	117.8	2.1
	8-27-82	11 (8, 20)	99.7	2.4
	11-10-82	13 (8, 45)	117.8	2.6
	4-29-83	20 (14, 43)	190.9	2.4
	6-24-83	19 (17, 26)	180.2	2.7
NR3	7-21-82[b]	16	98.8	0.9
	9-24-82	14 (9, 51)	89.0	0.8
	6-8-83	17 (8, c)	106.1	0.9
	7-22-83	31 (15, c)	191.0	2.0

[a]Dashes indicate that an insufficient number of fish were collected to derive a population estimate.

[b]Population estimate is based on Eq. (1) (Sect. 3.6.3).

[c]Upper confidence limit is undefined.

Densities of Age 1 and Age 2+ brown trout at LCC were significantly higher ($\alpha = 0.05$) than those at the other three sites; although Age 0 densities were also higher at LCC, the difference was not statistically significant (Table 4-35). Total densities (all ages combined) ranged from 0.5 fish/100 m^2 (BC1 in July 1983) to 18.3 fish/100 m^2 (LCC in August 1982). Mean total densities were significantly higher at LCC compared to those at the other sites, which were not significantly different from one another. Brown trout densities were similar to those of rainbow trout in LCC, but were generally lower than rainbow densities at the other sites with sympatric populations (BC1, BC2, NR3), primarily because of the substantially lower abundance of Age 0 brown trout compared with the abundance of Age 0 rainbow trout (Tables 4-28 and 4-32).

Poor sampling efficiency (i.e., collection of inadequate numbers of fish on the marking and/or recapture run) can result in potentially biased population estimates or undefined confidence intervals. Sampling efficiency was especially problematical for Age 0 trout for two reasons. First, newly emerged trout fry are approximately 3 cm in length, and their small size makes them less susceptible to electroshocking than larger fish (Bagenal 1978). Second, Age 0 fish tended to occupy shallow riffles. When stunned by the electric field, they would frequently be swept by the current into inaccessible areas between rocks and cobbles. As the season progressed and Age 0 fish grew larger, they became more susceptible to both stunning by the electric field and subsequent collection in the shallower, slower water, and the Age 0 population estimates improved accordingly.

Table 4-35. Comparison between sites of the mean densities of three age classes of brown trout, expressed both as number per unit area and number per length of stream. Some sites were not included because of very low densities (AC, MC) or absence of wild populations (NR1, NR2).

Age class	Sites[a]			
	(No./100 m^2)			
Age 0[b]	LCC (3.87)	BC2 (0.42)	BC1 (0.38)	NR3 (0.12)
Age 1[c]	LCC (3.94)	BC1 (0.48)	NR3 (0.47)	BC2 (0.29)
Age 2+[c]	LCC (2.43)	NR3 (1.14)	BC2 (0.35)	BC1 (0.23)
Total[c]	LCC (9.47)	NR3 (1.70)	BC2 (1.06)	BC1 (1.01)
	(No./km)			
Age 0[b]	LCC (167.6)	BC2 (37.2)	BC1 (33.7)	NR3 (12.4)
Age 1[c]	LCC (203.4)	NR3 (50.9)	BC1 (46.4)	BC2 (25.8)
Age 2+[c]	LCC (141.3)	NR3 (121.2)	BC2 (31.7)	BC1 (21.1)
Total[c]	LCC (478.8)	NR3 (181.4)	BC2 (94.8)	BC1 (94.6)

[a]Values connected by the same line are not significantly different ($\alpha = 0.05$), based on Duncan's multiple range test.

[b]N = 4 (LCC, BC1, BC2) and N = 3 (NR3), where N = no. of samples (i.e., population estimates) used to compute mean density.

[c]N = 5 (LCC, BC1) and N = 4 (BC2, NR3), where N is as defined in footnote 'b.'

Mathews (1978) reported the results of fish surveys in Abrams Creek in 1973-1974 and in 1977. Rainbow trout densities at sampling stations located immediately downstream from our study site were lower in 1973-1974 (approximately 0.5 to 0.7 rainbow trout/100 m^2). However, the 1977 survey yielded rainbow trout densities at these sites ranging from 2.5 to 4.0/100 m^2, closer to the densities estimated in our study (Tables 4-28 through 4-30). Mathews (1978) attributed the increase in trout densities between 1973 and 1977 to improved water quality, reduced summer water temperatures, and reduced fishing pressure.

Standing crops of rainbow trout (all ages combined) on particular dates ranged from a low of 24.2 g/100 m^2 at BC1 to a high of 1021.4 g/100 m^2 at MC (Tables 4-36 through 4-38). On the average, standing crops were relatively low at NR2, NR3, and BC1 (mean total standing crop less than 200 g/100 m^2) and relatively high at MC (mean total standing crop of 565 g/100 m^2). Although this difference between MC and these three sites was statistically significant ($\alpha = 0.05$), in most cases (e.g., differences between sites by age class), mean rainbow trout standing crops in Mill Creek were not significantly higher than those at several other sites (Table 4-39). This observation is consistent with the relatively low condition factors among trout in Mill Creek (Sect. 4.3.2.2); that is, this site is populated by relatively large numbers of rainbow trout in relatively poor condition. Thus, other sites with significantly lower densities become more comparable in terms of standing crops. Overall rankings among sites by density and standing crop were similar [i.e., sites with

Table 4-36. Standing crops of Age 0 rainbow trout at the study sites.

		Standing crop[a]	
Site	Date	(g/km)	(g/100 m^2)
AC	7-14-82	2001.3	29.6
	9-8-82	1115.3	14.0
	10-28-82	2008.9	29.8
	7-14-83	2718.6	40.3
BC1	6-23-82	--	--
	8-25-82	733.5	8.0
	11-12-82	2905.5	33.3
	6-20-83	--	--
BC2	6-23-82	33.7	0.4
	8-26-82	2464.6	28.0
	11-11-82	2266.4	26.0
	6-22-83	40.5	0.4
LCC	6-25-82	119.6	2.1
	8-27-82	1220.6	29.4
	11-10-82	1158.2	26.0
	6-24-83	28.5	0.4
MC	7-1-82	4104.1	57.6
	9-9-82	4057.2	37.0
	10-29-82	7176.6	94.2
	7-14-83	7736.0	121.4
NR1	7-22-82	228.7	2.6
	9-22-82	4362.6	31.0
	7-19-83	763.0	5.3
NR2	7-23-82	--	--
	9-23-82	137.6	1.5
	7-21-83	--	--
NR3	7-21-82	2423.5	21.9
	9-24-82	10089.4	92.6
	6-8-83	5.6	0.1
	7-22-83	1037.6	10.7

[a]Dash indicates that an insufficient number of fish were collected to derive a biomass estimate.

Table 4-37. Standing crops of Age 1 rainbow trout at the study sites.

		Standing crop[a]	
Site	Date	(g/km)	(g/100 m^2)
AC	7-14-82	6848.0	101.4
	9-8-82	3844.2	48.4
	10-28-82	5858.8	86.8
	3-17-83	3563.1	46.2
	7-14-83	16446.2	243.6
BC1	6-23-82	1240.8	14.2
	8-25-82	534.3	5.8
	11-12-82	780.1	8.9
	3-30-83	1033.1	9.6
	6-22-83	1409.3	14.0
BC2	6-23-82	1648.8	18.9
	8-26-82	4706.6	53.4
	11-11-82	598.1	6.9
	6-22-83	11084.0	117.2
LCC	6-25-82	3776.5	66.1
	8-27-82	7827.5	188.7
	11-10-82	9887.0	221.6
	4-29-83	1446.0	18.1
	6-24-83	4890.7	72.2
MC	7-1-82	14292.8	200.7
	9-9-82	19515.2	178.2
	10-29-82	11631.0	152.6
	3-17-83	11062.7	106.3
	7-14-83	33430.4	524.4
NR1	7-22-82	23936.6	276.8
	9-22-82	14140.8	100.4
	3-31-83	17847.9	100.7
	7-19-83	22733.4	156.6
NR2	7-23-82	262.4	2.8
	9-23-82	1483.9	15.7
	3-31-83	254.1	2.6
	7-21-83	2369.2	25.0
NR3	7-21-82	773.0	7.0
	9-24-82	5377.1	49.3
	6-8-83	4816.9	39.3
	7-22-83	8695.2	90.0

Table 4-38. Standing crops of Age 2+ rainbow trout at the study sites.

Site	Date	Standing crop[a] (g/km)	Standing crop[a] (g/100 m^2)
AC	7-14-82	41262.0	611.1
	9-8-82	4577.2	57.6
	10-28-82	9728.9	144.1
	3-17-83	11555.8	149.8
	7-14-83	22677.3	335.8
BC1	6-23-82	1865.6	21.4
	8-25-82	3480.9	37.9
	11-12-82	2218.5	25.4
	3-30-83	1562.9	14.6
	6-22-83	5779.0	57.3
BC2	6-23-82	19923.7	228.6
	8-26-82	42821.9	486.2
	11-11-82	3837.1	44.0
	6-22-83	21890.6	231.5
LCC	6-25-82	19755.2	345.5
	8-27-82	8738.4	210.7
	11-10-82	9420.8	211.1
	4-29-83	7311.5	91.7
	6-24-83	15945.2	235.3
MC	7-1-82	26808.6	376.4
	9-9-82	6404.5	58.5
	10-29-82	14519.5	190.5
	3-17-83	36823.4	353.8
	7-14-83	23944.7	375.6
NR1	7-22-82	24508.8	283.4
	9-22-82	6743.6	47.9
	3-31-83	11353.0	64.1
	7-19-83	34977.2	240.9
NR2	7-23-82	2800.4	30.2
	9-23-82	–	–
	3-31-83	2294.4	23.5
	7-21-83	2497.9	26.4
NR3	7-21-82	3529.2	31.9
	9-24-82	25599.0	234.9
	6-8-83	9420.6	76.9
	7-22-83	7170.3	74.3

[a]Dash indicates that an insufficient number of fish were collected to derive a biomass estimate.

Table 4-39. Comparison between sites of the mean standing crops of three age classes of rainbow trout, expressed both as grams per unit area and kilograms per length of stream. Stocked trout at NR1 excluded.

Age class	Sites[a]							
	(g/100 m^2)							
Age 0[b]	MC	NR3	AC	LCC	BC1	BC2	NR1	NR2
	(77.55)	(31.32)	(28.42)	(14.48)	(13.82)	(13.70)	(12.95)	(1.45)
Age 1[c]	MC	NR1	LCC	AC	BC2	NR3	NR2	BC1
	(232.44)	(158.61)	(113.34)	(105.27)	(49.11)	(46.43)	(11.53)	(10.51)
Age 2+[c]	MC	AC	BC2	LCC	NR1	NR3	BC1	NR2
	(270.95)	(259.68)	(247.58)	(218.88)	(159.06)	(104.49)	(31.30)	(26.69)
Total[c]	MC	AC	LCC	NR1	BC2	NR3	BC1	NR2
	(565.43)	(387.68)	(343.79)	(327.38)	(310.39)	(182.23)	(50.11)	(31.91)
	(kg/km)							
Age 0[b]	MC	NR3	AC	NR1	BC1	BC2	LCC	NR2
	(5.768)	(3.389)	(1.961)	(1.785)	(1.219)	(1.201)	(0.632)	(0.138)
Age 1[c]	NR1	MC	AC	LCC	NR3	BC2	NR2	BC1
	(19.665)	(17.986)	(7.312)	(5.566)	(4.916)	(4.509)	(1.092)	(1.000)
Age 2+[c]	BC2	MC	NR1	AC	LCC	NR3	BC1	NR2
	(22.118)	(21.700)	(19.396)	(17.960)	(12.234)	(11.430)	(2.981)	(2.531)
Total[c]	MC	NR1	BC2	AC	NR3	LCC	BC1	NR2
	(44.301)	(40.399)	(27.829)	(26.841)	(19.734)	(18.305)	(4.712)	(3.025)

[a]Values connected by the same line are not significantly different ($\alpha = 0.05$), based on Duncan's multiple range test.

[b]N = 4 (LCC, BC2, NR3, AC, MC), N = 3 (BC1, NR1), and N = 1 (NR2), where N = no. of samples (i.e., population estimates) used to compute mean standing crop.

[c]N = 5 (LCC, BC1, AC, MC), N = 4 (BC2, NR1, NR2, NR3), and N = 3 (NR2, adult only), where N is as defined in footnote 'b.'

low densities (e.g., NR2, BC1) generally also had low standing crops]. As with densities, few significant differences were noted among mean rainbow trout standing crops at the study sites.

Age 0 fish comprised a small percentage of the overall rainbow trout biomass, ranging from an average of 3.8% at NR2 to 33.1% at BC1. Age 0 fish accounted for less than 5% of the rainbow trout standing crop at four of the eight sites (BC2, LCC, NR1, NR2). On the other hand, Age 2+ fish comprised between 46 and 80% of the average rainbow trout standing crop at the eight study sites (Table 4-38).

Brown trout standing crops (all ages combined) on particular dates ranged from 28.1 g/100 m^2 at BC1 to 745.8 g/100 m^2 at LCC (Tables 4-40 through 4-42). On the average, brown trout biomass was lowest at BC1 and BC2 and highest at LCC. With the exception of Age 0 fish, mean total standing crops were significantly higher at LCC compared to those at the other sites (Table 4-43), a trend very similar to that observed for mean total densities (Table 4-35). As with rainbow trout, young-of-the-year brown trout contributed very little to the overall standing crop of this species. Age 0 brown trout averaged between 0.2 and 4.6% of the total biomass, whereas, on the average, Age 2+ fish made up 65 to 94.4% of the total biomass of brown trout. Although total densities were lower, overall standing crops of brown trout tended to be comparable or slightly greater than rainbow trout standing crops at the sites where both species coexisted, primarily because of the relatively large mean weights of Age 2+ brown trout.

Harshbarger (1975) reported average standing crops of trout in Bradley and Lost Cove creeks for the years 1973 through 1976. Combined

Table 4-40. Standing crops of Age 0 brown trout at the study sites.

Site	Date	Standing crop (g/km)	Standing crop (g/100 m^2)
BC1	6-23-82	21.9	0.3
	8-25-82	181.3	2.0
	11-12-82	282.1	3.2
	6-22-83	9.3	0.1
BC2	6-23-82	17.4	0.2
	8-26-82	189.6	2.2
	11-11-82	750.0	8.6
	6-22-83	33.9	0.4
LCC	6-25-82	61.7	1.1
	8-27-82	2299.0	55.4
	11-10-82	1882.5	42.2
	6-24-83	35.5	0.5
NR3	7-21-82	61.7	0.6
	9-24-82	75.3	0.7
	7-22-83	24.1	0.2

Table 4-41. Standing crops of Age 1 brown trout at the study sites.

Site	Date	Standing crop (g/km)	Standing crop (g/100 m^2)
BC1	6-23-82	1151.8	13.2
	8-25-82	1249.0	13.6
	11-12-82	472.7	5.4
	3-30-83	712.3	6.7
	6-22-83	251.7	2.5
BC2	6-23-82	949.5	10.9
	8-26-82	472.0	5.4
	11-11-82	1571.0	18.0
	6-22-83	582.2	6.2
LCC	6-25-82	16449.9	287.7
	8-27-82	9748.2	235.0
	11-10-82	10431.7	233.8
	4-29-83	1296.5	16.3
	6-24-83	3447.3	50.9
NR3	7-21-82	2158.0	19.5
	9-24-82	1153.8	10.6
	6-8-83	1143.9	9.3
	7-22-83	2514.8	26.0

Table 4-42. Standing crops of Age 2+ brown trout at the study sites.

		Standing crop	
Site	Date	(g/km)	(g/100 m^2)
BC1	6-23-82	1499.3	17.2
	8-25-82	2088.5	22.7
	11-12-82	12337.3	141.3
	3-28-83	2288.7	21.4
	6-22-83	4691.4	46.5
BC2	6-23-82	9000.0	103.3
	8-26-82	7853.3	89.2
	11-11-82	8270.6	94.9
	6-22-83	18317.9	193.8
LCC	6-25-82	17207.5	300.9
	8-27-82	15270.5	368.2
	11-10-82	20961.1	469.8
	4-29-83	21582.3	270.8
	6-24-83	18779.1	277.1
NR3	7-21-82	28189.1	254.6
	9-24-82	24622.7	226.0
	6-8-83	22036.4	179.9
	7-22-83	46445.6	481.0

Table 4-43. Comparison between sites of the mean standing crops of three age classes of brown trout, both as grams per unit area and kilograms per length of stream. Other sites not included because of very low densities (AC, MC) or absence of wild populations (NR1, NR2).

Age class	Sites[a]			
	(g/100 m^2)			
Age 0[b]	LCC	BC2	BC1	NR3
	(24.81)	(2.83)	(1.39)	(0.50)
Age 1[c]	LCC	NR3	BC2	BC1
	(164.73)	(16.36)	(10.11)	(8.27)
Age 2+[c]	LCC	NR3	BC2	BC1
	(337.36)	(285.36)	(120.27)	(49.81)
Total[c]	LCC	NR3	BC2	BC1
	(521.94)	(302.10)	(133.20)	(59.19)
	(kg/km)			
Age 0[b]	LCC	BC2	BC1	NR3
	(1.070)	(0.248)	(0.124)	(0.054)
Age 1[c]	LCC	NR3	BC2	BC1
	(8.275)	(1.743)	(0.894)	(0.767)
Age 2+[c]	NR3	LCC	BC2	BC1
	(30.323)	(18.760)	(10.860)	(4.581)
Total[c]	NR3	LCC	BC2	BC1
	(32.106)	(27.891)	(12.002)	(5.447)

[a]Values connected by the same line are not significantly different ($\alpha = 0.05$), based on Duncan's multiple range test.

[b]N = 4 (LCC, BC1, BC2) and N = 3 (NR3), where N = no. of samples (i.e., population estimates) used to compute mean standing crop.

[c]N = 5 (LCC, BC1) and N = 4 (BC2, NR3), where N is as defined in footnote 'b.'

average rainbow and brown trout biomass ranged from 1.21 to 1.87 g/m^2 in Bradley Creek and from 4.22 to 6.52 g/m^2 in Lost Cove Creek during these years. These values are similar to those for the trout standing crops observed in our study, which averaged 1.09 g/m^2 at BC1, 4.43 g/m^2 at BC2, and 8.66 g/m^2 at Lost Cove Creek.

Rainbow trout standing crops in Abrams Creek were reported by Mathews (1978). Standing crops at three sites downstream from site AC ranged from approximately 0.1 to 0.4 g/m^2 in 1973-1974 and from approximately 2 to 3.5 g/m^2 in 1977. The latter biomass estimates are similar to those observed in Abrams Creek in the present study, which ranged from 1.20 to 7.42 g/m^2 (Tables 4-36 through 4-38).

Our estimates indicate that the eight study sites have greatly different capacities to support trout biomass. Average standing crops of trout (both species combined) ranged from 31.9 g/100 m^2 at NR2 to 865.7 g/100 m^2 at Lost Cove Creek, over an order of magnitude difference. Although the confidence intervals for many of the population estimates are wide, the estimates for NR2 and LCC are relatively good. Recapture ratios [i.e., r/a from Eq. (1) in Sect. 3.6.3] at the two sites were 36 and 48%, respectively, with all sizes and species of trout combined. Both sites are located on third-order streams, and the lower streamflows probably enhanced capture efficiency. Consequently, the differences in population densities and standing crops, at least between these two sites, are real.

Harshbarger (1975) also noted the great variability of trout biomass between streams (even within a localized area) and between years. The variability in rainbow trout biomass at our eight sites can also be attributed, in part, to the presence or absence of other salmonids, namely brown trout. For example, both the density and standing crop of rainbow trout were significantly lower at sites with wild brown trout populations than at those sites where rainbow trout was the only salmonid (Table 4-44). This trend was especially evident with the younger age classes.

4.3.1.2 Nonsalmonids

Excluding trout, at least 18 species of fishes were collected from the sampling sites (Table 4-45). Included were three species of suckers, two of sunfishes, one or two of sculpins, ten of minnows, and two of darters. The low diversity of nonsalmonid species at some sites (e.g., only two species at LCC and NR3) may be related, in part, to the presence of natural or artificial barriers to fish movement. For example, a series of small cascades are located on a short reach of Lost Cove Creek below the study site. In addition, large log structures have been constructed on selected streams by the North Carolina Wildlife Resources Commission to prevent the upstream movement of nonsalmonids. A barrier of this type is located approximately 1.5 km below NR3; it was partially modified to permit the upstream migration of spawning steelhead in 1983 (NCWRC 1983). Another barrier is located on South Fork Mills River, approximately 1.0 km below the confluence with Bradley Creek (Fig. 2-6).

Mean total densities of nonsalmonids ranged from about 4 fish 100 m^2 at NR3 to 52 fish/100 m^2 at AC (Table 4-46). The second highest density was observed at NR2, followed in order of decreasing

Table 4-44. Mean standing crop and density estimates for three age classes of rainbow trout at sites with and without brown trout (BR). Standard deviation in parentheses; P is the significance level for rejecting the null hypothesis that means are equal.

	Standing crop (g/100 m^2)	P	Density (no./100 m^2)	P
Age 0				
w/o BR (N = 12)[a]	38.4(36.5)	0.06	11.20(13.50)	0.01
w/BR (N = 15)	18.6(24.1)		4.03(4.14)	
Age 1				
w/o BR (N = 18)	135(127)	<0.01	4.79(5.42)	<0.01
w/BR (N = 18)	54.4(61.3)		2.00(1.75)	
Age 2+				
w/o BR (N = 17)	194(166)	0.32	2.09(1.75)	0.15
w/BR (N = 18)	149(133)		1.48(1.29)	

[a]N = number of site and sampling date combinations used in the analysis.

Table 4-45. Common and scientific names of nonsalmonid fishes collected in 1982.

Family	Genus and species	Common name
Catostomidae	_Catostomus commersoni_ (Lacépède)	White sucker
	Hypentelium nigricans (Lesueur)	Northern hogsucker
	Moxostoma duquesnei (Lesueur)	Black redhorse
Centrarchidae	_Ambloplites rupestris_ (Rafinesque)	Rock bass
	Lepomis auritus (Linnaeus)	Redbreast sunfish
Cottidae	_Cottus_ spp.?[a]	
Cyprinidae	_Campostoma anomalum_ (Rafinesque)	Stoneroller
	Clinostomus funduloides Girard	Rosyside dace
	Hemitremia flammea (Jordan and Gilbert)	Flame chub
	Nocomis micropogon (Cope)	River chub
	Notropis coccogenis (Cope)	Warpaint shiner
	Notropis rubricroceus (Cope)	Saffron shiner
	Notropis spectrunculus (Cope)	Mirror shiner
	Rhinichthys atratulus (Hermann)	Blacknose dace
	Rhinichthys cataractae (Valenciennes)	Longnose dace
	Semotilus atromaculatus (Mitchill)	Creek chub
Percidae	_Etheostoma flabellare_ Rafinesque	Fantail darter
	Etheostoma simoterum (Cope)	Tennessee snubnose darter

[a]_Cottus bairdi_ Girard (mottled sculpin) and _C. carolinae_ (Gill) (banded sculpin): either one or both species may occur at the study sites.

Table 4-46. Mean densities (no./100 m^2) of nonsalmonid fishes at the eight study sites. Sampling conducted from June to November 1982 (N = 3 at all sites except NR1-3 where N = 2). Standard deviation in parentheses.

	AC	BC1	BC2	LCC	MC	NR1	NR2	NR3
Cyprinidae								
Saffron shiner	-	0.49(0.85)	1.03(0.98)	-	-	-	-	-
Warpaint shiner	0.06(0.10)	-	0.03(0.06)	-	0.13(0.11)	-	-	-
Blacknose dace	21.70(6.34)	6.53(4.38)	2.86(1.28)	11.40(6.28)	8.47(4.38)	0.14(0.08)	-	-
Longnose dace	-	-	0.20(0.08)	-	0.08(0.14)	1.29(0.18)	-	0.10(0.01)
Rosyside dace	0.71(0.49)	-	-	-	1.17(1.89)	0.32(0.19)	-	-
Creek chub	6.98(4.80)	-	-	-	2.03(1.96)	0.12(0.05)	1.60(0.29)	-
River chub	-	0.34(0.24)	0.40(0.17)	-	0.67(0.15)	-	-	-
Flame chub	0.15(0.25)	-	-	-	-	-	-	-
Stoneroller	2.94(3.17)	0.69(0.44)	0.36(0.32)	-	3.29(2.75)	9.80(1.78)	16.38(0.98)	-
Mirror shiner	-	-	-	-	-	-	3.20(1.24)	-
Percidae								
Fantail darter	-	0.46(0.62)	0.07(0.06)	-	-	-	-	-
Tennessee snubnose darter	0.38(0.17)	-	-	-	0.25(0.37)	-	-	-
Cottidae								
Cottus spp.?[a]	-	3.95(2.18)	3.83(1.15)	-	-	6.28(1.36)	9.63(1.17)	3.52(1.99)
Catostomidae								
Black redhorse	-	-	-	0.25(0.22)	-	0.03(0.06)	-	-
Northern hogsucker	1.05(0.63)	0.82(0.56)	0.42(0.26)	-	1.94(1.56)	3.10(0.04)	3.72(0.88)	-
White sucker	18.47(17.86)	-	-	-	0.54(0.59)	-	-	-
Centrarchidae								
Rock bass	-	-	-	-	-	-	3.86(1.13)	-
Redbreast sunfish	-	-	-	-	-	-	0.52(0.37)	-
Total	52.44(19.66)	13.17(8.23)	9.20(4.00)	11.65(6.50)	18.57(2.95)	21.08(3.11)	38.92(0.52)	3.61(1.99)

[a]_Cottus bairdi_ Girard (mottled sculpin) and _C. carolinae_ (Gill) (banded sculpin): either one or both may occur at the study sites.

abundance by NR1, MC, BC1, LCC, and BC2. Both the BC and NR series exhibited increasing densities with increasing distance downstream.

The blacknose dace was the most abundant nonsalmonid at AC, BC1, LCC, and MC; sculpins were the most numerous at BC2 and NR3; and the stoneroller was the most abundant species at NR1 and NR2. Other numerically important species included saffron shiners at BC1 and BC2; stonerollers and northern hogsuckers at all sites except LCC and NR3; rosyside dace at AC and MC; creek chubs at AC, MC, and NR2; white suckers at AC; longnose dace at NR1; and rock bass at NR2.

Mean standing crops of nonsalmonids ranged from 0.2 g/m^2 at NR3 to 9.9 g/m^2 at AC (Table 4-47). Other stations in order of decreasing biomass were NR1, NR2, MC, BC2, BC1, and LCC. White suckers constituted the majority of nonsalmonid biomass at AC (71%), whereas northern hogsuckers were most important at BC1, BC2, and MC. This species was also important at NR1 and NR2 and, together with the stoneroller, contributed 92 and 59% of the total nonsalmonid biomass at these sites, respectively. Other species contributing significantly to biomass densities were blacknose dace at AC, MC, BC1, and LCC; stonerollers at AC, BC1, BC2, and MC; northern hogsuckers at AC, BC1, and BC2; creek chubs at AC and MC; sculpins at BC1, BC2, and all three Nantahala River sites; black redhorse at LCC; river chubs at MC and BC2; longnose dace at NR1; and rock bass at NR2 (Table 4-47).

The percentage of total fish biomass consisting of nonsalmonids ranged from a low near 5% at LCC and NR3 to as much as 87% at NR2 (Table 4-48). Nonsalmonid biomass was also relatively high at AC (73%) and NR1 (65%) but comprised only about 40% of the total fish biomass at

Table 4-47. Mean standing crops (g/m^2) of nonsalmonid fishes at the eight study sites. Sampling conducted from June to November 1982 (N = 3 at all sites except NR1-3 where N = 2). Standard deviation in parentheses. T = <0.01 g/m^2.

	AC	BC1	BC2	LCC	MC	NR1	NR2	NR3
Cyprinidae								
Saffron shiner	-	0.01(0.01)	0.03(0.02)	-	-	-	-	-
Warpaint shiner	T	-	T	-	-0.01(0.01)	-	-	-
Blacknose dace	0.75(0.23)	0.14(0.10)	0.08(0.03)	0.43(0.20)	0.26(0.12)	0.01(0.00)	-	-
Longnose dace	-	-	0.01(0.01)	-	0.02(0.03)	0.18(0.04)	-	0.02(0.01)
Rosyside dace	0.02(0.01)	-	-	-	0.01(0.02)	0.02(0.01)	-	-
Creek chub	0.70(0.43)	-	-	-	0.30(0.40)	0.02(0.01)	0.12(0.04)	-
River chub	-	0.02(0.02)	0.13(0.09)	-	0.10(0.11)	-	-	-
Flame chub	T	-	-	-	-	-	-	-
Stoneroller	0.44(0.53)	0.15(0.05)	0.13(0.13)	-	0.45(0.58)	4.44(1.00)	2.21(1.03)	-
Mirror shiner	-	-	-	-	-	-	0.06(0.03)	-
Percidae								
Fantail darter	-	T	T	-	-	-	-	-
Tennessee snubnose darter	0.01(0.01)	-	-	-	0.01(0.01)	-	-	-
Cottidae								
Cottus spp.?[a]	-	0.14(0.07)	0.16(0.06)	-	-	0.44(0.10)	0.46(0.08)	0.22(0.15)
Catostomidae								
Black redhorse	-	-	-	0.28(0.26)	-	0.03(0.04)	-	-
Northern hogsucker	0.92(0.67)	0.39(0.19)	0.63(0.61)	-	1.28(0.95)	4.06(0.12)	2.57(0.65)	-
White sucker	7.05(5.92)	-	-	-	0.36(0.11)			
Centrarchidae								
Rock bass	-	-	-	-	-	-	2.54(0.49)	-
Redbreast sunfish	-	-	-	-	-	-	0.07(0.00)	-
Total	9.90(5.34)	0.85(0.35)	1.18(0.70)	0.72(0.45)	2.80(1.75)	9.20(1.22)	8.04(0.81)	0.29(0.16)

[a]_Cottus bairdi_ Girard (mottled sculpin) and _C. carolinae_ (Gill) (banded sculpin): either one or both may occur at the study sites.

Table 4-48. Estimated mean percentage of total fish numbers and biomass as nonsalmonids and salmonids, June-November 1982.

	Numbers		Biomass	
Site	Nonsalmonid	Salmonid	Nonsalmonid	Salmonid
AC	86.6	13.4	72.6	27.4
BC1	71.8	28.2	40.7	59.3
BC2	49.8	50.2	22.4	77.6
LCC	32.6	67.4	6.1	93.9
MC	38.6	61.4	38.5	61.5
NR1	72.9	27.1[a]	65.3	34.7[a]
NR2	98.1	1.9[b]	87.3	12.7[b]
NR3	21.9	78.1	4.8	95.2

[a]Includes stocked trout which comprised 15.9 and 23.8%, based on numbers and biomass, respectively, of the total salmonid population in 1982.

[b]Includes stocked trout which comprised 26.7 and 68.4%, based on numbers and biomass, respectively, of the total salmonid population in 1982.

MC and BC1 and only 22% at BC2. Although the percentage of nonsalmonids based on numbers was higher than the percentages based on biomass, the same general patterns were evident between sites (Table 4-48).

4.3.2 Trout Growth

An examination of growth rates and length-weight relationships can have considerable value in fisheries investigations. For example, growth rates will vary in response to season, food base, temperature, population density, and numerous other environmental factors, and the response frequently differs among cohorts of the same population. Consequently, age-class-specific growth rates can be used to compare utilization by trout populations of the environmental resources of different streams. The commonly calculated condition factor (K) is a convenient means of expressing the relative well-being of a fish population, because the larger the condition factor the heavier the fish for a given length (Everhart et al. 1975). There are numerous factors (e.g., food supply, age, sex, season) that can influence the condition of fish, and differences in the value of K have been used to gain insight into these circumstances. This section compares growth rates and length-weight relationships (condition factors and length-weight regressions) of trout populations living under different conditions of food, density, and physical habitat at the eight study sites.

4.3.2.1 Length-Weight Regressions

Length-weight regressions for rainbow and brown trout are presented in Tables 4-49 and 4-50, respectively. Because separate regression

Table 4-49. Length-weight regressions for rainbow trout at the eight study sites. General form of the equation is $\log_{10} W = \log_{10} a + b \log_{10} L$, where W = weight in grams and L = total length in centimeters.

Site	Number of observations	Length-weight regression	r^2	$s^2_{y \cdot x}$
AC	252	$\log_{10} W = -1.92 + 2.94 \log_{10} L$	0.99	0.003
BC1	78	$\log_{10} W = -2.02 + 3.00 \log_{10} L$	0.98	0.008
BC2	184	$\log_{10} W = -1.97 + 2.97 \log_{10} L$	0.99	0.005
LCC	162	$\log_{10} W = -1.92 + 2.91 \log_{10} L$	0.99	0.003
MC	503	$\log_{10} W = -2.02 + 2.97 \log_{10} L$	0.98	0.007
NR1	278	$\log_{10} W = -1.97 + 2.95 \log_{10} L$	0.99	0.003
NR2	46	$\log_{10} W = -2.14 + 3.07 \log_{10} L$	0.99	0.001
NR3	189	$\log_{10} W = -1.94 + 2.92 \log_{10} L$	0.99	0.004

Table 4-50. Length-weight regressions for brown trout at four study sites. General form of the equation is $\log_{10} W = \log_{10} a + b \log_{10} L$, where W = weight in grams and L = total length in centimeters.

Site	Number of observations	Length-weight regression	r^2	$s^2_{y \cdot x}$
BC1	54	$\log_{10} W = -2.21 + 3.16 \log_{10} L$	0.98	0.009
BC2	58	$\log_{10} W = -2.12 + 3.08 \log_{10} L$	0.99	0.006
LCC	190	$\log_{10} W = -2.02 + 3.01 \log_{10} L$	0.99	0.002
NR3	72	$\log_{10} W = -2.03 + 3.02 \log_{10} L$	0.99	0.002

equations calculated for 1982 and 1983 were virtually identical, length and weight data for the entire study period were combined to yield a single equation for each site and species combination. Total lengths of trout used to calculate the regression equations ranged from approximately 4 cm to a maximum of 25 to 45 cm, depending on the site and species. Coefficients of determination (r^2) were close to unity at all sites, indicating that most of the variation in trout weight can be accounted for by length variations. There were no apparent changes in slope within any of the length-weight regressions, which would suggest different growth stanzas in these fishes (Bagenal and Tesch 1978). The slopes of the regression lines were close to three in all cases, indicating that growth is isometric (i.e., body proportions and specific gravity do not change with length).

4.3.2.2 Condition

Length and weight measurements of 2043 rainbow and brown trout were used to calculate condition factors. Although individual values of K ranged from 0.32 to 1.57, 90% of the rainbow trout and 97% of the brown trout exhibited K's in the range of 0.75 to 1.25. Extreme values were nearly always for Age 0 fish and were the result of weighing errors due to body surface water or windy conditions.

Mean condition factors, calculated for each species, site, and date, of Age 0, Age 1, and Age 2+ trout are presented in Tables 4-51 through 4-53. No consistent seasonal trends in mean K at the eight sites were apparent (i.e., at some sites mean Ks declined over time, whereas at others mean K's remained the same or increased). There was no indication that condition in these fishes declined over the winter;

Table 4-51. Mean condition factors (K) for Age 0 trout at the study sites.

		Rainbow trout[a]		Brown Trout[a]	
Site	Date	No. of fish	Mean K	No. of fish	Mean K
AC	7-12-82	30	0.99	–	–
	8-31-82	14	0.92	–	–
	10-26-82	23	0.96	–	–
	3-15-83	–	–	–	–
	7-12-83	44	0.95	–	–
BC1	6-21-82	–	–	–	–
	8-23-82	9	1.04	6	0.97
	11-9-82	18	0.79	6	0.69
	3-28-83	–	–	–	–
	6-20-83	6	1.09	1	0.59
BC2	6-21-82	–	–	–	–
	8-23-82	53	1.04	5	1.10
	11-9-82	33	1.00	8	0.85
	6-20-83	4	0.99	–	–
LCC	6-22-82	1	1.36	2	0.85
	8-24-82	27	1.02	26	1.02
	11-8-82	10	0.98	14	0.91
	4-28-83	–	–	–	–
	6-21-83	4	0.87	1	1.16
MC	6-29-82	40	0.85	–	–
	9-7-82	26	0.87	–	–
	10-26-82	41	1.10	–	–
	3-15-83	–	–	–	–
	7-12-83	48	0.90	1	0.95
NR1	7-20-82	7	1.12	–	–
	9-20-82	24	0.90	–	–
	3-29-83	–	–	–	–
	7-18-83	20	0.99	–	–
NR2	7-20-82	–	–	–	–
	9-20-82	2	0.93	–	–
	3-29-83	–	–	–	–
	7-18-83	–	–	–	–
NR3	7-19-82	16	1.17	2	1.07
	9-21-82	41	1.00	2	1.04
	6-7-83	1	1.13	–	–
	7-20-83	20	0.96	2	0.76

[a]Dashes indicate that no Age 0 trout of the taxon were collected on that trip.

Table 4-52. Mean condition factors (K) for Age 1 trout at the study sites.

Site	Date	Rainbow trout[a]		Brown trout[a]	
		No. of fish	Mean K	No. of fish	Mean K
AC	7-12-82	20	0.95	-	-
	8-31-82	7	0.83	-	-
	10-26-82	13	0.83	-	-
	3-15-83	12	0.90	-	-
	7-12-83	34	0.86	-	-
BC1	6-21-82	5	1.11	5	1.05
	8-23-82	2	1.03	6	1.00
	11-9-82	3	1.00	2	0.92
	3-28-83	10	1.04	12	0.93
	6-20-83	6	0.97	2	0.89
BC2	6-21-82	6	1.01	3	1.01
	8-23-82	14	0.93	4	0.82
	11-9-82	5	0.94	8	0.95
	6-20-83	25	0.99	5	1.03
LCC	6-22-82	10	0.99	18	1.15
	8-24-82	17	0.90	24	0.97
	11-8-82	12	0.90	19	0.95
	4-28-83	9	1.02	7	0.98
	6-21-83	16	0.97	11	0.99
MC	6-29-82	36	0.89	-	-
	9-7-82	28	0.84	-	-
	10-26-82	27	0.82	-	-
	3-15-83	69	1.04	-	-
	7-12-83	76	0.86	-	-
NR1	7-20-82	14	0.93	-	-
	9-20-82	23	0.94	-	-
	3-29-83	26	0.95	-	-
	7-18-83	54	0.89	-	-
NR2	7-20-82	2	0.87	-	-
	9-20-82	6	0.84	-	-
	3-29-83	3	0.88	-	-
	7-18-83	13	0.88	-	-
NR3	7-19-82	7	1.03	5	1.08
	9-21-82	11	0.88	4	0.94
	6-7-83	25	0.93	8	0.98
	7-20-83	27	0.87	6	0.95

[a]Dashes indicate that no Age 1 trout of the taxon were collected on that trip.

Table 4-53. Mean condition factors (K) for Age 2+ trout at the study sites.

Site	Date	Rainbow trout[a] No. of fish	Rainbow trout[a] Mean K	Brown trout[a] No. of fish	Brown trout[a] Mean K
AC	7-12-82	13	0.90	–	–
	8-31-82	5	0.89	–	–
	10-26-82	10	0.92	–	–
	3-15-83	13	0.88	1	1.07
	7-12-83	24	0.91	–	–
BC1	6-21-82	3	0.91	1	1.10
	8-23-82	4	0.94	2	1.04
	11-9-82	4	1.07	6	1.05
	3-28-83	3	0.94	2	0.88
	6-20-83	5	0.93	2	0.89
BC2	6-21-82	7	0.94	2	1.05
	8-23-82	19	0.97	6	1.09
	11-9-82	8	1.00	5	1.04
	6-20-83	10	0.99	10	1.02
LCC	6-22-82	12	0.87	11	1.02
	8-24-82	10	0.86	10	1.00
	11-8-82	9	0.87	11	1.02
	4-28-83	9	0.98	17	0.97
	6-21-83	16	0.97	19	0.98
MC	6-29-82	22	0.89	–	–
	9-7-82	6	0.84	–	–
	10-26-82	16	0.89	–	–
	3-15-83	38	0.90	–	–
	7-12-83	30	0.89	–	–
NR1	7-20-82	15	0.95	–	–
	9-20-82	6	0.90	–	–
	3-29-83	12	0.90	–	–
	7-18-83	26	0.93	–	–
NR2	7-20-82	5	0.94	–	–
	9-20-82	–	–	–	–
	3-29-83	7	0.88	–	–
	7-18-83	8	0.88	–	–
NR3	7-19-82	7	1.00	8	1.02
	9-21-82	15	0.93	12	0.95
	6-7-83	7	0.87	9	0.94
	7-20-83	11	0.88	14	0.97

[a]Dashes indicate that no Age 2+ trout of the taxon were collected on that trip.

the number of instances in which mean K of a cohort either decreased or increased between the fall sample in 1982 and the spring sample of 1983 were equal. Statistical comparisons of mean Ks showed few significant differences, and no site exhibited consistently high or low mean K's across species, dates, or age groups.

Mean condition factors of sympatric and allopatric populations of rainbow trout were compared by analysis of variance. When effects of season and age were removed, allopatric populations of rainbow trout (sites AC, MC, and NR1; NR2 was not used in the analysis due to low numbers of trout collected there) exhibited significantly lower mean K's (α = 0.05) than rainbow trout in sympatry with brown trout (sites BC1, BC2, NR3, and LCC). The observation that rainbow trout had relatively better condition when in competition with brown trout runs contrary to expectations; its explanation may lie more in the nature of the streams we sampled than in the nature of competition between these congeners. Two of the three sites with wild populations of rainbow trout alone (AC and NR1) are relatively disturbed (Sects. 2.1 and 2.4, respectively). Abrams Creek is affected by sedimentation from bank erosion (due to cattle grazing), and the lower Nantahala River (NR1 and NR2) is subject to extreme fluctuations in flow due to hydropower operations. Consequently, anthropogenic stresses may be responsible for the lower mean K's of the allopatric rainbow trout populations compared to the sympatric populations that inhabit the other undisturbed sites.

To conclude, the calculation of condition factors and length-weight regressions are convenient ways to summarize body size information from fish populations. Although variations in these parameters have been reported in studies of other fish populations, due to differences in such factors as age, sex, stage of sexual maturity, season, environmental conditions, and even state of fullness of the alimentary canal (Weatherley 1972), few significant differences were noted among the trout populations at our study sites. It appears that environmental conditions at the eight sites are not different enough to produce demonstrable differences in the length-weight relationships among the trout populations inhabiting them. Alternatively, it is possible that condition factors are not sufficiently sensitive to detect real differences in the nutritional status of these fish. For example, Gardiner and Geddes (1980) noted that young salmon lost both fat and protein over the winter. Because this loss was balanced by a net uptake of water, however, fish weights remained reasonably constant. Thus, condition factors would not have been adequate to detect declining energy content (nutritional status) during periods of relative starvation.

4.3.2.3 Growth Rates

Instantaneous rates of growth (Ricker 1975) were calculated for the 1980–1982 cohorts of both rainbow and brown trout. The values, presented in Tables 4-54 and 4-55, represent the rate of change in mean weight of each cohort from the first sampling date in 1982 to the last sampling date in 1983, one year later. Growth rates of the youngest fish (1982 cohort) were highest at Lost Cove Creek and, for rainbow trout, lowest at the Nantahala River sites (Table 4-54). Rainbow trout

Table 4-54. Instantaneous growth rates (G in $g \cdot g^{-1} \cdot year^{-1}$) of rainbow trout at the study sites between June 1982 and July 1983.

Site	Cohort	(G)
AC	1980	0.51
	1981	0.79
	1982	2.10
BC1	1980	0.45
	1981	1.19
	1982	2.55
BC2	1980	0.31
	1981	1.14
	1982	3.07
LCC	1980	0.29
	1981	0.74
	1982	3.29
MC	1980	0.53
	1981	0.78
	1982	2.40
NR1	1980	0.04
	1981	0.15
	1982	1.96
NR2	1980	0.18
	1981	0.74
	1982	0.88
NR3	1980	0.55
	1981	0.90
	1982	1.64

Table 4-55. Instantaneous growth rates (G in $g \cdot g^{-1} \cdot year^{-1}$) of brown trout at the study sites between June 1982 and July 1983.

Site	Cohort	(G)
BC1	1980	-
	1981	1.35
	1982	2.16
BC2	1980	-
	1981	0.99
	1982	2.61
LCC	1980	0.33
	1981	0.48
	1982	2.78
NR3	1980	0.84
	1981	0.47
	1982	2.50

of all age classes had relatively low mean growth rates at NR1 and NR2, and relatively high growth rates at BC1. At Abrams Creek and NR3, growth rates were relatively high among 1980 year class trout, but low to moderate among younger fish (Tables 4-54 and 4-55).

Marked differences in seasonal growth rates were not observed at most sites, although growth rates were generally lowest during the winter for the 1982 cohort and during the summer for older fish. A notable exception to these patterns is Abrams Creek, where growth rates tended to be high among all age classes during the winter. This was probably the result of the relatively warm winter water temperatures in Abrams Creek (see Sect. 4.1 and Table B-1), which might have permitted continued growth. Summer water temperatures at NR1 and NR2 tend to be high, with a high diel fluctuation compared to, for example, Lost Cove Creek and Bradley Creek (Sect. 4.1). Greater-than-optimal summer water temperatures may at least partially explain the differences in growth rates among these sites. From June through September, deviations from the optimum growth temperature of 13°C (for brown trout on maximum ration, Elliott 1975) were greater at the two lower Nantahala River sites than either LCC or BC (Figs. 4-2 and 4-3).

4.3.3 Trout Production

Annual production was estimated for the period from June 1982 to June 1983 in Lost Cove and Bradley creeks, and July 1982 to July 1983 in Mill and Abrams creeks and the Nantahala River. Annual rainbow trout production ranged from 0.13 g/m^2 at NR2 to 6.72 g/m^2 in Mill Creek (Table 4-56) and was similar to other estimates of trout

Table 4-56. Annual production (P) in g/m^2, mean biomass (B) in g/m^2, and turnover ratios (P/B), by year class, for rainbow trout at the eight study sites, June/July 1982-June/July 1983.

Site	Year class: 1983[a]	1982	1981	1980	≤1979[a]	Total
AC						
P	0.85	1.09	0.60	0.57	0.28	3.39
B	0.19	0.69	0.81	0.68	0.91	3.28
P/B	4.47	1.58	0.74	0.84	0.31	1.03
BC1						
P	0.09	0.42	0.10	0.07	0.03	0.71
B	0.03	0.11	0.12	0.19	0.09	0.54
P/B	3.00	3.82	0.83	0.37	0.33	1.31
BC2						
P	0.28	1.21	0.28	0.17	0.06	2.00
B	0.08	0.36	0.30	0.86	0.63	2.23
P/B	3.50	3.36	0.93	0.20	0.10	0.90
LCC						
P	0.20	0.65	0.61	0.26	0.16	1.88
B	0.05	0.26	0.73	0.54	1.30	2.88
P/B	4.00	2.50	0.84	0.48	0.12	0.65
MC						
P	1.75	3.29	0.92	0.69	0.07	6.72
B	0.41	1.55	1.68	1.09	0.66	5.39
P/B	4.27	2.12	0.55	0.63	0.11	1.25
NR1						
P	0.67	1.18	0.32	<0.01	0.06	2.23
B	0.14	0.84	1.00	0.39	0.09	2.46
P/B	4.78	1.40	0.32	<0.01	0.67	0.91
NR2						
P	--	0.07	0.05	0.01	--	0.13
B	--	0.07	0.14	0.07	--	0.28
P/B	--	1.00	0.36	0.14	--	0.46
NR3						
P	0.39	1.27	0.21	0.12	0.13	2.12[b]
B	0.10	0.47	0.17	0.21	0.45	1.40
P/B	3.90	2.70	1.24	0.57	0.29	1.51

[a]Dash indicates that year class was not represented in samples.

[b]Excluding steelhead production which was estimated to be 0.05 g/m^2 for the period from early June to last July 1983.

production in streams with similar water chemistries (Table 4-57). The estimated production for Mill Creek is among the highest values reported for resident trout populations of soft-water streams in North America (Table 4-57). Despite a favorable thermal regime (Sect. 4.1) and high macrobenthos production (Sect. 4.4), trout production in Abrams Creek (Table 4-58) was lower than that expected from water chemistry profiles (Table 4-1). Water quality degradation (e.g., high sediment loading) and the presence of a large nonsalmonid population, which consists primarily of species that utilize invertebrate food resources, may limit trout production at this site. The high production at MC results primarily from the significantly higher densities of trout, especially Age 0 and Age 1, at this site compared to the densities at other sites (Table 4-31), rather than from higher growth rates (Table 4-54). A similar explanation has been used by Hunt (1966) and O'Connor and Power (1976) to account for differences in brook trout production among sites. In addition, the relationship between rainbow trout annual production and mean annual biomass among sites is linear with a slope (P/B) near 1.0 and $r^2 = 0.90$ (Fig. 4-7).

The youngest trout (i.e., the 1982 and 1983 year classes) accounted for most of the production (mean = 67%; range = 45 to 83%), a result consistent with those from studies of brook trout populations (e.g., Hunt 1966: mean = 88%; Cooper and Sherer 1967: 65%; O'Connor and Power 1976: 71%). Sites with relatively low contributions to total production from the younger age classes of rainbow trout included NR2, where densities of Age 0 trout were very low (Sect. 4.3.1), and AC

Table 4-57. Estimates of annual salmonid production (P) in g/m² for relatively infertile streams.

Site	Index of stream fertility: Conductivity (µS/cm)	Index of stream fertility: Total alkalinity ($CaCO_3$, mg/L)	Species[a]	P	Reference
Mill Creek, Tennessee	8	5	RB	6.7	This study
Bradley Creek, North Carolina	5	3	RB	1.4	This study
			BR	0.4	
Lost Cove Creek, North Carolina	5	3	RB	1.9	This study
			BR	2.0	
Nantahala River, North Carolina					This study
NR1	15	7	RB	2.2	
NR2	11	8	RB	0.1	
NR3	4	3	RB	2.1	
			BR	0.4	
Quebec (4 streams)	10-11	5[b]	BK	3.4(1.4-6.6)	O'Connor & Power (1976)
Georgia (3 streams)	-	3.8[b]	BK	0.5(0.3-0.7)	Michaels (1978)
Larry's Creek, Pennsylvania	27	<5	BK	5.8	Cooper & Scherer (1967)
Guy's Run, Virginia	44	24[b]	BK	1.4(0.5-1.9)	Neves & Pardue (1983)
Oregon (3 streams)	35-46	-	CT	4.1(3.5-4.9)	Lowry (1966)
			CO	8.6(5.4-13.5)	Chapman (1965)
Rocky Fork Creek, Tennesssee	-	51[c]	BK	1.4(1.1-1.7)	Whitworth & Strange (1983)
			RB	2.3(0.7-4.8)	
Shelligan Burn, Scotland	-	12-34	BR	10.1(7.7-12.3)	Egglishaw (1970)
			AS	9.4 (6.5-11.1)	
Walla Brook, England	-	1[d]	BR	12.1-12.6	LeCren (1969)
Docken's Water, England	-	9[d]	BR	12.1	Mann (1971)

[a] RB = rainbow trout, BR = brown trout, BK = brook trout, CT = cutthroat trout, CO = coho salmon, AS = Atlantic salmon.

[b] Total hardness, mg/L.

[c] Alkalinity not designated as $CaCO_3$ in reference.

[d] Calcium, mg/L.

Table 4-58. Estimates of annual salmonid production (P) in g/m^2 for relatively fertile streams.

Site	Index of stream fertility		Species[a]	P	Reference
	Conductivity (µS/cm)	Total alkalinity ($CaCO_3$, mg/L)			
Abrams Creek, Tennessee	110	44	RB	3.4	This study
England (5 streams)	-	28.0[b]	BR	6.3(3.0-10.0)	Le Cren (1969)
Horokiwi, New Zealand	-	30.0[c]	BR	54.3	Allen (1951)
Big Springs Creek, Idaho	-	134	SH	10.4	Goodnight & Bjornn (1971)
			BK	0.6	
Lemhi River, Idaho	-	160	SH	2.3	Goodnight & Bjornn (1971)
			CH	3.3	
Lawrence Creek, Wisconsin	273	162	BK	11.7(10.6-12.9)	Hunt (1974)
Big Springs Creek, Pennsylvania	374	130	BK	30.0	Cooper & Scherer (1967)
Valley Creek, Minnesota	-	220	BK	9.0(2.5-16.7)	Waters (1983)
			BR	2.7(<0.1-13.2)	
			RB	2.6(0.3-4.5)	
			TOTAL	14.3(10.2-17.3)	
Granslev ä, Denmark	362	-	BR	19.2(12.6-25.7)	Mortensen (1982)
Bere Stream, England	510	94[b]	BR	6.1(2.6-12.9)	Mann (1971)
			AS	2.4(<0.1-7.2)	
England (2 streams)	510-520	94-95[b]	BR	4.8-12.0	Mann (1971)

[a]RB = rainbow trout, BR = brown trout, BK = brook trout, SH = steelhead, CH = Chinook salmon, AS = Atlantic salmon.

[b]Calcium, mg/L.

[c]Total hardness, mg/L

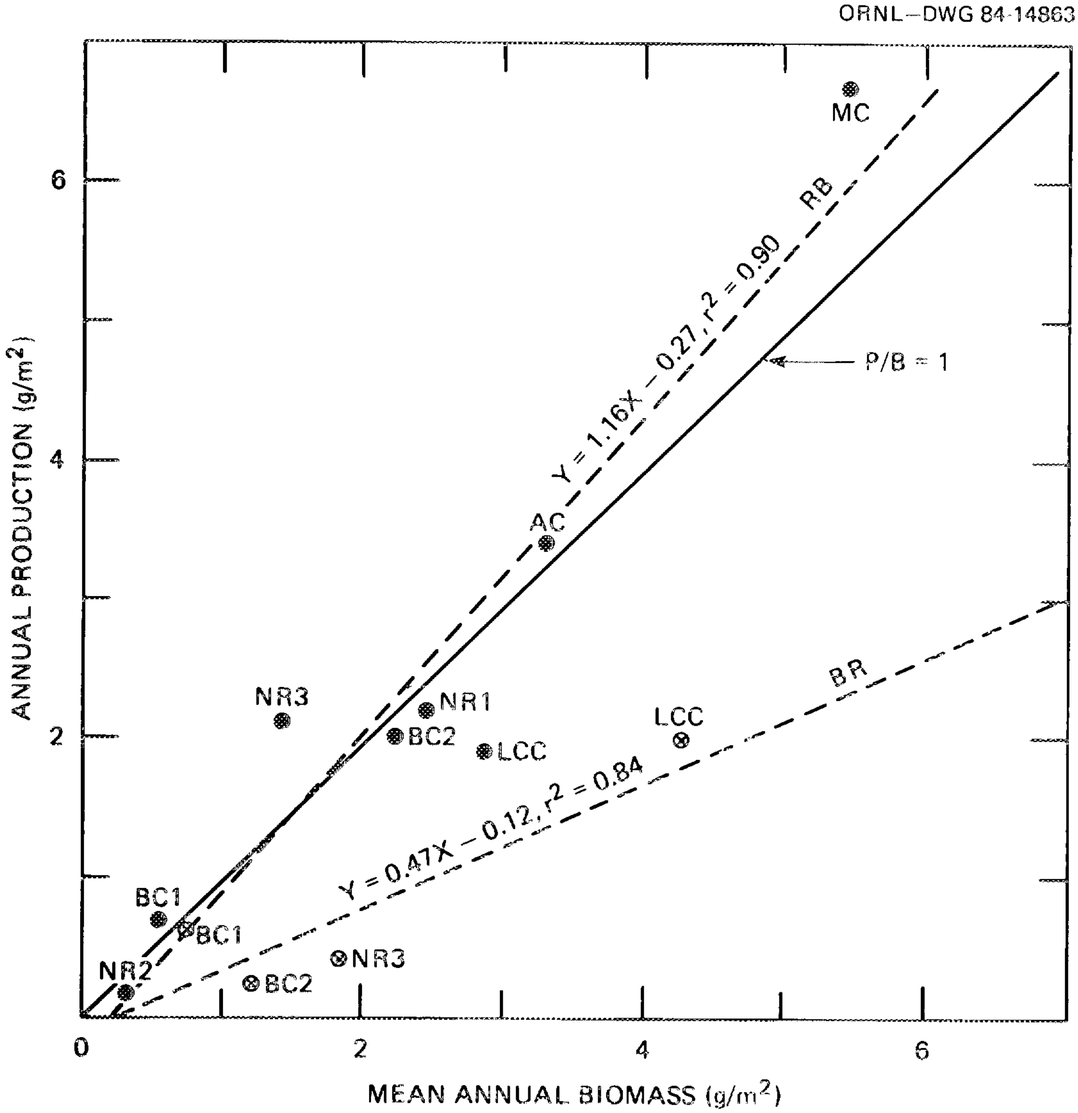

Fig. 4-7. Relationship between annual production (P) and mean annual biomass (B) for rainbow trout (RB) and brown trout (BR), all year classes combined.

and LCC, where the ≤1980 year classes (consisting of Age 2+ individuals) accounted for almost 25% of the production on an annual basis (Table 4-56).

Brown trout production was similar to that of rainbow trout at BC1 and LCC, but was substantially lower at BC2 and NR3 (Table 4-59). Although we are not aware of any published information on brown trout production in relatively infertile, soft-water streams of North America, our estimates are substantially lower than those reported from presumably infertile streams in Scotland and England (Table 4-57). The 1982 and 1983 year classes accounted for 69% of the total annual production at BC1, but the proportional contribution at the other sites was 50% or lower. In Lost Cove Creek, the distribution of production among year classes was very similar to that for rainbow trout, with older brown trout (Age 2+) accounting for 21% of the total production. Angling mortality may be negligible at this site, because regulations in effect during this study limited fishermen to one fish over 41 cm, and we collected no trout larger than 34 cm in total length. Although older trout accounted for an equally high proportion of the total production at NR3 and BC2, the low production of the two youngest year classes (only 13% of that at LCC) accounts for the lower total production at these sites compared to LCC or BC1. The low production of the 1982 and 1983 year classes is, in turn, related to the low densities (thus low mean annual biomass) of Age 0 trout at NR3 and BC2, rather than lower instantaneous growth rates.

Ratios of annual production (P) to mean annual biomass (B), or turnover ratios, were highest in the youngest year classes and

Table 4-59. Annual production (P) in g/m^2, mean biomass (B) in g/m^2, and turnover ratios (P/B), by year class, for brown trout at four study sites, June/July 1982–June/July 1983.

Site	Year class 1983	1982	1981	1980	≤1979	Total
BC1						
P	0.29	0.11	0.09	0.02	0.06	0.58
B	0.07	0.04	0.08	0.03	0.46	0.68
P/B	4.14	2.75	1.12	0.67	0.13	0.85
BC2						
P	0.01	0.12	0.05	0.03	0.05	0.26
B	<0.01	0.05	0.08	0.04	0.99	1.16
P/B	3.93	3.60	0.62	0.75	0.05	0.22
LCC						
P	0.17	0.84	0.58	0.18	0.24	2.01
B	0.04	0.34	1.49	0.66	1.70	4.23
P/B	4.25	2.47	0.39	0.27	0.14	0.48
NR3						
P	<0.01	0.13	0.03	0.07	0.16	0.39
B	<0.01	0.08	0.10	0.30	1.35	1.83
P/B	4.00	1.62	0.30	0.23	0.12	0.21

declined with age for both rainbow trout (Table 4-56) and brown trout (Table 4-59). These trends are similar to those reported for brook trout (e.g., Cooper and Scherer 1967; O'Connor and Power 1976). Because of declining numbers and growth rates over time, larger (older) fish contribute proportionately less to production and more to mean annual biomass.

Annual P/B ratios for rainbow trout populations ranged from 0.46 at NR2 to 1.51 at NR3 (mean = 1.00). As discussed previously, the majority of the production in trout populations is associated with the two youngest year classes. At NR2, the 1983 year class was absent and production of the 1982 year class was substantially lower than the other sites. The P/B ratio at LCC was 0.65, primarily because of the large biomass of the 1979 and older year classes (45% of the mean annual biomass). With the exception of these two sites, annual P/B ratios for rainbow trout were similar to values reported for other trout populations in streams (e.g., O'Connor and Powers 1976: mean = 1.12 and range = 0.70 - 1.65; Waters 1977: mean = 1.2; Waters 1983: mean = 1.35). Unlike production, P/B ratios are relatively constant among streams with different physicochemical profiles (Waters 1977; Neves and Pardue 1983).

An age structure dominated by older (Age 3+) individuals was characteristic of the brown trout populations at three of four study sites (Table 4-59). At both Bradley Creek sites and NR3, for example, the ≤1979 year classes accounted for 68 to 85% of the mean annual biomass. Consequently, annual P/B ratios were low, with the exception of BC1 where a transient population of large brown trout in spawning condition was encountered in the fall of 1982. Waters (1983) also attributed a low P/B ratio of 0.78 in one year (mean = 1.14, n = 8 years) to immigrants in the fall. Also contributing to the low ratios at BC2 and NR3 was the very low production of the 1983 year class compared to that at the other two sites. O'Connor and Power (1976) reported annual P/B ratios of 0.70 and 0.73 for brook trout populations where the youngest age class was absent. The low Age 0 abundance together with the relatively high Age 3+ biomass of brown trout compared with rainbow trout probably account for the differences in the P vs B relationship of the two species (Fig. 4-7).

Younger life stages of brown trout could be limited by physical habitat (e.g., spawning, incubation, or fry-rearing habitat). The high brown trout production at LCC, relative to the two Bradley Creek sites and NR3, could be related to the significantly greater amount of spawning habitat, estimated as weighted usable area (WUA), at this site (Table 4-22). If WUA is expressed as a percentage of the total wetted surface area (i.e., percent usable area or PUA as discussed in Sect. 4.2.3), then significantly more habitat (PUA) is available at LCC than the other three sites for all life stages (Table 4-24). Additional analyses using linear regression techniques showed a significant relationship ($P < 0.05$) between brown trout fry abundance and average PUA for spawning, although much of the variation in abundance was not explained by this single variable (Sect. 4.5).

Another variable that might also account for differences in production among sites is the food resource utilized by trout. Either of two indices of this resource, mean benthic biomass and annual benthic production (Sect. 4.4), was used as the independent variable in a simple linear regression analysis. Similarly, the dependent variable was either mean trout biomass [estimated over the period that macrobenthos were sampled (i.e., only data from 1982 were used; see Table A-1)] or annual trout production. No significant relationship was found ($r^2 < 0.10$ in all four cases; $P > 0.05$).

Salmonids, however, were the dominant component of the fish community at some sites (e.g., LCC, NR3) but only a minor component at others (e.g., NR2); their percent contribution to total fish biomass ranged from 13 to 95% among the eight sites (Table 4-48). Moreover, all nonsalmonid species at these sites, except stonerollers, utilize the macrobenthic resource to some extent (Carlander 1969, 1977; Pflieger 1975). Information on food habits was available for all but three species (flame chub, mirror shiner, Tennessee snubnose darter), but we assumed, based on data for closely related species, that at least a portion of their diet also consisted of benthic invertebrates.

Because of the importance of nonsalmonids, the analysis was expanded to include the total fish community. The dependent variables were mean total biomass (including stocked trout) with and without stonerollers. Again, no significant relationships were found ($\alpha = 0.05$), although values of r^2 were higher. With mean benthic biomass as the independent variable, an $r^2 = 0.27$ and $r^2 = 0.41$ were observed for mean total fish biomass with and without stonerollers, respectively. The latter regression approached statistical significance ($P = 0.09$), but almost 60% of the variability in fish biomass was not explained by the macrobenthic biomass in these streams. Using benthic production rather than biomass as the independent variable, or applying different transformations of the data, failed to significantly improve the r^2 values of these regressions. Although direct comparisons of production (fish vs macrobenthos) might be desirable in such an analysis, nonsalmonid annual production was not estimated from the limited data set (June through November 1982) because adequate information was not available on turnover ratios for most of the species.

Although the results of this analysis are consistent with the hypothesized importance of physical habitat as a determinant of trout production, other possible explanations for the observed low correlations should be noted. First, the estimates of trout production and salmonid/nonsalmonid biomass are based on population estimates which are subject to sampling error. Second, several sources of error, including sampling error, may be associated with our measure of the trout food resource. For example, only aquatic invertebrates were included when, in fact, much of the trout diet consists of terrestrial species and their contribution varies seasonally and across sites (Sect. 4.3.4). Because benthic species have widely different drift rates, their vulnerability to predation by species like brown trout that feed primarily on organisms in the water column rather than on the bottom (Bachman 1982) will also vary. Finally, all benthic habitats (e.g., pools, litter/detritus) were not sampled, whereas fish sampling was conducted over a wide range of habitats that included both riffles, pools, and the transition zone between them (runs). In recognition of these potential sources of error and the higher correlations obtained when nonsalmonid species were included in the analysis, a reasonable conclusion is that while production at the next-lower trophic level (invertebrate production) may ultimately limit fish production in streams, other resources, such as space (i.e., habitat), may limit production at some lower level (Krueger and Waters 1983).

4.3.4 Trout Diet

The stomach contents of 171 rainbow trout and 120 brown trout were examined in 1982. Of these, 38 rainbow and 35 brown trout had empty stomachs. Tables 4-60 and 4-61 summarize aquatic and terrestrial components of the diet at each site. Specific food items, listed by lowest identifiable taxonomic category, are provided in Table D-1.

Based on both numbers and weight of food items, more than one-half of the rainbow trout diet came from aquatic organisms at five of the eight sites (Table 4-60). The exceptions were AC, BC1, and NR3, where a greater percentage (in terms of numbers) of the rainbow trout diet came from drifting terrestrial insects. At most sites, percentages calculated by numbers or by weights followed the same patterns; the two exceptions were AC, where aquatic organisms contributed a relatively low percentage of the diet by number but a high percentage by weight, and MC, where aquatic organisms constituted a high percentage of the diet by number but low percentage by weight (Table 4-60).

Mayflies were the most common food item among rainbow trout, comprising over 25% of the total diet by number (Table D-1). Among the mayflies, members of the family Heptageniidae were consumed in particularly large numbers and by large numbers of trout. Caddisflies

Table 4-60. Percent of rainbow trout diet (by number and weight) made up of aquatic and terrestrial food items, all dates pooled.

Site	Number of stomachs	Percent by number		Percent by weight	
		Aquatic	Terrestrial	Aquatic	Terrestrial
AC	24	39.7	60.3	83.6	16.4
BC1	7	11.4	88.6	38.4	61.6
BC2	15	56.7	43.3	63.0	37.0
LCC	19	64.6	35.4	59.3	40.7
MC	41	70.1	29.9	48.2	51.8
NR1[a]	15	87.7	12.3	89.2	10.8
NR2	1	93.7	6.3	99.1	0.9
NR3	11	43.9	56.1	14.6	85.4
Mean		58.5	41.5	61.9	38.1

[a]Wild trout only.

Table 4-61. Percent of brown trout diet (by number and weight) consisting of aquatic and terrestrial food items, all dates pooled.

Site[a]	Number of stomachs	Percent by number		Percent by weight	
		Aquatic	Terrestrial	Aquatic	Terrestrial
BC1	5	1.1	98.9	44.6	55.4
BC2	14	81.4	18.6	95.9	4.1
LCC	37	82.6	17.4	98.4	1.6
NR1[b]	15	85.7	14.3	91.6	8.4
NR3	14	27.3	72.7	48.2	51.8
Mean		55.6	44.4	75.7	24.3

[a]Due to low abundance of brown trout, stomachs were not sampled at AC, MC, or NR2.

[b]Fish probably of hatchery origin; no evidence of natural reproduction observed.

were also relatively common in the diet, comprising 12% by number. Among terrestrial insects, ants and adult dipterans each contributed over 10% to the diet. Numerous other aquatic and terrestrial taxa were found in rainbow trout stomachs, many comprising 1% or less of the total diet by number (Table D-1).

Brown trout were similar to rainbow trout in terms of the predominance of aquatic or terrestrial food items at particular sites (Table 4-61). On the average, aquatic organisms constituted slightly more than one-half of the brown trout diet by number and about 76% by weight. As with rainbow trout, aquatic taxa contributed relatively less to the brown trout diet at BC1 and NR3. In terms of weight, aquatic organisms were particularly important to brown trout (i.e., comprised more than 90% of the diet) at BC2, LCC, and NR1.

The breakdown of brown trout diet by taxa indicates that mayflies, caddisflies, terrestrial diptera, and ants were also numerically important components at these sites (Table D-1). Like rainbow trout, brown trout tended to be relatively nonspecific, opportunistic feeders, as evidenced by the large number of both aquatic and terrestrial taxa that appeared in the stomach samples.

Trout are known to take much of their food from the drift (Elliott 1970, 1973; Allan 1981). As a means of determining the relationship between trout diet and food availability at the eight study sites, paired drift samples were taken concurrently with the trout stomach sampling. Results of the drift sampling, summarized by taxon, are presented in Table I-1.

On the average, approximately 65% of the drift was made up of terrestrial organisms. However, there was considerable variability about this mean, both among sites (Table 4-62) and among dates at a particular site (Table 4-63). For example, the numerical contribution of aquatic organisms to the drift ranged from an average of 37% at BC1 to 96% at BC2. Even greater variations between sites were observed when the percentages were expressed in terms of weight (Table 4-62). In most cases, relative contributions of aquatic and terrestrial organisms to the drift were similar whether expressed as numbers or weights; a notable exception was BC1, where aquatic organisms constituted a relatively small percentage of the drift by number (37%) but far surpassed terrestrials in terms of biomass (92 vs 8%). This inconsistency was due to large numbers of ants in the August drift samples at BC1, which dominated the numerical contribution of terrestrials at this site but added little to the weight (Table 4-63). Variability in drift among dates at a given site can be illustrated by AC, which on two dates was comprised solely of aquatic organisms but on another date was dominated by terrestrial homopterans. Two sites (BC2 and NR1) exhibited a preponderance of aquatic organisms regardless of the sampling date or basis for comparison (i.e., numbers vs weights).

Table 4-64 displays the relative contribution (all samples combined) of various taxa to the drift and to the diets of rainbow and brown trout. At this level of comparison (order rather than family or genus), there is a very good correspondence between the availability of particular taxa in the drift and their consumption by trout. The greatest disparities between drift and diet occur for aquatic dipterans

Table 4-62. Percent of drift composed of aquatic and terrestrial organisms all dates combined.

	Percent by number		Percent by weight	
Site	Aquatic	Terrestrial	Aquatic	Terrestrial
AC	44	56	14	86
BC1	37	63	92	8
BC2	96	4	95	5
LCC	74	26	61	39
MC	57	43	41	59
NR1	94	6	96	4
NR2	58	42	58	42
NR3	40	60	61	39
Mean	63	37	65	35

Table 4-63. Percent of drift composed of aquatic and terrestrial organisms.

		Percent by number		Percent by weight	
Site	Date	Aquatic	Terrestrial	Aquatic	Terrestrial
AC	5-7-82	100	0	100	0
	7-14-82	67	33	8	92
	9-8-82	100	0	100	0
	10-28-82	32	68	18	82
BC1	8-25-82	23	77	69	31
	11-12-82	82	18	95	5
BC2	4-28-82	98	2	99	1
	6-23-82	100	0	100	0
	8-26-82	100	0	100	0
	11-11-82	81	19	54	46
LCC	4-26-82	95	5	96	4
	6-25-82	93	7	15	85
	8-27-82	96	4	00	1
	11-10-82	41	59	29	71
MC	5-5-82	67	33	35	65
	7-1-82	80	20	95	5
	9-9-82	95	5	92	8
	10-29-82	30	70	28	72
NR1	7-22-82	100	0	100	0
	9-22-82	93	7	96	4
NR2	7-23-82	100	0	100	0
	9-23-82	58	42	15	85
NR3	7-21-82	100	0	100	0
	9-24-82	35	65	49	51

Table 4-64. Percent contribution (based on numbers) of particular taxa to drift, rainbow trout diet, and brown trout diet, all samples pooled.

Taxon	Drift	Rainbow trout diet	Brown trout diet
Ephemeroptera	18.5	25.7	15.6
Plecoptera	9.4	4.9	5.5
Trichoptera	12.4	12.1	14.0
Coleoptera	1.9	1.4	1.1
Diptera	17.6	6.2	4.5
Hemiptera	0.9	0.3	0.1
Other aquatic	3.3	4.5	9.2
Terrestrials	35.9	44.9	52.6

and terrestrial organisms. Both rainbow and brown trout appear to consume fewer aquatic dipterans than would be expected, based on their abundance in the drift, probably due to the relatively small size of most larvae. On the other hand, both species tended to consume relatively more terrestrial organisms than would have been expected, based on the drift samples. The close correspondence of a taxon's presence in both the drift and trout diet, coupled with the wide range of food items consumed (Table D-1), suggests that trout are nonspecific, opportunistic feeders in these streams.

Tebo and Hassler (1963) reported the results of diet studies of trout in western North Carolina streams, including samples from the Nantahala River. Drifting terrestrial insects were also relatively important components of trout diets in their survey (33 and 50% of the total number of food items in rainbow and brown trout stomachs, respectively). Caddisflies and mayflies were the most common aquatic orders in the diet, and hymenopterans, coleopterans, and ants were the most common terrestrial taxa. Their results also indicated that trout were opportunistic feeders, availability being the most important factor determining what foods were eaten. Hence, aquatic insects predominated in the diet of trout during the winter months, while during the summer terrestrial drift assumed greater importance (Tebo and Hassler 1963).

4.4 MACROBENTHOS ANALYSES

Mean wet weight of macrobenthic fauna at the eight study sites ranged from 3.0 (NR3) to 16.9 (AC) g/m^2, while mean abundance ranged from 241 (NR2) to 724 (LCC) individuals/m^2 (Table 4-65). At most of the sites, biomass per unit area declined over the collection period (Fig. 4-8), while no obvious pattern characterized abundance (Fig. 4-9). A decline in invertebrate biomass from early spring through late summer would be consistent with the typical stream pattern illustrated by Hynes (1970). Taken as a whole, the weight and abundance data for the eight sites appear to be in line with comparable data reported for Abrams and Mill creeks and other streams in the Great Smoky Mountains National Park (GSMNP) and western North Carolina (Table 4-66).

Table 4-67 lists the most abundant macrobenthic fauna collected at each of the eight study sites. A complete list of the taxa collected at each site is presented in Table C-1. For comparison, Table 4-68 summarizes the dominant taxa (based on abundance or combinations of abundance and weight) recorded for Abrams and Mill creeks and other small streams in the region. There is a noticeable difference among the study sites in the relative abundance of taxa; this difference is apparent even at separate sites within a given stream (i.e., Bradley Creek and Nantahala River). Nevertheless, the abundant fauna at the study sites are, in general, similar to those reported to be dominant in area streams (e.g., midge fly larvae of the family Chironomidae and mayfly nymphs of the genus Stenonema were each dominant in at least five of the six stream systems shown in Table 4-68 and were also among the ten most abundant taxa sampled from at least seven of our eight study sites).

Estimated annual production of benthic macroinvertebrates (exclusive of large vertebrates and crayfish) ranged from 8 to 42 g

Table 4-65. Wet weight and abundance of macrobenthic fauna at the eight study sites, 1982.

	Wet weight (g/m^2)		Abundance (no./m^2)		
Site	Mean	S.E.[a]	Mean	S.E.	N[b]
AC	16.9	3.5	655	128	33
BC1	4.6	0.8	514	55	47
BC2	3.1	1.0	340	33	50
LCC	4.7	0.9	724	84	44
MC	4.7	0.7	429	38	51
NR1	4.3	0.8	496	68	54
NR2	5.6	1.2	241	27	44
NR3	3.0	1.0	366	30	54

[a]S.E. = standard error of the mean.

[b]N = number of samples.

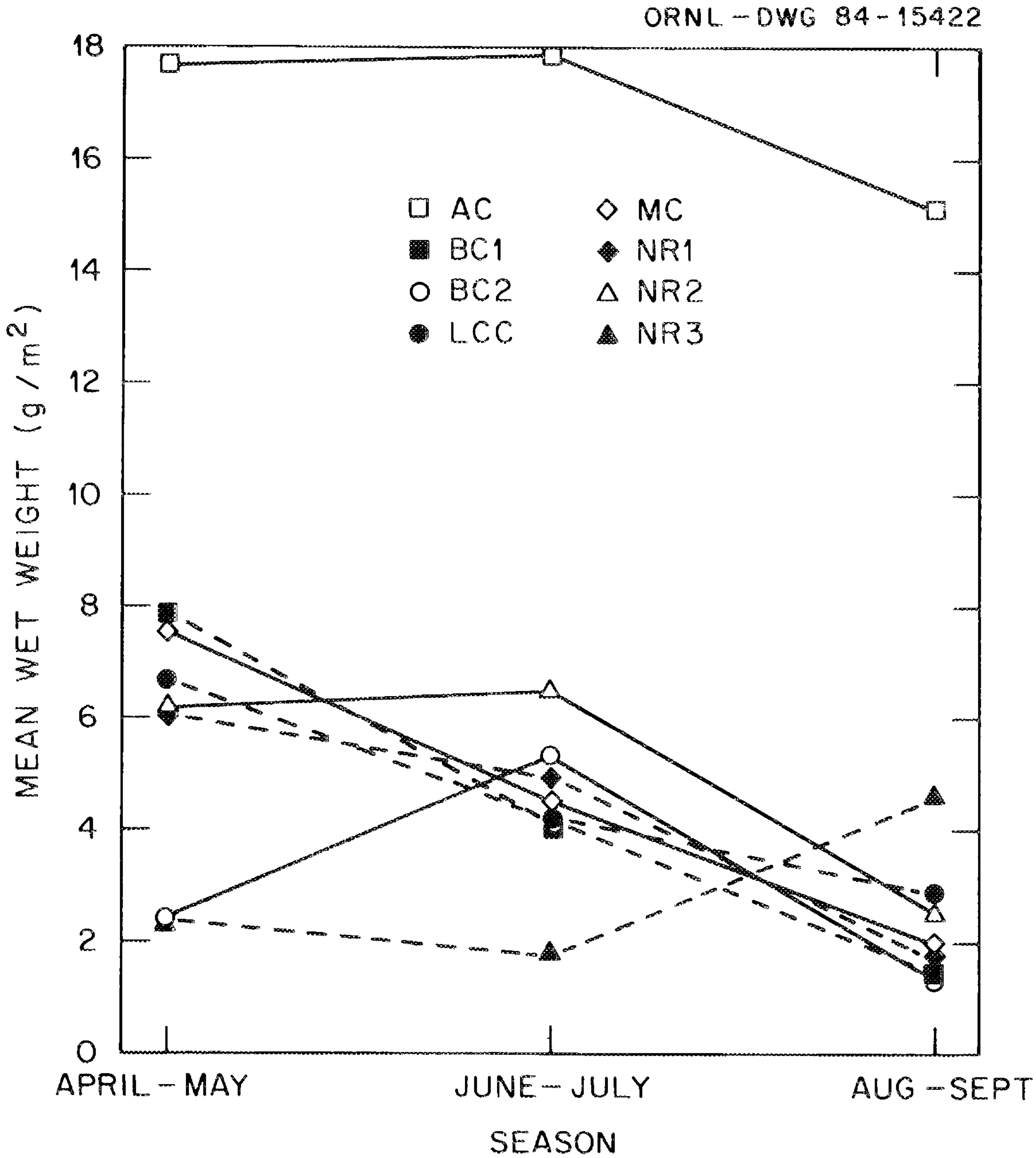

Fig. 4-8. Mean macrobenthic wet weight at the eight study sites for the three sampling seasons, 1982.

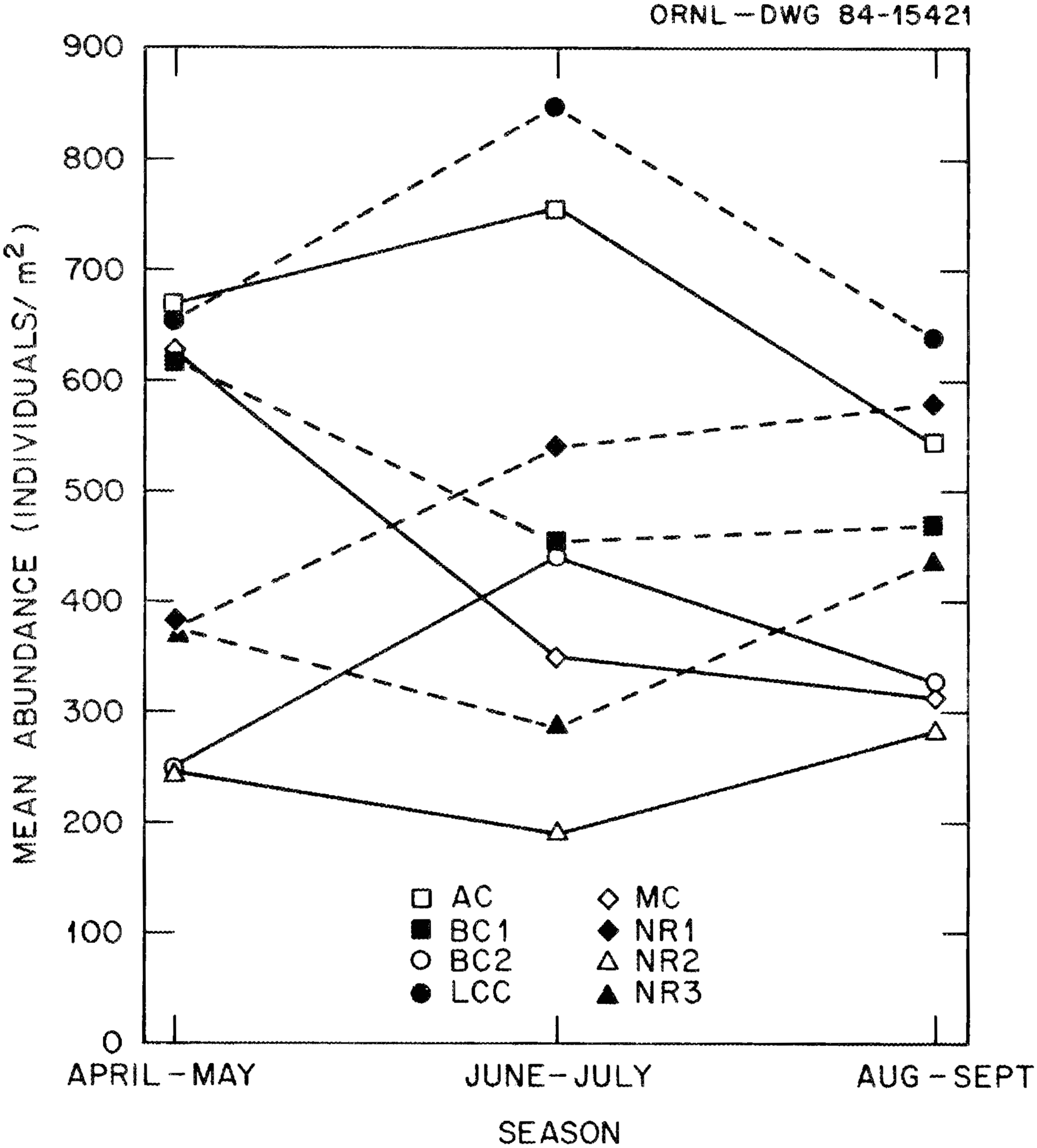

Fig. 4-9. Mean macrobenthic abundance at the eight study sites for the three sampling seasons, 1982.

Table 4-66. Wet weight and abundance of macrobenthic fauna in selected streams of the Great Smoky Mountains National Park (GSMNP) and western North Carolina.[a]

Streams	Wet weight[b] (g/m^2)	Abundance[b] (no./m^2)	Reference
Abrams Creek, GSMNP[c]	0.002-0.088[d]	151-1572	Mathews 1978
Mill Creek, GSMNP	0.001-0.018[d]	258-908	Mathews 1978
Camel Hump Creek, GSMNP	1.70[e]	576	Silsbee and Larson 1983
Huskey Branch, GSMNP	4.01[e]	938	Silsbee and Larson 1983
Four logged streams, GSMNP	2.02[e]	761	Silsbee and Larson 1983
Four unlogged streams, GSMNP	1.25[e]	475	Silsbee and Larson 1983
Four streams, Coweeta Hydrologic Lab, NC	3.94-18.32[f]	716-1214	Woodall and Wallace 1972
Ball and Shope creeks, Coweeta Hydrologic Lab, NC[h]	1.58-9.72[g]	207-1002	Tebo and Hassler 1961
Eighteen streams, upper Little Tennessee River basin, NC/GA	0.23-14.01[i]	65-915	TVA 1971
Cullowhee Creek, NC[h,j]	13.01-16.62[e]	721-818	Lemly 1982

[a]Based on Surber or Hess samples.

[b]Mean value or range of mean values.

[c]Station 15 in cited report.

[d]Units in cited report probably in error; these data will not be considered further in this report.

[e]Dry weight data in cited report multiplied by 6 to approximate wet weight (after Waters 1977).

[f]Ash-free dry weights in cited report multiplied by 6.7 to approximate wet weight (after Waters 1977).

[g]Volumetric data (cm^3) in cited paper multiplied by 1.05 to approximate wet weight in mg (after Hynes 1961).

[h]Insects.

[i]Crustaceans and mollusks not included.

[j]Zone 1 in cited report.

Table 4-67. Most abundant macrobenthic taxa collected at the eight study sites, 1982, listed in decreasing rank.

Rank	Site: AC	BC1	BC2	LCC	MC	NR1	NR2	NR3
1	Cheumatopsyche	Chironomidae[a]	Leuctra	Oligochaeta	Oligochaeta	Cheumatopsyche	Goniobasis	Ephemerella
2	Oligochaeta	Hexatominae[b]	Oligochaeta	Leuctra	Leuctra	Chironomidae[a]	Oligochaeta	Oligochaeta
3	Stenonema	Leuctra	Chironomidae[a]	Tanypodinae[b]	Psephenus	Ephemerella	Chironomidae[a]	Chironomidae[a]
4	Goniobasis	Oligochaeta	Tanypodinae[b]	Chironomidae[a]	Cinygmula	Baetis	Stenonema	Stenonema
5	Antocha	Tanypodinae[b]	Acroneuria	Ephemerella	Ephemerella	Oligochaeta	Cheumatopsyche	Brachycentrus
6	Chironomidae[a]	Rhyacophila	Hexatominae[b]	Pseudocloeon	Stenonema	Antocha	Ferrissia	Chloroperla
7	Isonychia	Cheumatopsyche	Stenonema	Optioservus	Chironomidae[a]	Hydropsyche	Antocha	Paraleptophlebia
8	Ephemerella	Ferrissia	Cheumatopsyche	Antocha	Isoperla	Pseudocloeon	Micrasema	Cheumatopsyche
9	Hydropsyche	Antocha	Brachycentrus	Acroneuria	Isonychia	Goniobasis	Isonychia	Pseudocloeon
10	Acroneuria	Acroneuria	Baetis	Stenonema	Cheumatopsyche	Stenonema	Leuctra	Leuctra

[a]Unidentified subfamilies.

[b]Unidentified genera.

Table 4-68. Dominant macrobenthic taxa in selected small streams of the Great Smoky Mountains National Park (GSMNP) and western North Carolina.[a]

Streams	Dominant taxa	Reference
Abrams Creek, GSMNP[bc]	*Tipula*, *Agapetus*, *Antocha*, *Cambarus*, *Goniobasis*, *Stenonema*, *Hydropsyche*, *Orconectes*, Chironomidae	Mathews 1978
Mill Creek, GSMNP[c]	*Pseudocloeon*, *Ephemerella*, *Chrysmura*, *Epeorus*, *Stenonema*, *Glossosoma*, *Psephenus*, *Chauliodes*, Chironomidae, *Pteronarcys*, *Isoperla*, *Tipula*, *Baetis*	Mathews 1978
Camel Hump Creek, GSMNP[d]	*Heptagenia*, *Ephemerella*, *Epeorus*, *Alloperla*, *Baetis*, *Paraleptophlebia*, Chironomidae, *Isogenus*, *Stenonema*, *Glossosoma*	Silsbee and Larson 1983
Huskey Branch, GSMNP[d]	*Glossosoma*, Chironomidae, *Parapsyche*, *Heptagenia*, *Ephemerella*, *Epeorus*, *Baetis*, *Leuctra*, *Alloperla*, *Peltoperla*	Silsbee and Larson 1983
Four streams, Coweeta Hydrologic Lab, NC[e]	*Peltoperla*, Chironomidae, *Diplectrona*, *Tipula*, *Eriocera*, *Parapsyche*, *Lanthus*, *Optioservus*, *Limnius*, *Stenonema*	Woodall and Wallace 1972
Eighteen streams, upper Little Tennessee River basin, NC/GA[d]	Elmidae, *Cheumatopsyche*, *Heptagenia*, Chironomidae, *Ephemerella*, *Stenonema*, *Psephenus*, Oligochaeta, *Iron*, *Isogenus*	TVA 1971

[a]Based on Surber samples.

[b]Station 15 in cited report.

[c]Based on the sum of percent relative contribution in abundance and weight (not ranked in this table).

[d]The ten most abundant taxa, in decreasing rank.

[e]Based on the product of percent relative contribution in abundance and weight, in decreasing rank.

wet wt•m^{-2}•$year^{-1}$, with the highest value found at Abrams Creek (Table 4-69). Although the mean turnover ratio at Abrams Creek was significantly lower than that at the other sites (3.8 versus 4.2-4.6), the mean biomass was significantly higher (11.0 versus 1.0-5.5 g/m^2). The calculated annual production at the eight study sites falls at the lower end of the range of production values reported for other streams (Table 4-70). Some of the reported values are for highly productive streams or stream segments (e.g., rock outcrop or riffle communities); this, plus our exclusion of a portion of the samples for the production estimates, may explain our somewhat lower production estimates.

4.5 HABITAT VERSUS TROUT RELATIONSHIPS

The relationship between habitat values (WUA or PUA) and trout resources was examined, using fish numbers and biomass per unit length of stream as dependent variables. These estimates, expressed on a per-kilometer basis, were used as an index of the trout resource because they were judged to be a better measure of fishery resource value than either standing crop (g/100 m^2) or density (no./100 m^2) variables. For example, if a stream reach is dewatered and total surface area is reduced, areal-based variables may remain the same or even increase even though total fish population numbers are reduced. Total numbers and biomass of fish per unit length of stream, however, would not be subject to this artifact of measurement. Nevertheless, per-unit-area and per-unit-length values were highly correlated across study sites for all age classes (Table 4-71).

Table 4-69. Mean biomass, estimated mean turnover ratio, and estimated annual production (wet weight) of benthic macroinvertebrates at the eight study sites (exclusive of large vertebrates and crayfish).

Site	Mean biomass (g/m^2)	Estimated mean turnover ratio	Estimated annual production ($g \cdot m^{-2} \cdot year^{-1}$)
AC	11.0	3.8	42
BC1	3.8	4.5	17
BC2	2.0	4.4	9
LCC	3.4	4.5	15
MC	4.1	4.5	18
NR1	4.3	4.6	20
NR2	5.5	4.2	23
NR3	1.9	4.4	8

Mean biomass[a]: AC NR2 NR1 MC BC1 LCC BC2 NR3

Mean turnover ratio: NR1 MC LCC BC1 NR3 BC2 NR2 AC

[a]A line connecting the site designations indicates that those sites were not statistically different from one another ($P > 0.05$).

Table 4-70. Published estimates of total annual production of benthic invertebrates in streams.

Stream	Production (g wet wt$\cdot m^{-2} \cdot year^{-1}$)	Reference
Bisballe Baek, Denmark	151[a]	Mortensen and Simonsen 1983
Nivelle River, France	55-58[b,c]	Lapchin and Neveu 1980
Bear Brook, New Hampshire	25-33[d]	Fisher and Likens 1973
Factory Brook, Massachusetts	26-29[d,e]	Neves 1979
Speed River, Ontario	1200[d]	Waters 1977, citing published data
River Thames, England	150[d]	Waters 1977, citing published data
Middle Oconee River, Georgia	377[f,g]	Nelson and Scott 1962

[a]Ash-free dry weight multiplied by 6.7 to approximate wet weight (after Waters 1977).

[b]13 species.

[c]Riffle.

[d]Dry weight multiplied by 6 to approximate wet weight (after Waters 1977).

[e]Cobble.

[f]Rock outcrop.

[g]Calories multiplied by 0.0012 to approximate wet weight in g (after Waters 1977).

Table 4-71. Correlation coefficients (r) between per-unit-area and per-unit-length estimates of trout numbers and biomass (all correlations are statistically significant, $\alpha = 0.01$).

Species/age class	(no./km vs no./100 m^2)	(g/km vs g/100 m^2)
Brown trout		
Age 0	0.99	0.99
Age 1	0.97	0.98
Age 2+	0.88	0.82
Total population	0.98	0.83
Rainbow trout		
Age 0	0.97	0.89
Age 1	0.93	0.90
Age 2+	0.91	0.92
Total population	0.96	0.90

Although production provides a better index of the trout resource because it incorporates both abundance (i.e., mean biomass, $\bar{B}$) and growth into a single measure, simple biomass and abundance measures were chosen over production (P) as dependent variables in the validation. Several problems are encountered if production were used as the dependent variable. First, no measure of variability is associated with the single production estimate at a given site. To obtain such data would require measurements of P over several years. Second, calculation of production by year class includes several life stages. For example, the 1982 year class includes both fry and juveniles with no direct method for combining the habitat values (WUA) of the two life stages. The problem is even greater for older year classes because another life stage (adults) is included. Although the 1983 year class consists only of fry (Age 0 trout), production, in this case, had to be indirectly estimated (with the exception of sites AC and MC; see Sect. 3.6.3.3). Finally, biomass may be a suitable surrogate for production because of the strong relationship between P and $\bar{B}$ for the total population (Fig. 4-7) and for individual year classes (e.g., small variability in P/B ratios across sites, Tables 4-56 and 4-59).

4.5.1 Instantaneous Correlations

The first approach was to examine the simple relationship between observed habitat values for a life stage/target species (e.g., adult brown trout) and the observed standing crop for that life stage at the time of the observation. This so-called "instantaneous" correlation approach is similar to that used in previous validation studies (Stalnaker 1979; Wesche 1980; Orth and Maughan 1982).

4.5.1.1 Brown Trout

The results of a simple correlation analysis (CORR procedure in SAS) between brown trout abundance and biomass and habitat values are presented in Table 4-72. Several significant (α = 0.05) relationships were found, especially when PUA was used as the habitat variable. The strongest correlations were:

- Age 0 abundance and biomass vs incubation PUA (r = 0.72 for both),
- Age 1 abundance and biomass vs spawning PUA (r = 0.86 and r = 0.84, respectively),
- Age 2+ abundance vs adult PUA (r = 0.69),
- Age 2+ biomass vs fry WUA (r = -0.64),
- Total biomass vs spawning PUA (r = 0.86), and
- Total biomass vs fry WUA (r = 0.67).

Although numerous, significant positive correlations were observed, none of the relationships explained more than 75% of the variability in brown trout abundance or biomass. In addition, several negative correlations were observed with both streamflow and total surface area. These latter results are, in part, an artifact of sampling, at least for Age 0 trout. Reduction in streamflow (and, therefore, surface area) from June through November coincided with the increased abundance of Age 0 trout resulting from increased sampling efficiency (i.e., Age 0 trout in June were generally less than 6.0 cm in total length and could not be sampled effectively by electroshocking). Finally, total brown trout biomass is plotted against adult brown trout WUA in Fig. 4-10 as an example of the data

Table 4-72. Correlation coefficients (r) for brown trout abundance and biomass vs observed habitat values. All values are significant at α = 0.05; NS = not statistically significant at α = 0.05.

Habitat variables	Abundance (no./km)				Biomass (g/km)			
	Age 0	Age 1	Age 2+	Total	Age 0	Age 1	Age 2+	Total
				Weighted usable area				
Adult	NS	NS	0.53	NS	NS	NS	NS	NS
Juvenile	NS	NS	NS	NS	NS	NS	-0.51	NS
Fry	NS	NS	-0.47	NS	NS	NS	-0.64	-0.67
Incubation	NS	NS	NS	NS	NS	NS	-0.54	NS
Spawning	NS	0.71	0.61	0.66	NS	0.65	NS	NS
				Percent usable area				
Adult	NS	0.46	0.69	NS	NS	NS	NS	NS
Juvenile	0.55	0.79	NS	0.72	0.57	0.72	NS	NS
Fry	0.51	0.68	NS	0.56	0.52	0.60	NS	NS
Incubation	0.72	0.76	NS	0.79	0.72	0.76	NS	NS
Spawning	0.55	0.86	0.53	0.86	0.58	0.84	NS	NS
Flow, m^3/s	-0.65	NS	NS	-0.48	-0.65	-0.50	NS	NS
Area, m^2/km	-0.72	-0.75	NS	-0.82	-0.73	-0.77	NS	NS

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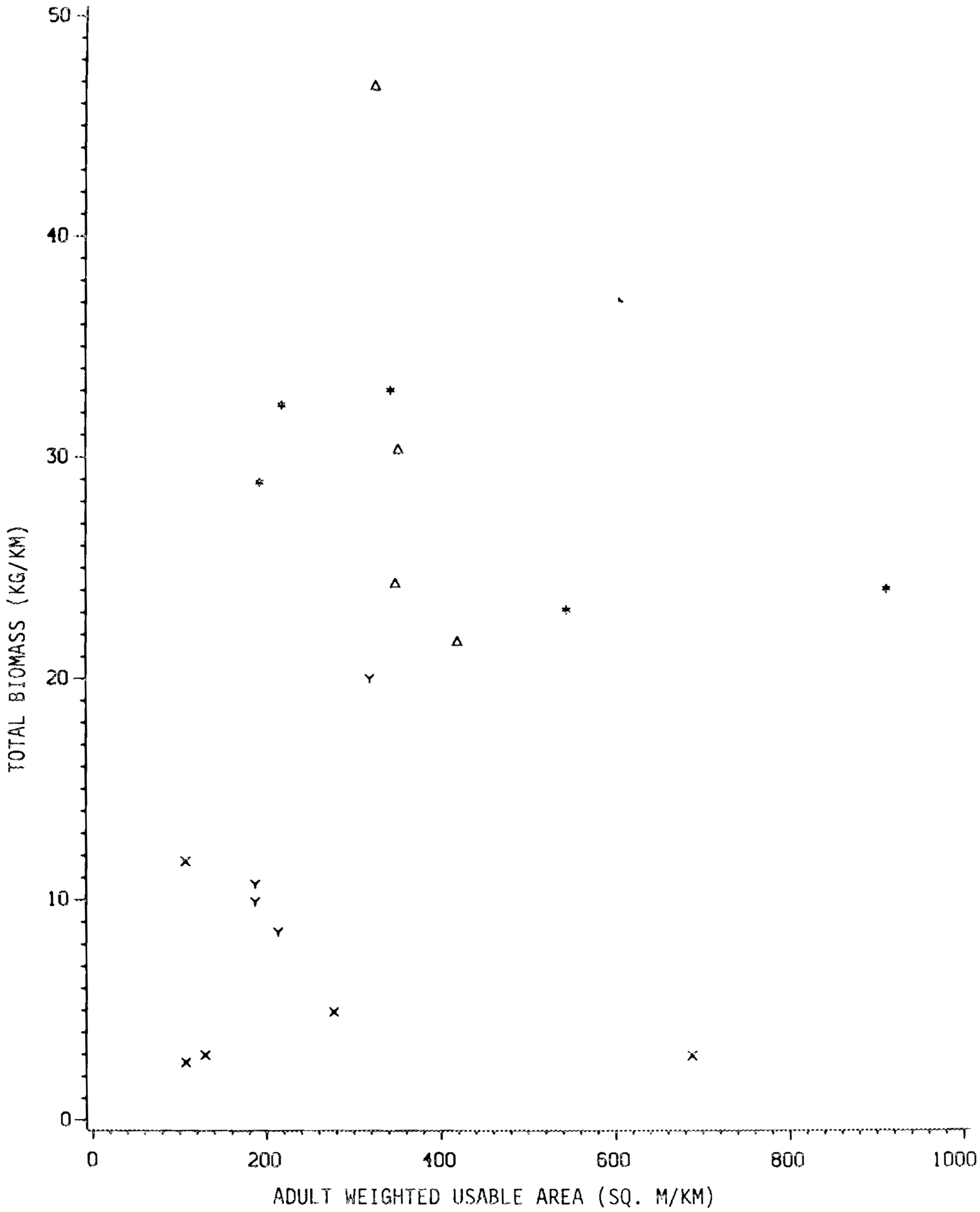

Fig. 4-10. Estimated total brown trout biomass vs observed weighted usable area for adult brown trout. X = BC1, Y = BC2, * = LCC, and Δ = NR3.

set used by Stalnaker (1979) and Wesche (1980) to support the validity of the Instream Flow Incremental Methodology (IFIM) in western streams. In the four streams with wild brown trout populations included in this study, the correlation between these two variables was not statistically significant at $\alpha = 0.05$ (Table 4-72).

4.5.1.2 Rainbow Trout

Although some significant "instantaneous" correlations were observed between abundance and biomass vs habitat for brown trout, none were found for rainbow trout. The only correlation that approached significance was between biomass of Age 1 rainbow trout and juvenile WUA ($r = -0.30$; $P = 0.07$). Moreover, the negative correlations that occurred between the abundance and biomass of brown trout and streamflow or surface area were not observed for rainbow trout, possibly because of the two sites (AC and MC) with relatively high populations of Age 0 rainbow trout and no brown trout. At these sites, Age 0 populations could be sampled effectively in early July (Table 4-28), so no bias due to sampling efficiency was included. Also, sampling was conducted in early September at higher flows than occurred on the July or October sampling dates. Finally, total rainbow trout biomass was plotted against adult rainbow trout WUA (Fig. 4-11) as an example of the rainbow data set and for comparison with a similar plot for brown trout. This figure shows the large variation in biomass over a relatively narrow range of habitat values and the absence of any correlation between the two variables.

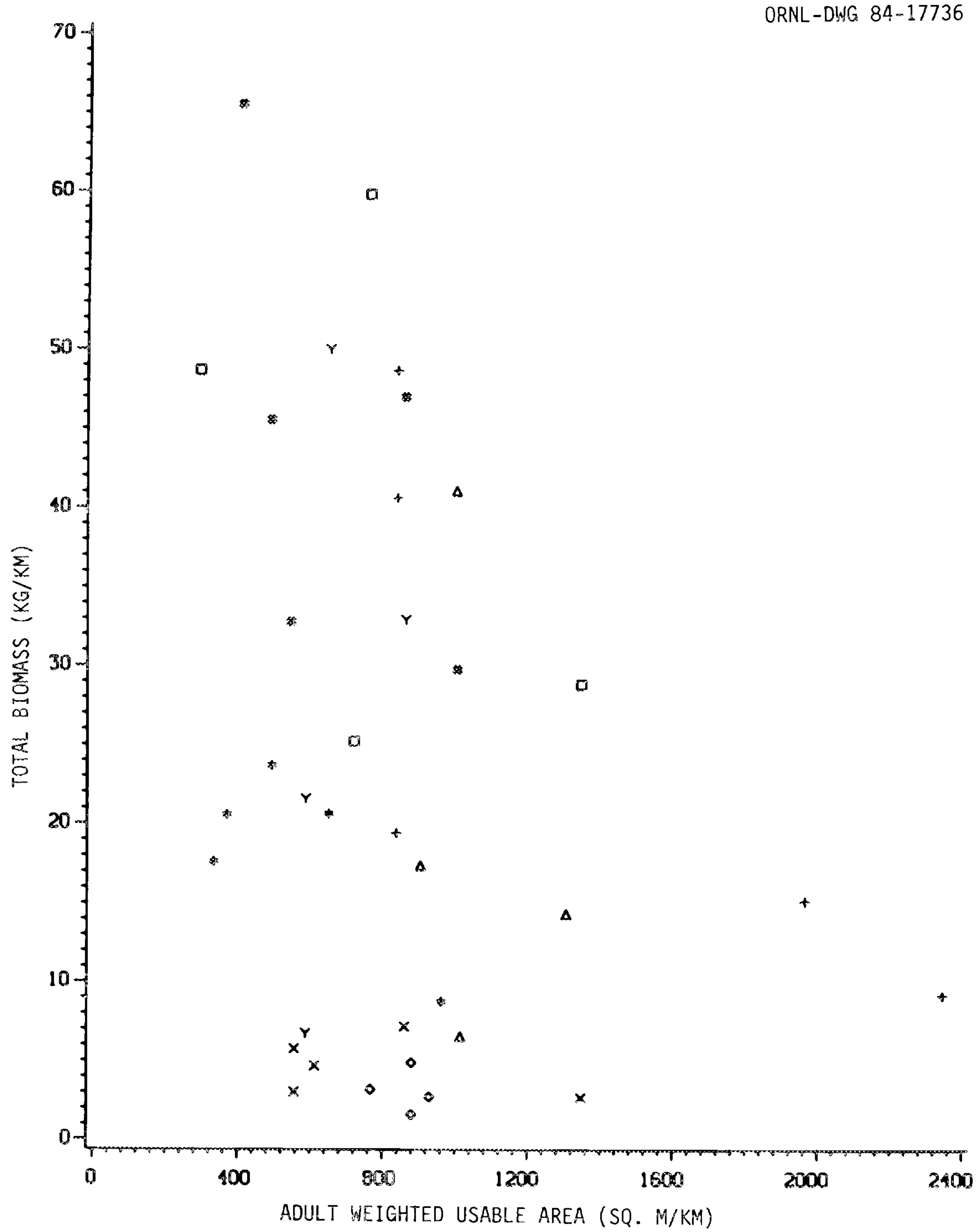

Fig. 4-11. Estimated total rainbow trout biomass vs observed weighted usable area for adult rainbow trout. + = AC, X = BC1, Y = BC2, * = LCC, # = MC, □ = NR1, ◇ = NR2, Δ = NR3.

4.5.2 Minimum Habitat Correlations

The second approach to the analysis of habitat-trout relationships involved a modification of the independent habitat variables by using minimum habitat values derived from historical monthly flow regimes (i.e., a mean value for each month). A record of long-term habitat values was calculated for each site and month of the year by finding the WUA value that corresponded to each mean monthly flow value (see also Sect. 4.2.3). In this analysis, a habitat value for spawning, incubation, fry, juvenile, and adult life stages was computed for each month the life stage was present (see Table 4-21). Individual years were not analyzed. This procedure produced a modified data set in which each study site received one value for the independent habitat variable for each life stage (e.g., minimum WUA for spawning), and the trout abundance and biomass estimates became essentially replicate values for the dependent variable.

4.5.2.1 Brown Trout

Results of this analysis are shown as correlation coefficients (r) for the pairwise correlations between the brown trout abundance and biomass estimates and the minimum habitat values for each life stage (Table 4-73). In comparison to the "instantaneous" correlations (Table 4-72), regressions with minimum habitat values produced more significant relationships ($\alpha = 0.05$), which, in general, explained more of the variability in trout abundance or biomass. Of all possible combinations of fish and habitat variables, 41% were significant using observed or "instantaneous" habitat variables, whereas 56% were

Table 4-74. Best single-variable models for predicting brown trout biomass and abundance.

Equation[a]	R^2	Prob > F
Fry (no./km) = -6.95 + 43.0 PUA_{spawn}	0.32	0.026
Fry (g/km) = -96.4 + 293.4 PUA_{spawn}	0.35	0.020
Juvenile (no./km) = -101.8 +41.1 PUA_{adult}	0.58	0.0002
Juvenile (g/km) = -5337 + 1832 PUA_{adult}	0.53	0.0006
Adult (no./km) = -16.3 + 30.4 $minPUA_{adult}$	0.64	0.0001
Adult (g/km) = -80960 - 43.5 $minPUA_{fry}$	0.74	0.0001

4.5.2.2 Rainbow Trout

As with the previous analysis of "instantaneous" observations for brown trout, rainbow trout abundance and biomass showed little relationship to habitat values derived from the annual flow regime. The only significant (α = 0.05) correlations with minimum habitat values were between Age 0, Age 1, and total rainbow trout biomass and minimum fry WUA (r = -0.33, -0.37, and -0.28, respectively). As discussed previously, such relationships, at least for Age 0 populations, more likely represent an artifact of sampling efficiency than any underlying biological phenomenon.

The absence of a relationship between habitat and rainbow trout populations (e.g., Fig. 4-13) could have at least two different explanations: (1) physical habitat is simply not the most important significant using minimum habitat variables. Fewer inverse relationships were observed when using minimum habitat values, and abundance and biomass were again more frequently related to habitat expressed as PUA than as WUA.

In addition to correlation analysis, the relationship between trout resources and historical mean monthly WUA or PUA was investigated using multiple linear regression analyses (STEPWISE/MAXR procedure in SAS). The best single-variable linear regression model for each age class of brown trout is given in Table 4-74. For comparison with the "instantaneous" relationship between habitat and trout (Fig. 4-10), a plot of total brown trout biomass vs minimum adult WUA is shown in Fig. 4-12. This single-variable model explained more than 70% of the variation in brown trout biomass at the four study sites (BC1, BC2, LCC, and NR3). Harshbarger and Bhattacharyya (1981) used the same regression procedure to examine the relationship between cover and trout biomass (brook, brown, and rainbow trout combined), by age class, in Bradley Creek and four other streams in this region. Their analysis included 10 types of cover, many of which are not directly influenced by streamflow, as the independent variables (total of 18). Their best single-variable model had an $R^2 = 0.31$, while the best six-variable model had an $R^2 = 0.66$. These results and our own analyses, including tests of the relationship between cover and trout resources (see Sect. 4.5.4), indicate not only that WUA-based variables are significantly correlated with brown trout abundance and biomass, but also that these variables may be better predictors of trout resources in southern Appalachian streams than nonhydraulic cover variables.

Table 4-74. Best single-variable models for predicting brown trout biomass and abundance.

Equation[a]	R^2	Prob > F
Fry (no./km) = $-6.95 + 43.0\ PUA_{spawn}$	0.32	0.026
Fry (g/km) = $-96.4 + 293.4\ PUA_{spawn}$	0.35	0.020
Juvenile (no./km) = $-101.8 + 41.1\ PUA_{adult}$	0.58	0.0002
Juvenile (g/km) = $-5337 + 1832\ PUA_{adult}$	0.53	0.0006
Adult (no./km) = $-16.3 + 30.4\ minPUA_{adult}$	0.64	0.0001
Adult (g/km) = $-80960 - 43.5\ minPUA_{fry}$	0.74	0.0001
Total (no./km) = $-85.6 + 97.5\ minPUA_{adult}$	0.68	0.0001
Total (g/km) = $-10080 + 125\ minWUA_{adult}$	0.71	0.0001

[a]Variable definitions:

PUA = average percent usable area for months in which subscripted life stage is present.

minPUA = minimum percent usable area over all months in which subscripted life stage is present.

minWUA = minimum weighted usable area (m^2/km) over all months in which subscripted life stage is present.

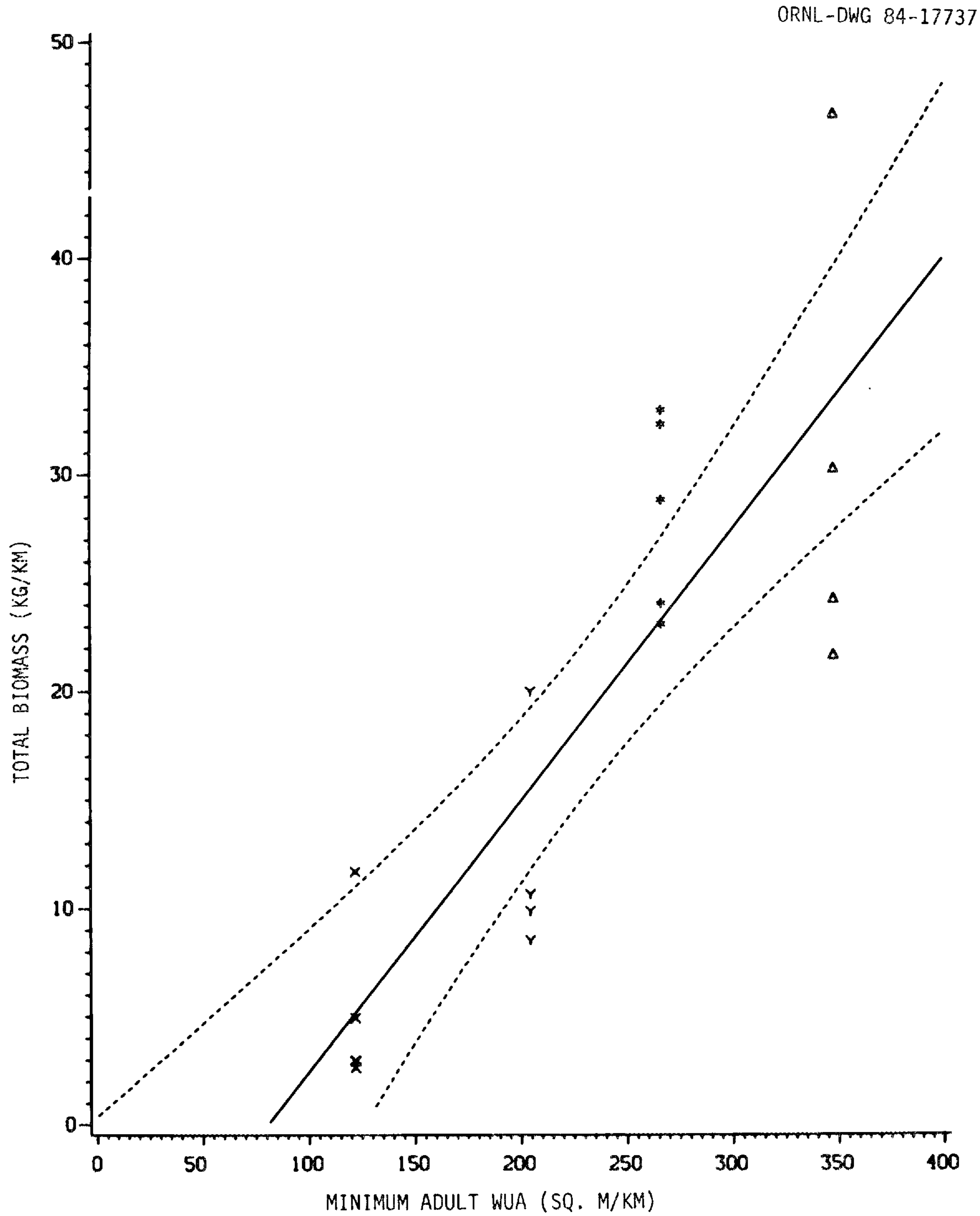

Fig. 4-12. Linear regression of estimated total brown trout biomass vs minimum weighted usable area for adult brown trout. X = BC1, Y = BC2, * = LCC, and Δ = NR3.

4.5.2.2 Rainbow Trout

As with the previous analysis of "instantaneous" observations for brown trout, rainbow trout abundance and biomass showed little relationship to habitat values derived from the annual flow regime. The only significant (α = 0.05) correlations with minimum habitat values were between Age 0, Age 1, and total rainbow trout biomass and minimum fry WUA (r = -0.33, -0.37, and -0.28, respectively). As discussed previously, such relationships, at least for Age 0 populations, more likely represent an artifact of sampling efficiency than any underlying biological phenomenon.

The absence of a relationship between habitat and rainbow trout populations (e.g., Fig. 4-13) could have at least two different explanations: (1) physical habitat is simply not the most important factor controlling rainbow trout abundance in our study streams, or (2) the habitat values used are not an accurate representation of rainbow trout behavior and requirements. Available data point to the second explanation. For example, studies of habitat utilization (Sect. 4.2.2) indicated that rainbow trout existing in sympatry with brown trout select different habitat types than allopatric populations. This competitive behavior was not considered in the development of the suitability curves routinely used to estimate WUA. Moreover, rainbow trout densities and standing crops were lower at sites with brown trout than at sites with only rainbow trout (Table 4-44).

Because this evidence implied the possibility of strong interspecific interactions, the data set was subdivided for further analysis: allopatric sites with only rainbow trout (AC, MC, NR1, and

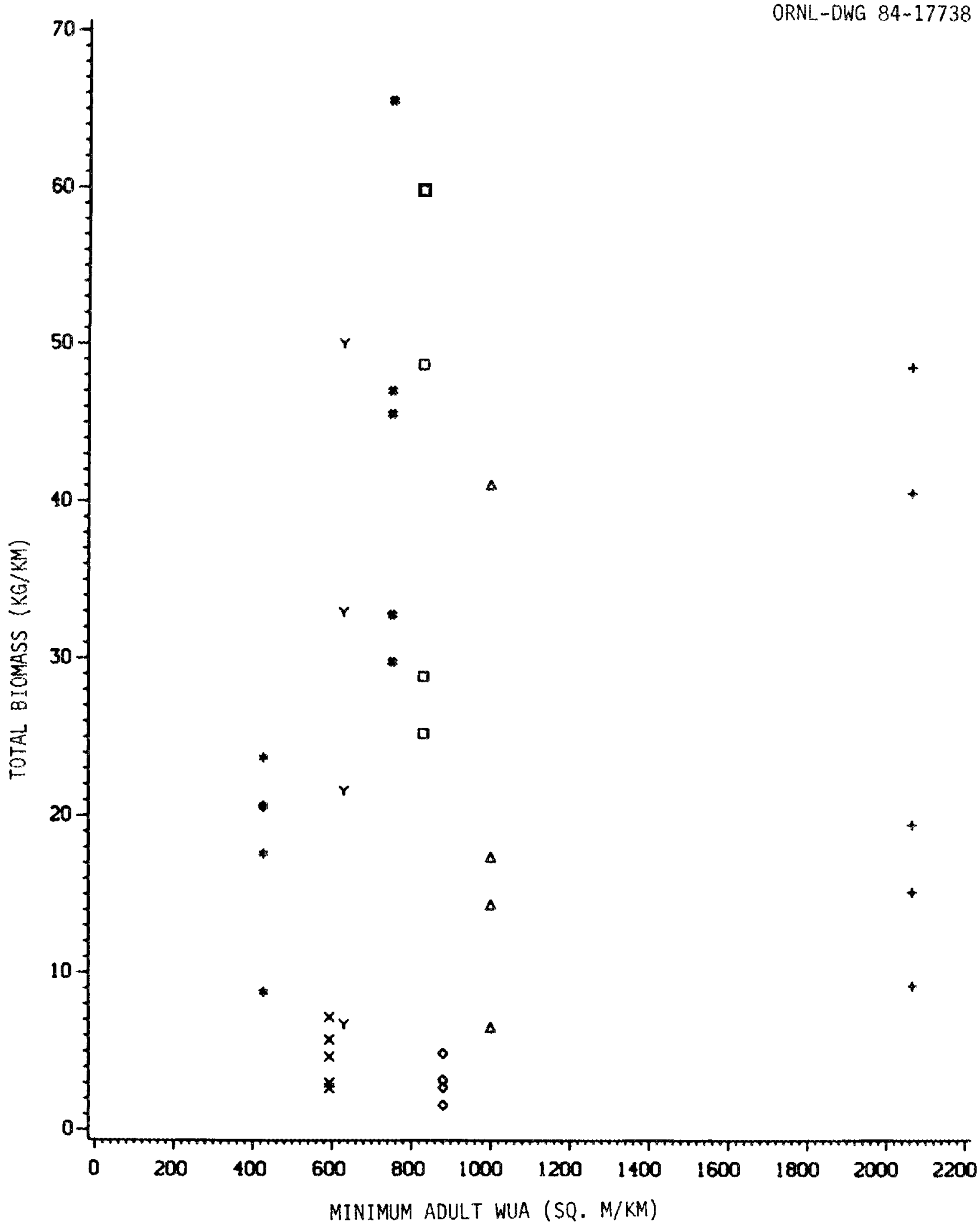

Fig. 4-13. Linear regression of estimated total rainbow trout biomass vs minimum weighted usable area for adult rainbow trout. + = AC, X = BC1, Y = BC2, * = LCC, # = MC, □ = NR1, ◊ = NR2, and Δ = NR3.

NR2) and sympatric sites with both rainbow and brown trout populations (BC1, BC2, LCC, and NR3). When these data sets were subjected to the minimum-habitat correlation analysis, some important differences were found. Although no significant habitat vs trout relationships were found in the sympatric data set, several significant ($\alpha = 0.05$) relationships were observed among the allopatric sites (Table 4-75). Abundance of all age classes was related to incubation WUA, and, less strongly, to fry WUA. The best single-variable linear regression models for allopatric rainbow trout are shown in Table 4-76, and the model with total abundance (no./km) as the dependent variable is shown in Fig. 4-14.

4.5.3 Flow Regime Effects

An evaluation of the biological response of trout to the periods of flow-related habitat degradation predicted in Sect. 4.2.3 was somewhat limited due to the resolution of our data set. Specifically, because fish sampling was only conducted over two field seasons, data were incomplete for several cohorts or year classes. Nevertheless, some comparison of relative year-class strength can be made for relating high- or low-flow events to trout populations. For example, the persistent low flows that occurred in Abrams Creek from July through December 1980 (Event 1 in Sect. 4.2.3) reduced fry and juvenile WUAs and should have resulted in reduced survival of fry (1980 year class) and juveniles (1979 year class) present during that time. To assess relative strengths of year classes affected by the low-flow period, the population numbers of Age 2 trout in 1982 and 1983 (1980

Table 4-75. Correlation coefficients (r) for abundance and biomass of allopatric rainbow trout vs minimum habitat values. All values of r are significant at $\alpha = 0.05$; NS = not statistically significant at $\alpha = 0.05$.

Habitat variables	Abundance (no./km)				Biomass (g/km)			
	Age 0	Age 1	Age 2+	Total	Age 0	Age 1	Age 2+	Total
				Weighted usable area				
Adult	NS	NS	NS	NS	NS	NS	NS	NS
Juvenile	NS	NS	NS	NS	NS	NS	NS	NS
Fry	0.82	0.54	NS	0.65	0.71	NS	NS	NS
Incubation	0.86	0.62	0.42	0.79	0.75	NS	NS	NS
Spawning	NS	NS	NS	NS	NS	NS	NS	NS
				Percent usable area				
Adult	NS	NS	NS	NS	NS	NS	NS	NS
Juvenile	NS	NS	NS	NS	NS	NS	NS	NS
Fry	NS	NS	NS	0.62	NS	NS	NS	NS
Incubation	0.73	0.52	NS	0.72	0.62	NS	NS	NS
Spawning	NS	NS	NS	NS	NS	NS	NS	NS

Table 4-76. Best single-variable models for predicting rainbow trout biomass and abundance at sites without brown trout (AC, MC, NR1, NR2).

Equation[a]	R^2	Prob > F
Fry (no./km) = $-478.2 + 3.13\ minWUA_{inc}$	0.74	0.0004
Fry (g/km) = $-184.1 + 7.65\ minWUA_{inc}$	0.56	0.0051
Juvenile (no./km) = $92.08 + 1.01\ minWUA_{inc}$	0.38	0.0064
Total (no./km) = $-104.89 + 3.90\ minWUA_{inc}$	0.62	0.0001

[a]Variable definitions:
minWUA = minimum weighted usable area (m^2/km) over all months in which subscripted life stage is present.

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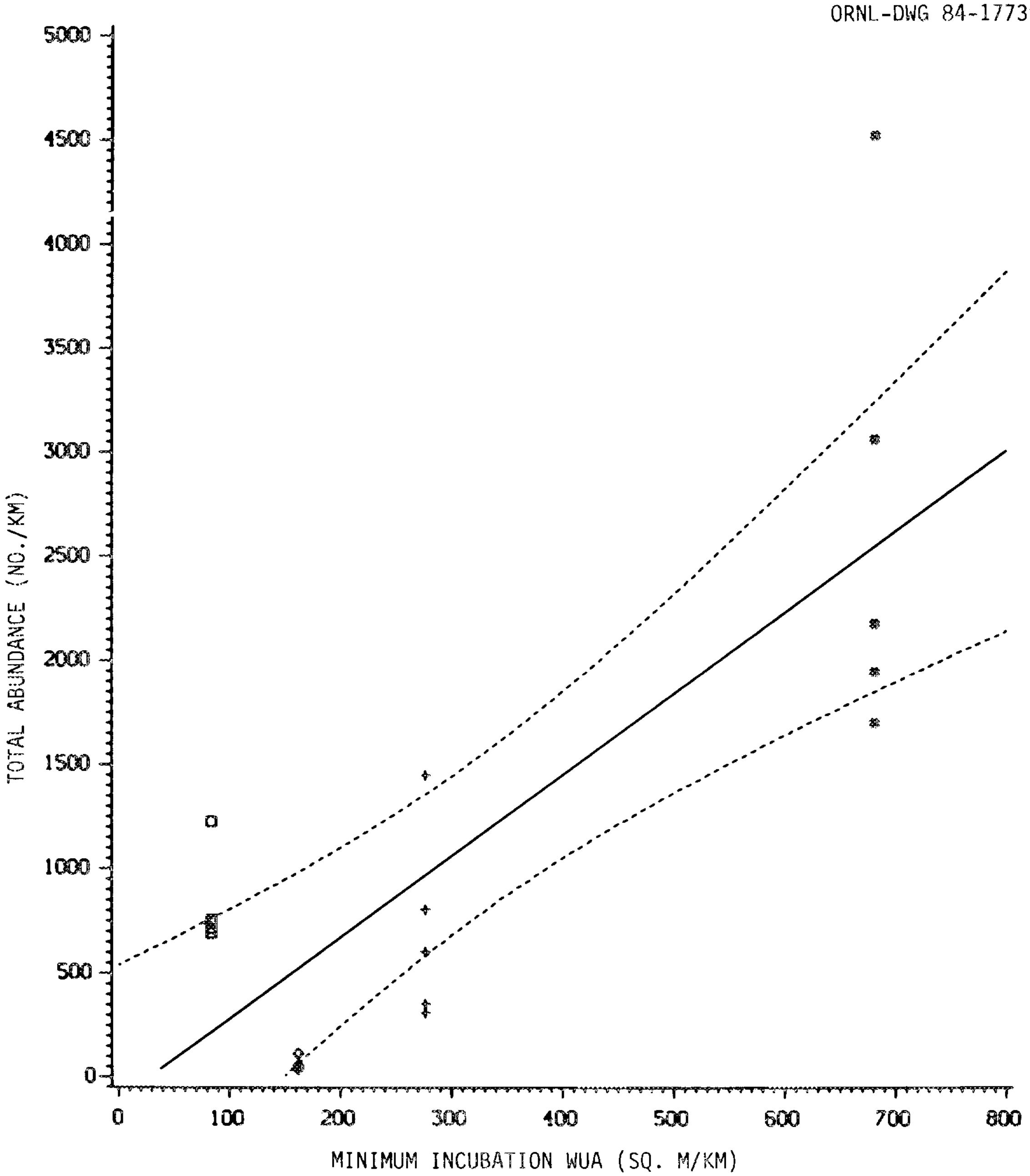

Fig. 4-14. Linear regression of estimated total rainbow trout abundance (allopatric populations only) vs minimum weighted usable area for rainbow trout incubation. + = AC, # = MC, □ = NR1, and ◊ = NR2.

and 1981 year classes, respectively) and Age 3 trout in 1982 and 1983 (1979 and 1980 year classes) were compared. The 1980 year class subjected to low flows as fry was only 33% of the 1981 year class, whereas numbers of juveniles in 1979 and 1980, as represented by the subsequent numbers of Age 3 trout in 1982 and 1983, respectively, were probably similar.

Using a similar procedure to evaluate the effects of other habitat-stress periods (Sect. 4.2.3) resulted in a mixed response to physical habitat conditions. For example, unusually high flows in February, March, and April 1983 in Lost Cove and Bradley creeks reduced rainbow trout spawning WUA, yet the 1983 and 1982 year classes were similar (comparisons of the population numbers of Age 0 trout in October of 1982 and 1983). The weak brown trout year class in 1983 at LCC and BC2 may be associated with the high flows that occurred in the spring during incubation and emergence. At these sites, populations of Age 0 trout in late October 1983 were approximately 75% lower than the Age 0 population in early November 1982, a year with no unusual high-flow events (>150% mean monthly flow; Table 4-26). The brown trout populations at BC1, however, did not exhibit this same pattern; Age 0 abundance in the fall was higher in 1983 than in 1982.

In summary, both high and low flows that occurred during 1980-1983 resulted in reductions in habitat of various life stages, with some evidence of subsequent effects on year-class strength. At all sites, the 1982 year class of rainbow trout was substantially stronger than the 1981 year class (based on comparisons of Age 1 trout in 1982 and 1983) and similar to the 1983 year class, with the exception of BC1 (lower in 1983) and AC (higher in 1983). No unusual low-flow events (<50% mean monthly flow) were recorded in 1982, and high flows occurred at all sites only in December (Table 4-26). Brown trout, on the other hand, exhibited a stronger year class in 1981 than in 1982 at LCC and BC1. At BC2 and NR3, densities of Age 1 brown trout were similar between the two years. As noted previously, the 1983 year class was, in turn, lower than the 1982 year class at LCC, BC2, and NR3.

Reasons for the generally opposite trends in year-class strength exhibited by brown (1981 $\geq$ 1982 > 1983) and rainbow trout (1981 < 1982 $\simeq$ 1983) may be related to (1) seasonal differences in spawning and incubation periods, with differential effects from unusual hydrologic events (i.e., very low or very high flows during spawning of brown and rainbow trout, respectively) and/or (2) species interactions that result in strong year classes of rainbow trout only when brown trout abundance is low. Results of our analysis of the effects of extreme hydrologic events (high or low flows) on year-class strength in trout populations, as predicted by reductions in WUA for specific life stages, are inconclusive. The significance of such events can only be adequately evaluated by following several year classes through a complete life cycle. However, the inference regarding opposite trends in year-class strength is consistent with the hypothesis that interspecific interactions between brown and rainbow trout affect habitat utilization patterns of the latter species (Sect. 4.2.2).

4.5.4 Cover Relationships

To evaluate the importance of cover to trout populations in southern Appalchian streams, simple rank correlation analyses of the relationships between various cover types (Table 4-77) and trout biomass and production (Tables 4-56 and 4-59) were performed. Because both biomass and production are per-unit-area expressions, only variables expressing cover per unit area (e.g., percent study site area consisting of undercut banks) were analyzed. In addition to the four simple variables listed in Table 4-77, several combinations of these variables were considered: (1) percent undercut cover = percent undercut banks plus percent undercut objects; (2) percent instream cover = percent undercut cover plus percent object cover; (3) percent overhead cover = percent undercut cover plus percent vegetation <1 m above the water; and (4) percent total cover = percent overhead cover plus percent object cover.

For all seven sites, the only significant values of Spearman's coefficient of rank correlation (r_s) were between total trout production and percent vegetation <1 m above the water or percent overhead cover or percent total cover (all $r_s = -0.893$, $P < 0.01$). Considering only the three allopatric sites (rainbow trout alone), both biomass and production of rainbow trout showed $r_s = -1$ for five of the cover variables: percent vegetation <1 m above the water, percent object cover, percent instream cover, percent overhead cover, and percent total cover. At only the four sympatric sites (both species present), no significant correlations were observed between any of the cover variables and either brown trout biomass or production, total trout biomass or production, or rainbow trout biomass. The only significant correlation was $r_s = -1$ for rainbow trout production and percent undercut banks and may well be spurious.

Table 4-77. Estimates of various cover types for seven study sites (cover was not measured at NR1). All values expressed in m^2 and as percent total surface area (in parentheses). Cover types are defined in Sect. 3.2.3.

Site	Surface area	Overhead cover: Undercut banks	Overhead cover: Undercut objects	Overhead cover: Vegetation <1 m above water	Object cover
AC	729	23.9 (3.3)	0.5 (0.1)	44 (6.0)	4.9 (0.7)
BC1	1046	9.6 (0.9)	3.3 (0.3)	253 (24.2)	2.7 (0.3)
BC2	304	8.6 (2.8)	0.4 (0.1)	141 (46.4)	5.8 (1.9)
LCC	496	4.7 (0.9)	1.4 (0.3)	18 (3.6)	9.7 (2.0)
MC	461	8.9 (1.9)	5.0 (1.1)	0 (0.0)	2.5 (0.5)
NR2	573	5.7 (1.0)	12.6 (2.2)	141 (24.6)	5.3 (0.9)
NR3	412	2.8 (0.7)	0.4 (0.1)	66 (16.0)	14.3 (3.5)

The basic pattern seen in all nine significant relationships was a negative correlation between the measure of cover and trout biomass and production. This pattern, along with the preponderance of nonsignificant correlations (82 of 96), is contrary to what one might expect on the basis of the extensive work with brook trout (e.g., Hunt 1976) which showed that increasing cover tends to increase trout numbers or biomass. The many nonsignificant correlations are interpreted to indicate that the amount of instream cover (simple and compound variables) is unimportant at the low levels of variation seen among the study sites (Table 4-77). On the other hand, percent vegetation <1 m above the water may, in fact, be important; it is either the variable of interest or a component of the compound variable in 64% of the significant correlations identified. The negative association found is in accord with earlier literature. Both Murphy et al. (1981) and Hawkins et al. (1983) reported that removal of riparian vegetation increased trout populations in streams in the northwestern United States, and attributed this result to increases in production throughout the trophic pyramid. Whether this same explanation applies to our study streams is unknown because no data are available on microbial respiration and primary production.

Overall, using measures of cover, either instream or overhead, to predict trout abundance would not be successful in streams similar to those in our study. Instream cover is already adequate at these sites, given other limitations on the systems; Hartzler (1983) reached a similar conclusion for a stream in Pennsylvania.

5. CONCLUSIONS AND RECOMMENDATONS

The adequacy, or validity, of any assessment model must be evaluated in context with the problem for which the model was initially developed (Shannon 1975). The habitat evaluation models considered in this study were developed to assess the water requirements of aquatic biota and their response to changing flow patterns in lotic ecosystems, specifically below dams and other diversion structures. The rationale for setting minimum flow requirements usually involves either the conservation or enhancement of one or more downstream fishery resources. The negotiation of minimum flows is usually accompanied by the expectation that a positive relationship exists between physical habitat indices and some measure of the fishery resource, such as biomass, abundance, or production (Sect. 1.2). Translated further, the expectation is that more, or better, habitat will lead directly to more, or larger, fish. An acceptable instream flow assessment model should therefore be capable of predicting one or both of the following: (1) relative strength of fishery resources among streams with different physical characteristics, and (2) relative value or capacity of alternative flow regimes to support fish populations at a specified location. In the absence of flow-regulating structures and an experimental study design, the second point can be interpreted as distinguishing between annual hydrographs for their ability to produce strong year classes within a target fish population.

5.1 FINDINGS

Several specific conclusions can be drawn from this study with important implications to instream flow assessment. These findings and recommendations are outlined below.

Hydraulic modeling. The IFG4 hydraulic simulation model is not reliable for PHABSIM applications in higher gradient streams with mobile bed material (Sect. 4.2.1). Therefore, IFG4 should not be required a priori in regional or state-wide instream flow assessments as it now is by some regulatory agencies. The guidance that exists from the Instream Flow Group regarding the application of IFG4 to stream types with mobile bed forms (Bovee and Milhous 1978) has been interpreted with respect to sand-bed streams (e.g., Hilgert 1981). The problems caused by scour and fill are also significant in steeper gradient streams with cobble or larger substrates. The IFG4 model is often used in these streams due to the presence of nonuniform flow. However, calibration of this model becomes very difficult, if not impossible, when cross sections are changing even by a relatively small amount. A flexible approach to hydraulic modeling must be maintained with the emphasis on demonstration of calibration accuracy rather than on the requirement of a specific model.

Habitat preference of trout. The concept of habitat preference in trout populations is valid. Rainbow and brown trout are found in locations with depth, velocity, and substrate characteristics in disproportion to what is available in their environment (Sect. 4.2.2). This behavior appears to be replicable and, therefore, can be represented in weighting factors such as the suitability curves of the

Instream Flow Incremental Methodology (IFIM). Habitat preference is both species- and life-stage-specific among trout.

Variability in trout populations. The density (no./m^2), standing crop (g/m^2), and production ($g \cdot m^{-2} \cdot year^{-1}$) of trout in streams without major water quality perturbations or fishing pressure can vary by more than an order of magnitude (Sect. 4.3). When sites are selected to control for water quality and food base, this variability can be related to differences in physical habitat availability. Habitat is important even when other resources appear to be low. Therefore, it is realistic to expect a biological response to changes in habitat, at least in streams similar to those examined in this study.

Shifts in habitat use. The habitat utilization patterns that do exist among trout are influenced by at least two site-specific factors: habitat availability and interspecific interactions (Sect. 4.2.2). Therefore, observed utilization and the suitability criteria derived from utilization data will vary among sites. Because no true preference index has yet been developed which can factor out the influence of habitat availability or the effects of interspecific interactions, suitability criteria are subject to error unless they are verified on a site-specific basis.

Habitat/trout resource relationships. The weighted usable area (WUA) habitat index calculated from published suitability criteria is related to several measures of the trout resource (Sect. 4.5). Therefore, the general null hypothesis that habitat was not related to trout biomass/abundance can be rejected. Habitat-vs-trout correlations are improved by standardizing across sites by total surface area and by using minimum habitat values experienced over an annual cycle by each life stage. These habitat-trout relationships are found most frequently with dominant species (i.e., brown trout) and with subdominant species when they are not influenced by a potential major competitor (i.e., rainbow trout in the absence of brown trout). Therefore, instream flow assessments should not be conducted using WUA indices from nonlimiting times of the year or for species that may be influenced by major competitors. Also, predictions of biological response to habitat changes require a relatively detailed understanding of the population dynamics of the target species to identify sensitive life stages. For example, at the sites examined in this study, it can be hypothesized that brown trout populations (all age classes combined) were most strongly influenced by adult habitat, while allopatric rainbow trout were most strongly influenced by habitat for younger life stages (fry and incubation). The sensitivity and importance of younger life stages in determining rainbow trout standing crop were also identified in field studies by Nehring and Anderson (1983). Identification of sensitive life stages, based either on longer-term empirical studies or on inferences from the scientific literature for similar sites, should be part of an instream flow assessment.

5.2 ROLE OF HABITAT IN FISHERIES MANAGEMENT

Proper application of habitat models in instream flow management must be consistent with a more comprehensive theory for fishery management and lotic ecology. In an early critique of the IFIM, Patten et al. (1979) outlined the necessary and sufficient conditions for predicting fish distribution. Although depth, velocity, substrate, and cover are necessary to support fish in a stream, these physical habitat variables are not always sufficient to explain either macro- or microdistribution patterns. For example, temperature, water quality, food resources, or interspecific competition can act to suppress trout populations even in the presence of adequate physical habitat. The conceptual model implied by Patten et al. (1979) can be called a "limiting-variable" model where fish biomass and abundance are determined by a single, limiting environmental resource. Trout populations in soft-water streams are often hypothesized as being food limited. Production, however, can be highly variable in these systems (Table 4-57). Studies on brook trout in streams with similar water quality in Georgia (Michaels 1978) and Quebec (O'Connor and Power 1976) reported variations of two and five times, respectively, which were related to habitat differences. This study shows a similar trend with rainbow and brown trout; that is, at sites with similar, apparently limiting water quality and instream food resources, the variability in abundance and biomass can be related to habitat differences.

An alternative to the limiting-variable model is a potentiation model. A general potentiation model for predicting trout biomass can be hypothesized as:

$$B = a * \pi_i X_i^{\beta_i} \quad ,$$

where B is total biomass of a target population measured as weight per unit length of stream, α and β_i are regression coefficients, and X_i are variables such as habitat condition, water quality, temperature, food resources, or interspecific competition.

This analytical structure was used successfully by Binns and Eiserman (1979) to predict trout standing crop in Wyoming and earlier by Huet (1964) and Kolbing (1978) for European fishery management. With such an empirical approach, it would be unreasonable to expect an absolute prediction of B using only physical habitat variables unless all other influences are held constant (all other X_i and β_i fixed). However, it is still reasonable to find B proportional to habitat variables (H) with a site interaction term (the slope of the B vs H relationship).

The difference between limiting-variable models and potentiation models is critical to the use of habitat variables in instream flow management. If the limiting-variable model holds, then fish will show no response to flow-related habitat changes when habitat is not limiting. In this case, minimum flow requirements based on indices such as WUA would be of questionable validity. However, if the potentiation model holds, then habitat variables would still be important determinants of fishery resources. The results of this study argue for the latter model and suggest that habitat-based assessments of instream flow needs are appropriate in stream types such as were studied here.

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APPENDIX A

Dates of Hydraulic and Biological Sampling

Table A-1. Dates of hydraulic data collection (H); macrobenthos sampling (B), 1982; cover analysis (C), 1983; and fish population sampling (F), March 1982 through October 1983. Dates of hydraulic data collection refer to discharge measurements at a single transect, unless noted otherwise. Fish population sampling indicates dates fish were marked (numerator) and recaptured (denominator). A dash indicates no sampling.

							Bradley Creek									Nantahala River								
	Abrams Creek			Mill Creek			BC1			BC2			Lost Cove Creek			NR1			NR2			NR3		
Date	H	B/C	F	H	B/C	F	H	B/C	F	H	B/C	F	H	B/C	F	H	B/C	F	H	B/C	F	H	B/C	F
1982																								
March	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24[a]	-	-	22[a]	-	-	25[a]	-	-
April	-	-	-	-	-	-	29[a]	28	-	30[a]	28[b]	-	27[a]	27	-	-	-	-	-	-	-	-	-	-
May	6[a]	6	-	7[a]	7	-	-	-	-	-	-	-	-	-	-	26[a]	26	-	26	26	-	24	24	-
June	30	30	-	30	-	29	24[a]	24	21/23	23[a]	24	21/23	22[a]	22[b]	22/25	-	-	-	-	-	-	-	-	-
July	14	-	12/14	12	12	/1	-	-	-	-	-	-	-	-	-	21	21	20/22	21	21	20/23	19[a]	19	19/21
August	31	31	31	-	-	-	-	25	23/25	25	25	23/26	24	24	24/27	-	-	-	-	-	-	-	-	-
September	8	-	/8	3[a,c]	7	7/9	-	-	-	-	-	-	-	-	-	22[a]	23	20/22	23[a,d]	23	20/23	21[a]	21	21/24
October	28	-	26/28	29[a,b,d]	-	26/29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
November	-	-	-	-	-	-	-	-	9/12	11[a]	-	9/11	8	-	6/10	-	-	-	-	-	-	-	-	-
1983																								
March	15	-	15/17	15	-	15/17	30	-	28/30	28	-	28[e]	-	-	-	29	-	29/31	29	-	29/31	-	-	-
April	-	-	-	-	-	-	-	-	-	-	-	-	28	-	28/29	-	-	-	-	-	-	18	-	18[e]
May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
June	-	-	-	-	-	-	-	23	20/22	22[d]	-	20/22	21	21	21/24	-	-	-	-	-	-	7	-	7/8
July	12	-	12/14	12	-	12/14	-	-	-	-	-	-	-	-	-	18	-	18/19	18	19[b]	18/21	20	20	20/22
August	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
September	30	30	-	28	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
October	-	-	-	-	-	-	-	-	-	26	26[b]	-	-	-	-	-	-	-	-	-	-	-	-	-

[a]Hydraulic data (depth, velocity, and substrate) collected at all transects.

[b]Majority of the data (samples) were collected on this date; sampling actually conducted over 2-d period.

[c]Discharge measurements also taken on September 7 and 9.

[d]Discharge measurements also taken on date of fish population sampling, marking run.

[e]Adequate sample could not be obtained due to high flows.

Table A-2. Dates and sampling designs utilized in the habitat preference and habitat availability studies, 1983. Sample sizes are shown for Age 0 and Age 1+ trout.

	Habitat preference					Habitat availability		
		Rainbow		Brown			Sampling method	
Site	Date	Age 0	Age 1+	Age 0	Age 1+	Date	Grid	Transect
AC	8-25	8	17	-	-	10-4	X	
	9-20	29	28	-	1	10-30		X
BC1	9-8[a]	16	31	15	22	10-24		X
	10-26	2	-	12	2			
BC2	9-8	15	10	1	9	10-26		X
LCC	9-6[a]	20	38	7	54	10-25		X
	10-27	-	-	3	-			
MC	8-23	13	16	-	-	10-2	X	
	9-20	31	57	-	-	11-9		X
NR3	9-1[a]	40	17	-	17	10-7	X	
	11-3	-	11	-	10	11-8		X
TOTAL		174	225	38	115			

[a]Sampling continued on the following day.

APPENDIX B

Mean Monthly Temperatures

e B-1. Mean monthly stream temperatures in °C (absolute minimum and maximum in parentheses) and the number of days of record for the period from May 1982 through September 1983. ND = no data available for 50% or more of the month; NS = not sampled.

	1982								1983								
	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
ms Creek	16.1 (13.1-19.3) 27[a]	ND	14.3 (12.4-18.1) 27[a]	ND	15.1 (13.4-17.7) 23[a]	13.5 (10.4-15.4) 31	9.5 (5.4-12.8) 30	8.6 (4.1-13.3) 31	7.3 (4.9-10.2) 31	8.3 (3.7-15.1) 28	8.6 (4.6-12.3) 23[a]	10.1 (5.7-15.1) 30	13.8 (10.3-17.1) 31	15.1 (11.8-17.6) 30	15.0 (13.5-18.3) 31	15.0 (13.6-18.7) 31	14.5 (13.2-15.7) 28[b]
Creek	15.0 (11.0-18.7) 27[a]	16.6 (13.4-19.5) 30	18.5 (16.0-20.0) 20[b]	ND	14.7 (10.2-17.8) 22[a]	12.1 (6.1-17.8) 31	ND	ND	2.5 (0.0-5.5) 19[a]	4.2 (0.8-7.7) 28	6.3 (2.2-12.0) 31	7.5 (2.9-12.1) 30	11.4 (8.1-14.4) 31	14.2 (9.3-17.7) 29	17.9 (14.5-20.7) 31	18.4 (15.3-20.6) 28[b]	16.1 (8.4-21.8) 28[b]
iley Creek	12.1 (7.3-14.8) 31	14.2 (11.7-15.9) 27[c]	15.9 (13.6-17.6) 31	15.7 (13.7-17.9) 31	14.0 (9.6-16.4) 30	11.3 (6.6-15.7) 31	8.1 (3.8-12.5) 30	7.8 (3.4-12.4) 31	4.4 (1.1-8.2) 31	3.9 (1.0-6.4) 28	6.0 (2.8-9.6) 31	8.5 (4.3-13.3) 30	11.9 (8.6-14.6) 31	13.8 (10.0-16.9) 30	16.7 (14.1-19.4) 31	17.0 (14.4-19.1) 27[b]	NS
t Cove Creek	11.3 (7.6-13.3) 31	13.6 (11.9-17.2) 30	15.9 (13.9-17.1) 31	15.9 (14.0-17.5) 31	13.7 (10.8-16.3) 30	10.9 (6.7-15.2) 31	8.1 (4.8-11.0) 30	6.9 (3.1-12.0) 31	3.6 (0.4-6.5) 31	3.5 (1.1-6.2) 24[a]	5.1 (2.4-8.1) 31	7.0 (2.9-12.8) 30	11.7 (9.4-13.9) 31	13.4 (10.7-15.3) 24[b]	ND	ND	NS
tahala River R1	NS	ND	ND	ND	ND	11.7 (6.2-16.8) 31	8.2 (3.3-12.7) 29	7.7 (3.6-13.3) 31	4.2 (0.5-7.5) 31	ND	7.6 (3.7-11.8) 23[a]	9.3 (3.9-14.7) 30	13.4 (9.3-16.7) 31	14.8 (10.7-18.5) 27[a]	17.2 (13.6-21.2) 31	17.4 (15.3-19.7) 17[b]	NS
R2	NS	17.3 (12.8-21.8) 30	19.5 (16.7-23.7) 29	17.4 (14.6-20.7) 31	15.6 (10.8-20.4) 20[c]	12.0 (6.0-16.7) 31	8.4 (3.7-12.4) 30	8.2 (3.6-12.2) 31	5.6 (0.9-9.0) 31	6.3 (1.9-9.8) 28	9.0 (4.7-14.4) 31	10.5 (5.3-16.4) 30	14.0 (9.5-18.8) 21[b]	14.9 (11.6-19.4) 23[a]	17.2 (13.6-21.5) 31	17.5 (14.6-21.0) 31	NS
R3	NS	12.4 (9.6-14.7) 30	14.1 (12.1-15.8) 31	13.2 (11.5-15.0) 31	12.6 (9.8-14.7) 20[b]	ND	ND	6.0 (2.8-9.2) 16[a]	3.8 (0.7-7.7) 31	4.2 (1.2-6.8) 28	5.6 (2.1-9.7) 31	7.4 (3.6-12.6) 30	11.2 (7.6-14.4) 20[b]	11.1 (8.4-13.5) 24[a]	13.6 (10.7-16.4) 31	14.2 (11.9-16.9) 31	NS

data available for consecutive days at the beginning of the month.

data available for consecutive days at the end of the month.

data available for consecutive days in the middle of the month.

APPENDIX C

Checklist of Macrobenthic Taxa

Table C-1. Checklist of macrobenthic taxa collected at the eight study sites, 1982. An "X" indicates that the taxon was taken at least once at that site. Number in parentheses is the estimated turnover ratio (see Sect. 3.6.2).

	AC	BC1	BC2	LCC	MC	NR1	NR2	NR3
Mollusca	X	X	X	X	X	X	X	X
Gastropoda	X	X	X	X	X	X	X	X
Ctenobranchiata	X					X	X	X
Pleuroceridae (3.2)	X					X	X	X
<u>Goniobasis</u> (3.2)	X					X	X	X
Pulmonata	X	X	X	X	X	X	X	X
Ancylidae	X	X	X	X	X	X	X	X
<u>Ferrissia</u> (3.2)		X	X	X	X	X	X	X
Planorbidae (3.2)							X	
Pelecypoda	X	X	X	X	X	X	X	X
Heterodonta	X	X	X	X	X	X	X	X
Sphaeriidae	X	X	X	X	X	X	X	X
<u>Sphaerium</u> (3.5)	X	X	X	X	X	X	X	X
Nematoda	X	X	X	X	X	X	X	X
Nematomorpha	X					X		
Platyhelminthes	X	X	X	X	X	X	X	X
Turbellaria	X	X	X	X	X	X	X	X
Tricladida	X	X	X	X	X	X	X	X
Planariidae	X	X	X	X	X	X	X	X
Annelida	X	X	X	X	X	X	X	X
Oligochaeta (3.4)	X	X	X	X	X	X	X	X

Table C-1 (continued)

	AC	BC1	BC2	LCC	MC	NR1	NR2	NR3
Chordata	X			X		X	X	X
Amphibia				X			X	X
Urodela				X			X	X
Osteichthyes	X					X	X	X
Teleostei	X					X	X	X
(eggs)	X							
Cottidae						X	X	X
Cottus						X	X	X
Cyprinidae							X	
Arthropoda	X	X	X	X	X	X	X	X
Insecta	X	X	X	X	X	X	X	X
Collembola	X	X						
Isotomidae	X	X						
Isotoma	X	X						
Plecoptera (5.0)	X	X	X	X	X	X	X	X
Pteronarcidae		X	X	X	X	X		X
Pteronarcys (1.2)		X	X	X	X	X		X
Peltoperlidae		X	X	X	X	X		X
Peltoperla (5.0)		X	X	X	X	X		X
Nemouridae								X
Nemoura (6.2)								X
Leuctridae	X	X	X	X	X	X	X	X
Leuctra (5.0)	X	X	X	X	X	X	X	X
Perlidae	X	X	X	X	X	X	X	X
Acroneuria (1.2)	X	X	X	X	X	X	X	X
Perlesta (1.2)		X	X	X	X	X	X	X
Perlodidae (4.4)		X	X	X	X	X		X

Table C-1 (continued)

	AC	BC1	BC2	LCC	MC	NR1	NR2	NR3
Isogenus (4.3)		X	X	X	X			X
Isoperla (4.4)		X	X	X	X	X		X
Chloroperlidae	X	X	X	X	X		X	X
Chloroperla (5.0)	X	X	X	X	X		X	X
Alloperla (5.0)		X	X	X	X			X
Odonata (3.6)	X	X	X	X	X		X	X
Cordulegasteridae	X		X	X	X			
Cordulegaster (3.6)	X		X	X	X			
Gomphidae	X	X	X	X	X		X	X
Hagenius (3.6)	X		X	X	X		X	X
Lanthus (3.6)	X	X	X	X	X			X
Agrionidae							X	
Agrion (3.6)							X	
Ephemeroptera (5.0)	X	X	X	X	X	X	X	X
Ephemeridae	X	X	X	X	X	X		
Ephemera (5.0)	X	X	X	X	X	X		
Neoephemeridae		X						
Neoephemera (5.0)		X						
Baetidae (7.8)	X	X	X	X	X	X	X	X
Baetis (10.5)	X	X	X	X	X	X	X	X
Pseudocloeon (5.0)	X	X	X	X	X	X	X	X
Heptageniidae (5.0)	X	X	X	X	X	X	X	X
Cinygmula (5.0)	X	X	X	X	X	X	X	X
Epeorus (5.0)	X	X	X	X	X	X	X	X
Heptagenia (4.0)	X	X	X	X	X	X		X
Rhithrogena (5.0)		X	X	X	X			X
Stenacron (5.0)				X			X	X
Stenonema (3.7)	X	X	X	X	X	X	X	X
Baetiscidae	X	X	X	X	X			
Baetisca (5.0)	X	X	X	X	X			

Table C-1 (continued)

	AC	BC1	BC2	LCC	MC	NR1	NR2	NR3
Ephemerellidae	X	X	X	X	X	X	X	X
Ephemerella (5.0)	X	X	X	X	X	X	X	X
Caenidae							X	
Caenis (5.0)							X	
Leptophlebiidae (3.3)	X	X	X	X	X	X	X	X
Habrophlebia (3.3)			X	X				
Paraleptophlebia (3.3)	X	X	X	X	X	X	X	X
Siphlonuridae	X	X	X	X	X	X	X	
Ameletus (5.0)			X	X	X		X	
Isonychia (5.0)	X	X	X	X	X	X	X	
Megaloptera	X	X	X	X	X	X	X	
Corydalidae (5.0)	X	X	X	X	X	X	X	
Nigronia (5.0)	X	X	X	X	X	X	X	
Sialidae		X	X	X	X	X	X	
Sialis (3.7)		X	X	X	X	X	X	
Hemiptera	X				X			
Corixidae (5.0)	X							
Gerridae					X			
Gerris (5.0)					X			
Coleoptera	X	X	X	X	X	X	X	X
Elmidae (5.0)	X	X	X	X		X	X	X
Optioservus (5.0)	X	X	X	X		X	X	X
Promoresia (5.0)	X	X	X	X		X	X	X
Hydrophilidae (5.0)				X				
Psephenidae	X	X	X	X	X	X	X	X
Ectopria (5.0)		X	X	X		X	X	X
Psephenus (5.0)	X			X	X	X	X	
Trichoptera (5.0)	X	X	X	X	X	X	X	X
Philopotamidae (5.0)	X	X	X	X	X	X	X	X

Table C-1 (continued)

	AC	BC1	BC2	LCC	MC	NR1	NR2	NR3
Dolophilodes (5.0)	X	X	X	X	X	X	X	X
Psychomyiidae (5.0)	X	X	X	X	X	X	X	X
Psychomyia (5.0)	X	X	X	X	X	X	X	X
Polycentropodidae (3.9)	X	X	X	X	X	X	X	X
Neureclepsis (3.9)			X	X				
Polycentropus (3.9)	X	X	X	X	X	X	X	X
Hydropsychidae (3.4)	X	X	X	X	X	X	X	X
Arctopsyche (3.4)				X				X
Cheumatopsyche (2.9)	X	X	X	X	X	X	X	X
Diplectrona (3.4)			X	X	X			X
Hydropsyche (3.8)	X	X	X	X	X	X	X	X
Rhyacophilidae (5.0)	X	X	X	X	X	X	X	X
Rhyacophila (5.0)	X	X	X	X	X	X	X	X
Glossosomatidae (5.0)	X	X	X	X	X	X		X
Agapetus (5.0)	X	X	X	X	X	X		X
Glossosoma (5.0)	X	X	X	X	X	X		X
Matrioptila (5.0)								X
Hydroptilidae	X	X		X		X	X	X
Hydroptila (5.0)	X	X		X		X	X	X
Oxyethira (5.0)	X							
Brachycentridae	X	X	X			X	X	X
Brachycentrus (4.6)		X	X				X	X
Micrasema (4.6)	X	X	X			X	X	X
Limnephilidae (5.0)	X	X	X	X	X	X	X	X
Goera (5.0)	X	X	X	X	X	X		X
Neophylax (5.0)		X		X				X
Pycnopsyche (5.0)		X		X	X	X	X	X
Lepidostomatidae		X		X			X	

Table C-1 (continued)

	AC	BC1	BC2	LCC	MC	NR1	NR2	NR3
Lepidostoma (4.5)		X		X			X	
Sericostomatidae (5.0)		X	X	X				X
Fattigia (5.0)		X	X	X				X
Odontoceridae								X
Psilotreta (5.0)								X
Leptoceridae (5.0)		X	X	X		X	X	X
Ceraclea (7.0)							X	
Leptocerus (5.0)						X		
Setodes (5.0)		X	X					
Diptera	X	X	X	X	X	X	X	X
Simuliidae (13.3)		X	X	X		X	X	X
Simulium (13.3)		X	X	X		X	X	X
Blephariceridae		X	X		X			X
Blepharicera (5.0)		X	X		X			X
Tipulidae (5.0)	X	X	X	X	X	X	X	X
Antocha (3.9)	X	X	X	X	X	X	X	X
Dicranota (3.3)	X	X	X	X	X		X	X
Hexatoma/*Eriocera*(5.0)	X	X	X	X	X	X	X	X
Hexatominae[a] (5.0)		X	X	X	X			X
Ormosia (5.0)								X
Penthoptera (5.0)				X				
Tipula (5.0)	X	X	X	X	X	X	X	X
Tanyderidae		X	X	X	X			
Protoplasa (5.0)		X	X	X	X			
Ceratopogonidae		X	X		X			X
Palpomyia (5.3)		X	X		X			X
Chironomidae (5.0)	X	X	X	X	X	X	X	X
Chironominae[a] (5.9)		X	X	X				
Microtendipes) (5.9)		X						
Orthocladiinae[a] (5.9)		X	X	X				

Table C-1 (continued)

	AC	BC1	BC2	LCC	MC	NR1	NR2	NR3
Polypedilum (5.9)			X					
Tanypodinae[a] (4.5)	X	X	X	X	X	X	X	X
Athericidae		X	X	X	X	X		X
Atherix (5.0)		X	X	X	X	X		X
Tabanidae (4.5)	X				X		X	
Tabanus (4.5)	X				X			
Empididae (2.5)	X	X	X	X	X	X	X	X
Hemerodromia (2.5)	X	X	X	X	X	X	X	X
Dolichopodidae (5.0)	X							
Arachnida				X				
Araneida (terrestrial)				X				
Arachnoidea		X					X	
Parasitengona		X					X	
Crustacea	X	X	X	X	X			X
Decapoda	X	X	X	X	X			X
Astacidae	X	X	X	X	X			X
Cambarus		X						
Cambarinae[a]	X	X	X	X	X			X

[a]Unidentified genera.

APPENDIX D

Trout Stomach Contents

Table D-1. Total number, percent of total, and frequency of occurrence of aquatic and terrestrial organisms found in the stomachs of 171 rainbow trout and 120 brown trout during 1982.

Taxon	Rainbow trout			Brown trout		
	Total[a] number	Percent[b] of total	Frequency[c]	Total[a] number	Percent[b] of total	Frequency[c]
Ephemeroptera						
Baetis	9	0.58	7	19	2.50	6
Pseudocleon	4	0.26	4	1	0.13	1
Baetidae	23	1.48	16	16	2.11	8
Baetisca	3	0.19	3	1	0.13	1
Ephemerella	31	2.00	15	7	0.92	7
Ephemera	1	0.06	1	0	0.00	0
Epeorus	5	0.32	4	2	0.26	2
Stenonema	12	0.77	7	10	1.32	5
Heptageniidae	256	16.52	81	42	5.53	24
Neoephemera	1	0.06	1	0	0.00	0
Isonychia	28	1.81	18	6	0.79	6
Unidentified	25	1.61	9	14	1.84	4
TOTAL	398	25.68		118	15.55	
Trichoptera						
Brachycentrus	13	0.84	3	11	1.45	8
Micrasema	4	0.26	3	3	0.39	1
Glossosoma	9	0.58	6	19	2.50	15
Agapetus	4	0.26	1	0	0.00	0
Glossosomatinae	0	0.00	0	4	0.53	2
Hydropsyche	11	0.71	9	3	0.39	3
Cheumatopsyche	3	0.19	2	0	0.00	0
Hydropsychidae	25	1.61	17	11	1.45	6
Lepidostoma	1	0.06	1	8	1.05	2
Apatania	0	0.00	0	4	0.53	2
Goera	1	0.06	1	4	0.53	2
Limnephilidae	39	2.52	4	0	0.00	0
Psilotreta	1	0.06	1	4	0.53	2
Dolophilodes	16	1.03	12	5	0.66	3
Polycentropus	1	0.06	1	0	0.00	0
Psychomyia	2	0.13	2	2	0.26	2
Lype	1	0.06	1	0	0.00	0
Rhyacophila	4	0.26	4	2	0.26	2
Unidentified	52	3.35	29	26	3.42	14
TOTAL	187	12.06		106	13.97	
Plecoptera						
Chloroperlidae	3	0.19	3	2	0.26	2
Leuctra	6	0.39	5	7	0.92	5
Peltoperla	6	0.39	5	0	0.00	0
Acroneuria	8	0.52	6	5	0.66	4
Perlidae	18	1.16	16	9	1.18	2
Isoperla	1	0.06	1	8	1.05	3
Perlodidae	3	0.19	3	1	0.13	1
Pteronarcys	3	0.19	2	1	0.13	1
Unidentified	28	1.81	21	9	1.18	7
TOTAL	76	4.90		42	5.53	

Table D-1 (continued)

Taxon	Rainbow trout: Total[a] number	Rainbow trout: Percent[b] of total	Rainbow trout: Frequency[c]	Brown trout: Total[a] number	Brown trout: Percent[b] of total	Brown trout: Frequency[c]
Diptera						
Blepharicera	1	0.06	1	0	0.00	0
Palpomyia	3	0.19	3	0	0.00	0
Tanypodinae	3	0.19	3	0	0.00	0
Chironomidae	51	3.29	29	11	1.45	8
Hemerodromia	2	0.13	2	0	0.00	0
Empedidae	3	0.19	1	2	0.26	1
Simulium	0	0.00	0	1	0.13	1
Simuliidae	7	0.45	5	2	0.26	2
Tetanoceridae	8	0.52	3	10	1.32	6
Antocha	6	0.39	6	5	0.66	5
Tipulidae	11	0.71	7	3	0.39	3
TOTAL	96	6.19		34	4.48	
Coleoptera						
Elmidae	7	0.45	6	7	0.92	3
Hydrophilidae	1	0.06	1	1	0.13	1
Mycetophilidae	1	0.06	1	0	0.00	0
Ectopria	2	0.13	2	0	0.00	0
Psephenus	7	0.45	6	0	0.00	0
Unidentified	4	0.26	4	0	0.00	0
TOTAL	22	1.42		8	1.05	
Hemiptera						
Rhagovelia	2	0.13	1	0	0.00	0
Hydrometridae	1	0.06	1	0	0.00	0
Unidentified	2	0.13	2	1	0.13	1
TOTAL	5	0.32		1	0.13	
Other aquatic						
Collembola	2	0.13	2	1	0.13	1
Odonata	3	0.19	3	1	0.13	1
Lepidoptera	2	0.13	2	0	0.00	1
Nigronia	1	0.06	1	0	0.00	1
Oligochaeta	1	0.06	1	0	0.00	0
Parasitengona	1	0.06	1	2	0.26	2
Cambarinae	5	0.32	4	4	0.53	4
Astacidae	6	0.39	6	5	0.66	5
Urodela	1	0.06	1	1	0.13	1
Goniobasis	1	0.06	1	9	1.18	7
Ferrissia	1	0.06	1	0	0.00	0
Planorbidae	0	0.00	0	1	0.13	1
Nematoda	17	1.10	11	37	4.87	19
Semotilus	1	0.06	1	0	0.00	0
Cyprinidae	3	0.19	2	5	0.66	5
Cottus	2	0.13	2	2	0.26	2
Trout eggs	20	1.29	1	0	0.00	0
Unidentified fish	1	0.06	1	2	0.26	2
Unidentified insect	2	0.13	1	0	0.00	0
TOTAL	70	4.52		70	9.22	

Table D-1 (continued)

Taxon	Rainbow trout Total[a] number	Rainbow trout Percent[b] of total	Rainbow trout Frequency[c]	Brown trout Total[a] number	Brown trout Percent[b] of total	Brown trout Frequency[c]
Terrestrials						
Asilidae	1	0.06	1	0	0.00	0
Phoridae	2	0.13	1	0	0.00	0
Diptera	166	10.71	42	102	13.42	14
Formicidae	165	10.65	32	93	12.24	8
Ichneumonidae	2	0.13	2	2	0.26	2
Hymenoptera	41	2.65	24	19	2.50	9
Aphididae	7	0.45	5	7	0.92	3
Membracidae	6	0.39	1	2	0.26	1
Homoptera	73	4.71	27	35	4.61	10
Tingidae	2	0.13	2	0	0.00	0
Hemiptera	14	0.90	10	6	0.79	3
Orthoptera	28	1.81	13	70	9.21	8
Psocoptera	32	2.06	7	0	0.00	0
Neuroptera	1	0.06	1	0	0.00	0
Lepidoptera	19	1.23	13	10	1.32	8
Curculionidae	27	1.74	14	5	0.66	5
Mycetophilidae	3	0.19	1	2	0.26	1
Rhysodidae	1	0.06	1	0	0.00	0
Elateridae	3	0.19	3	0	0.00	0
<u>Popillia</u>	13	0.84	4	0	0.00	0
Scarabidae	1	0.06	1	0	0.00	0
Coleoptera	60	3.87	32	14	1.84	9
Chilopoda	3	0.19	3	0	0.00	0
Araneida	23	1.48	16	13	1.71	7
Arachnida	2	0.13	1	0	0.00	0
Unidentified	1	0.06	1	0	0.00	0
TOTAL	696	44.90		380	52.63	
GRAND TOTAL	1550			759		

[a]Total number collected in all rainbow trout or brown trout stomachs.

[b]Percent of the total number of food items (aquatic and terrestrial combined) represented by that taxon.

[c]Total number of rainbow trout or brown trout stomachs which contained that taxon.

APPENDIX E

Habitat Suitability Curves for Spawning and Incubation

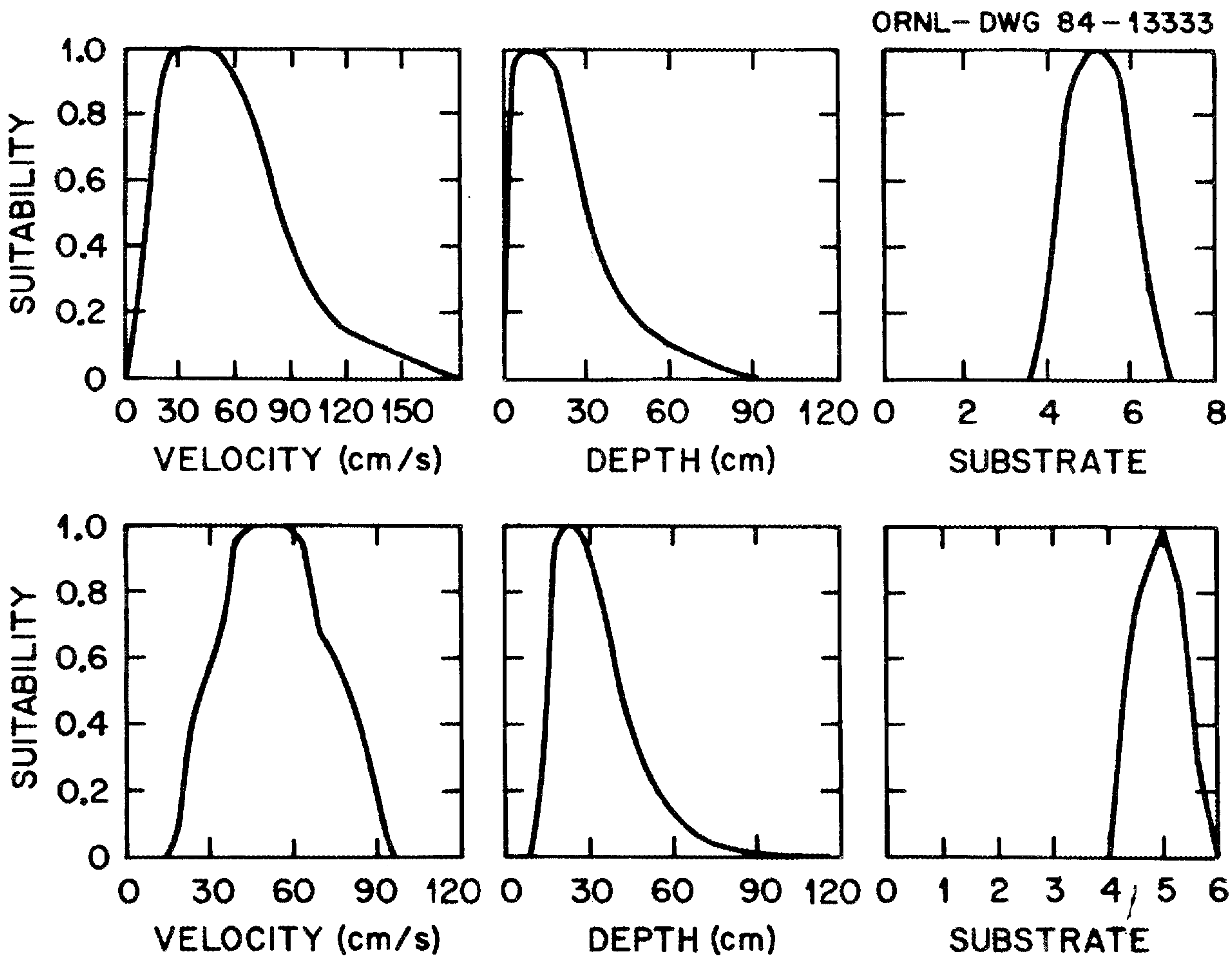

Fig. E-1. Habitat suitability curves for incubation (top) and spawning (bottom) of rainbow trout (from Bovee 1978). Curves for fry, juvenile, and adult life stages are shown in Fig. 4-5.

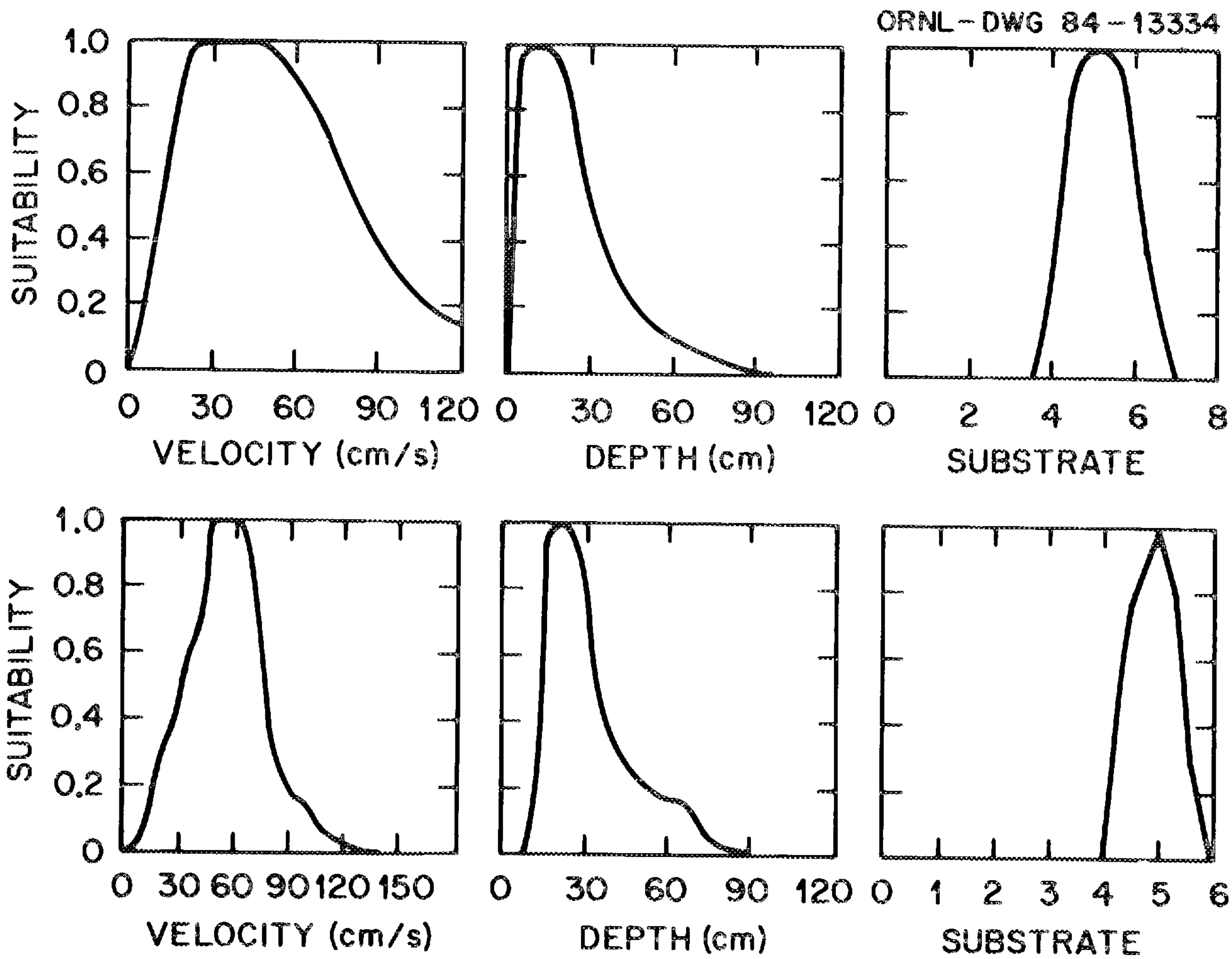

Fig. E-2. Habitat suitability curves for incubation (top) and spawning (bottom) of brown trout (from Bovee 1978). Curves for fry, juvenile, and adult life stages are shown in Fig. 4-6.

APPENDIX F

Habitat Response Curves

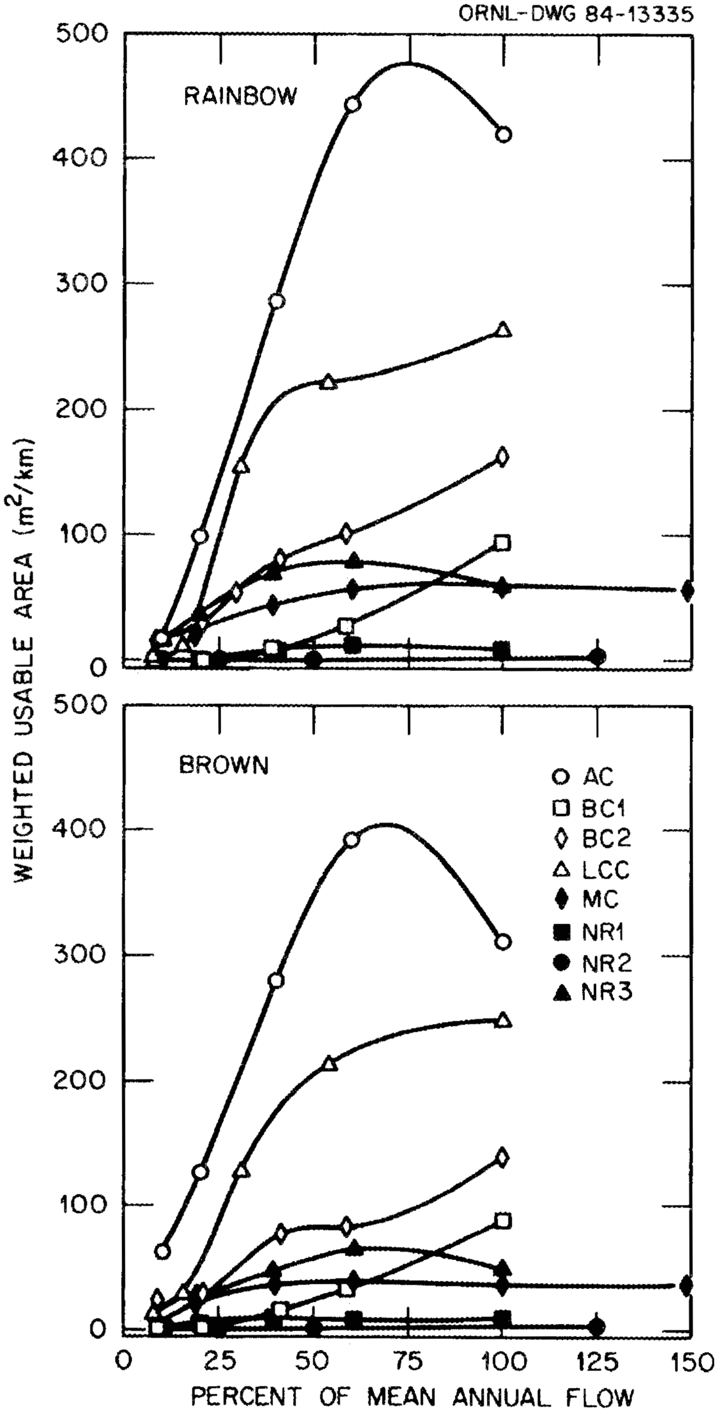

Fig. F-1. Weighted usable area vs flow for rainbow and brown trout spawning.

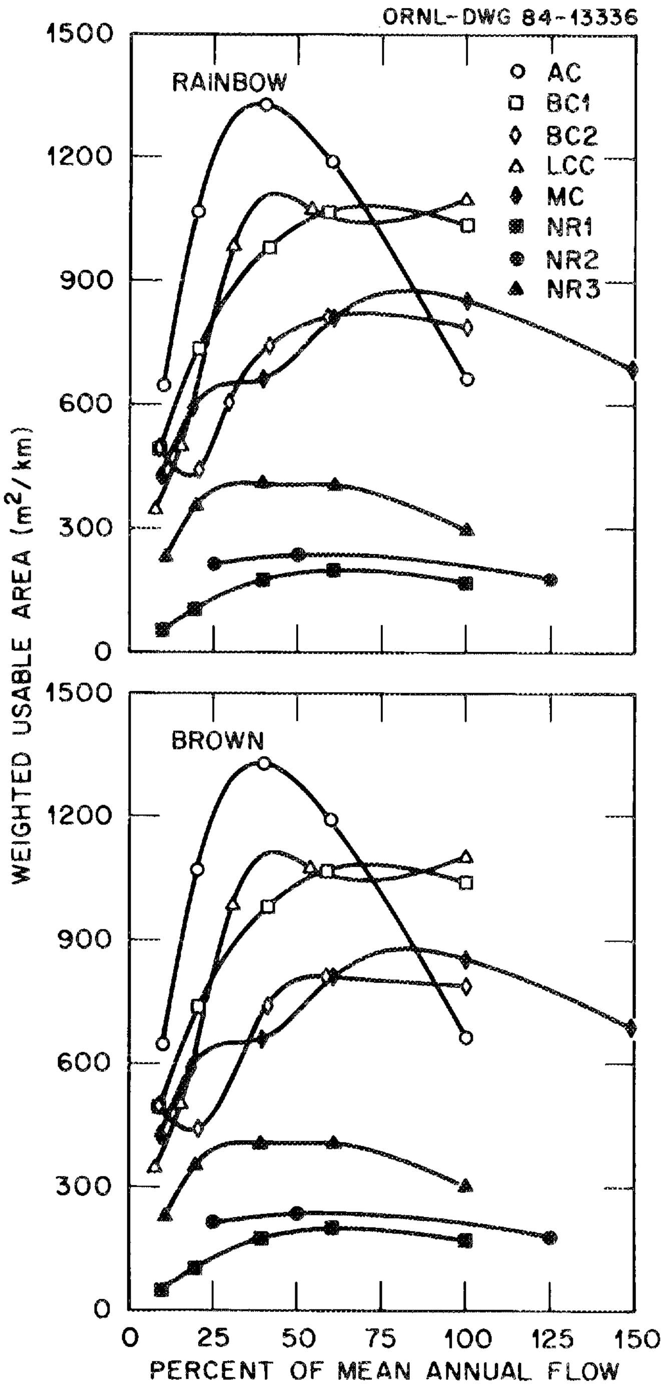

Fig. F-2. Weighted usable area vs flow for rainbow and brown trout incubation.

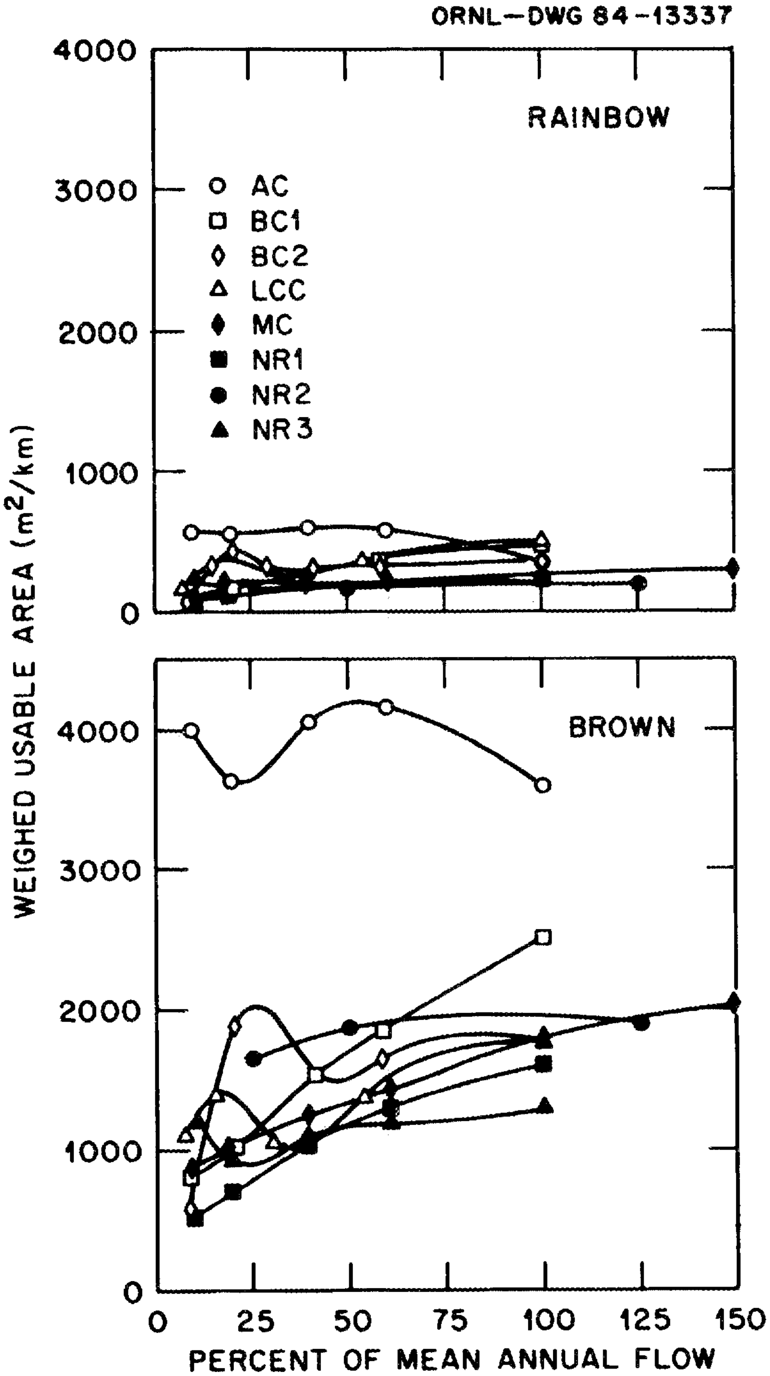

Fig. F-3. Weighted usable area vs flow for rainbow and brown trout fry.

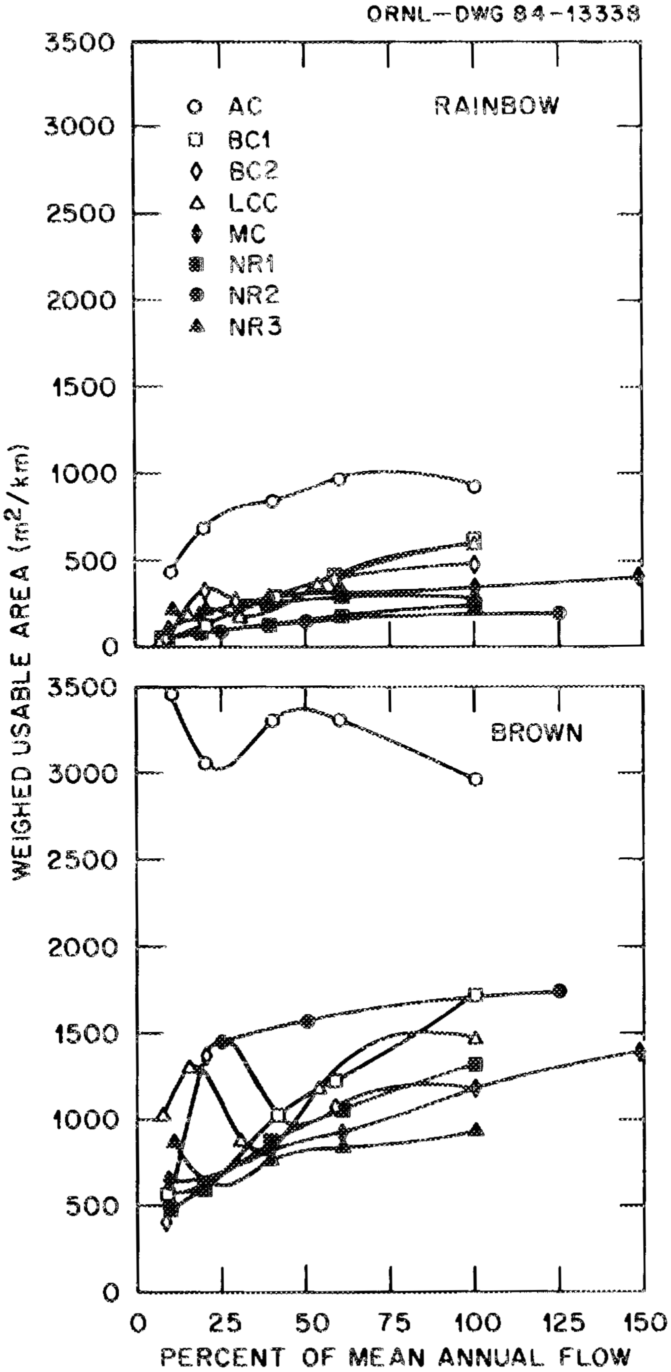

Fig. F-4. Weignted usable area vs flow for rainbow and brown trout juveniles.

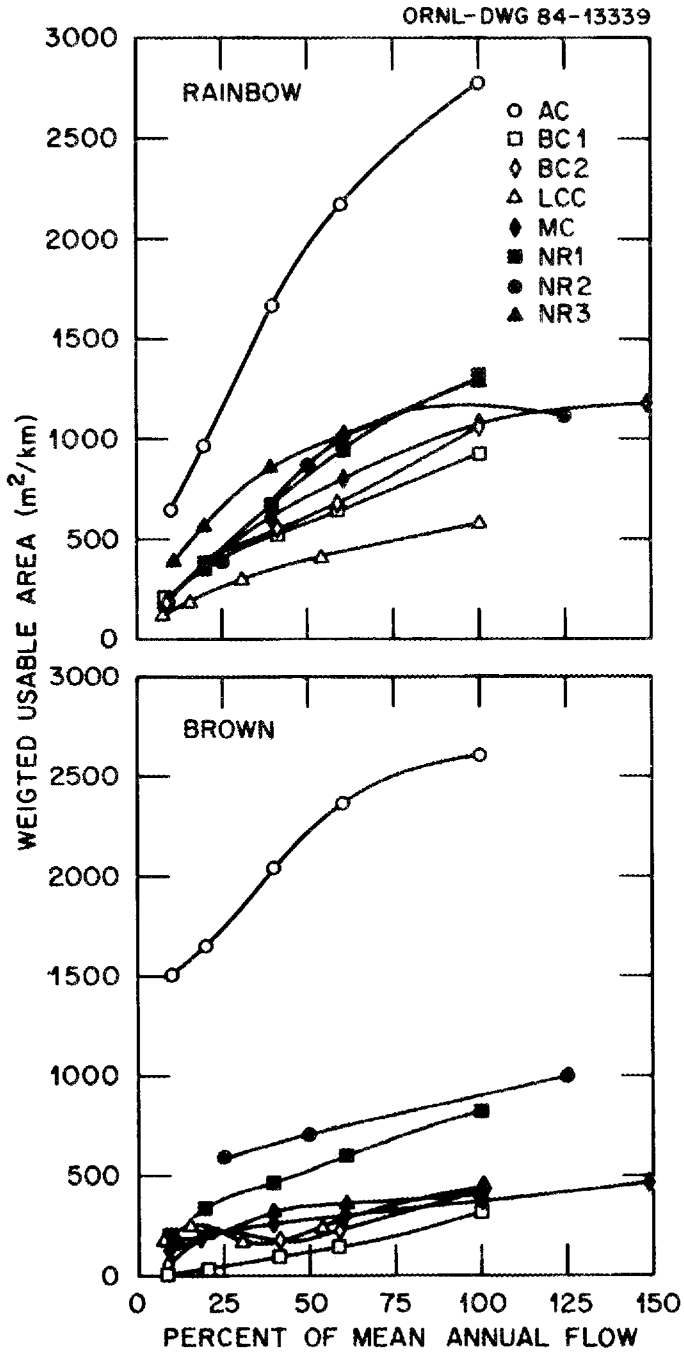

Fig. F-5. Weighted usable area vs flow for rainbow and brown trout adults.

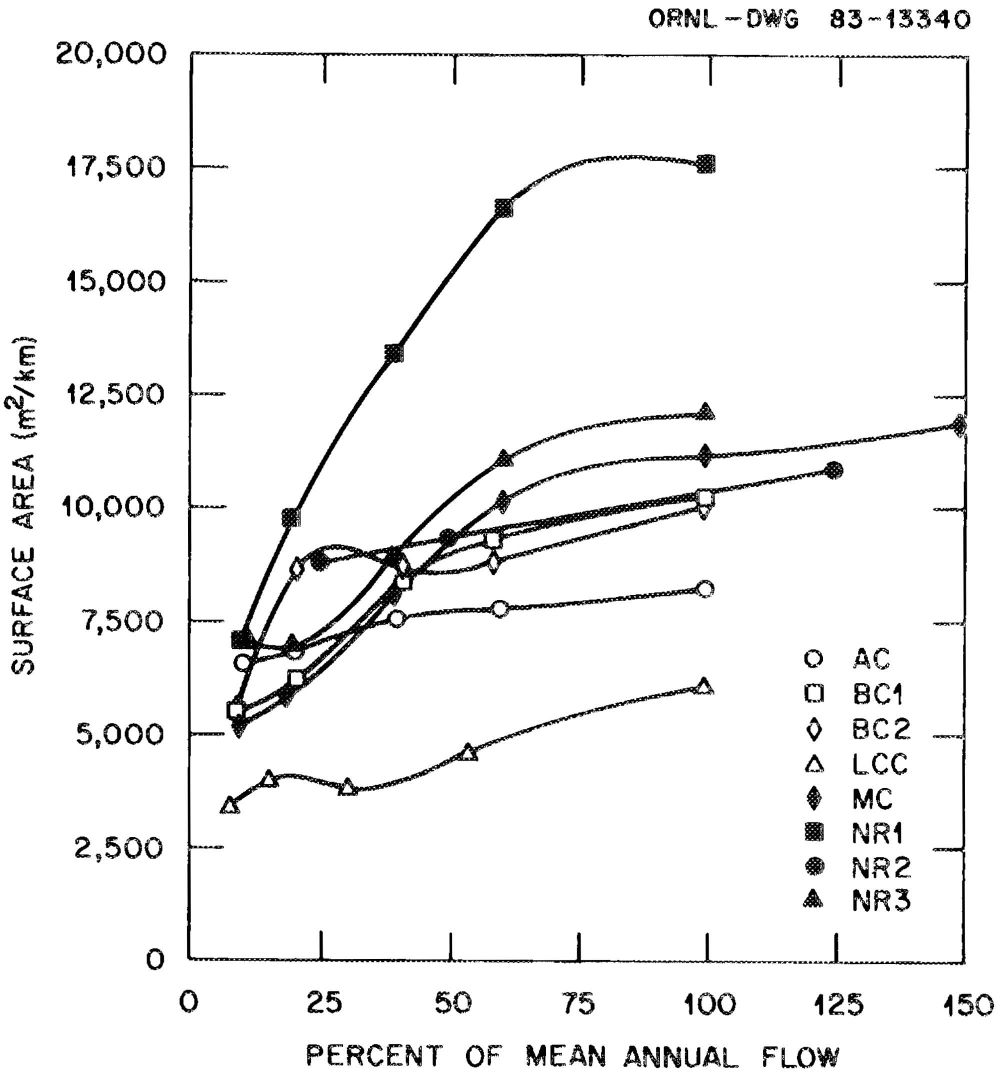

Fig. F-6. Total wetted surface area (m^2/km) vs flow.

APPENDIX G

Annual Hydrographs, 1980-1983

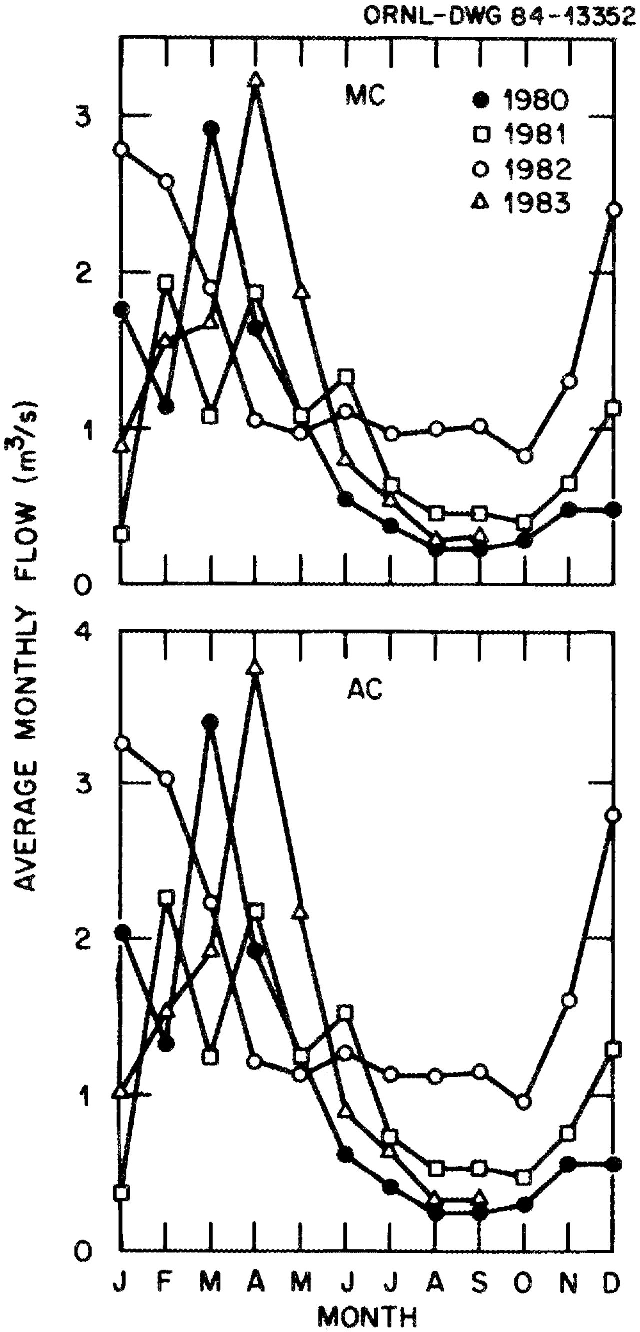

Fig. G-1. Annual hydrographs at sites MC and AC, 1980-1983.

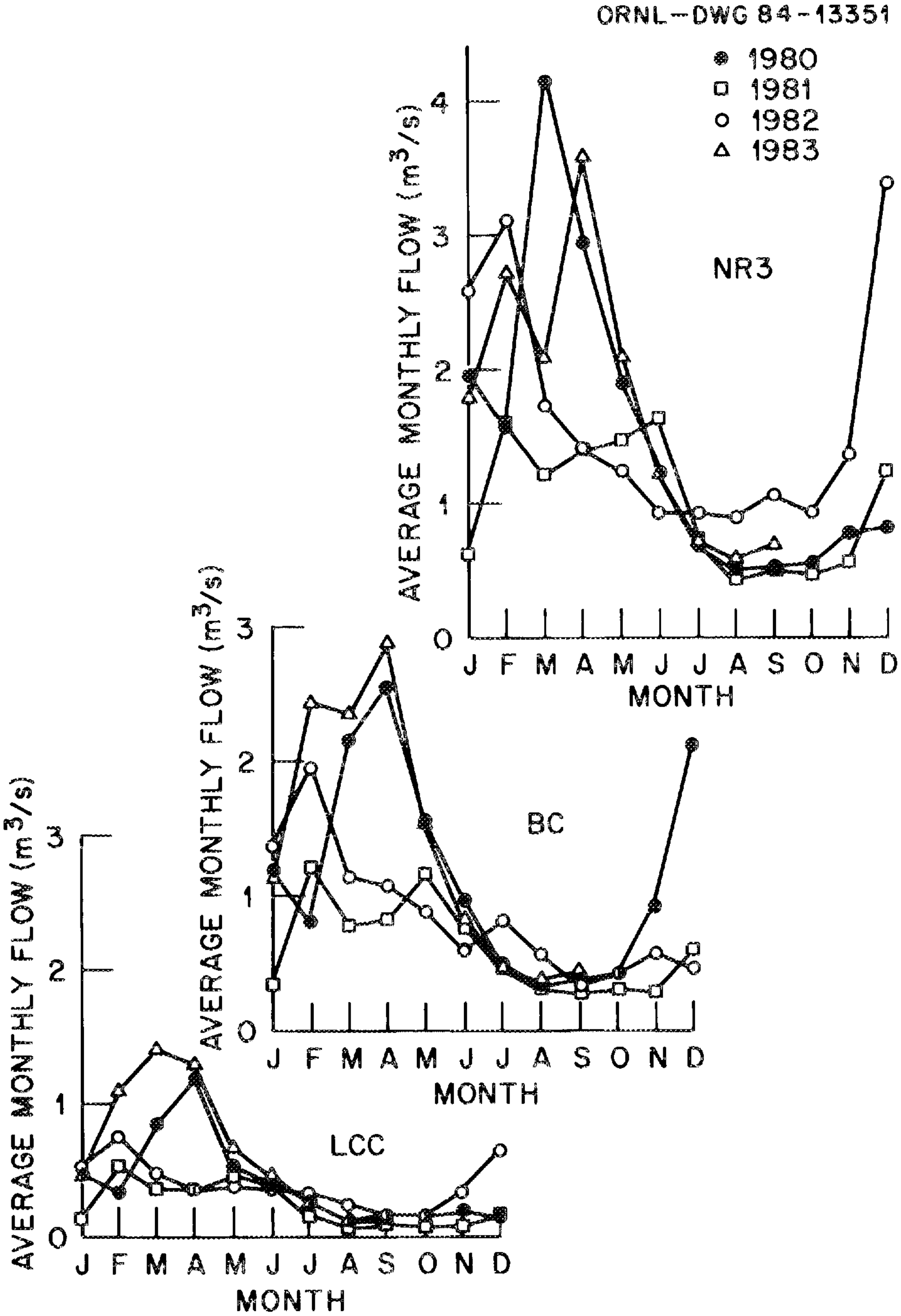

Fig. G-2. Annual hydrographs at sites NR3, BC, and LCC, 1980-1983.

APPENDIX H

Annual Habitat Regimes, 1980-1983

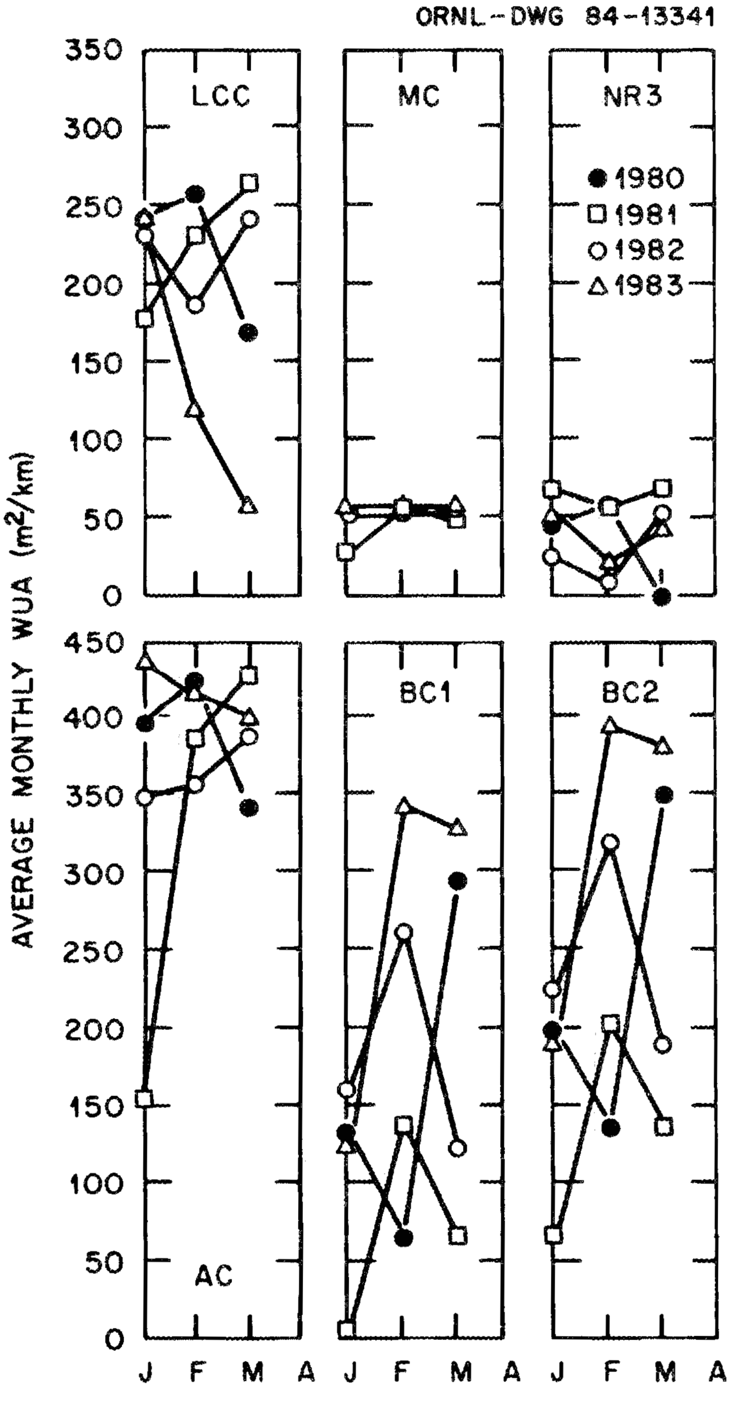

Fig. H-1. Annual habitat regimes for rainbow trout spawning based on average monthly flows, 1980-1983.

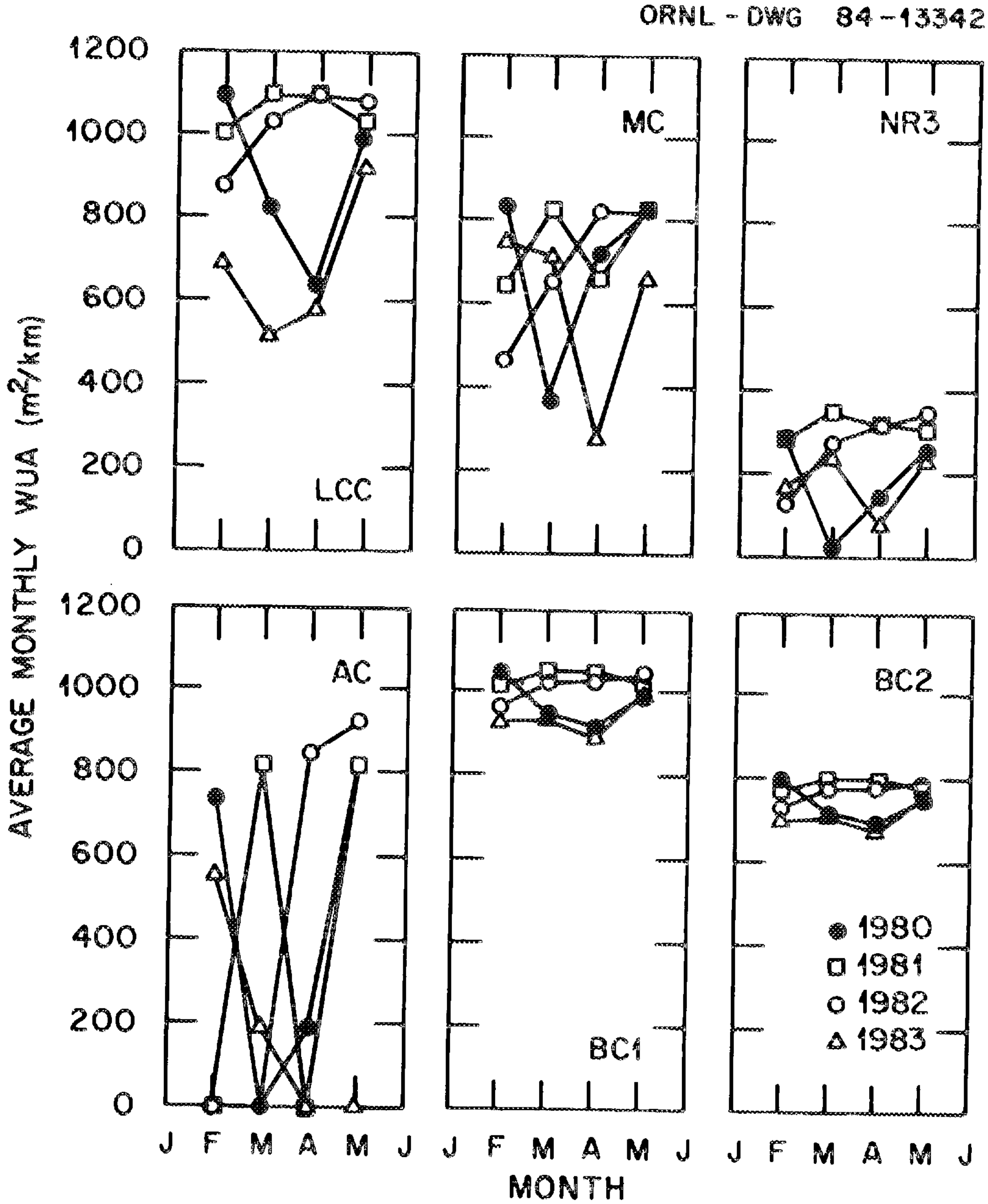

Fig. H-2. Annual habitat regimes for rainbow trout incubation based on average monthly flows, 1980-1983.

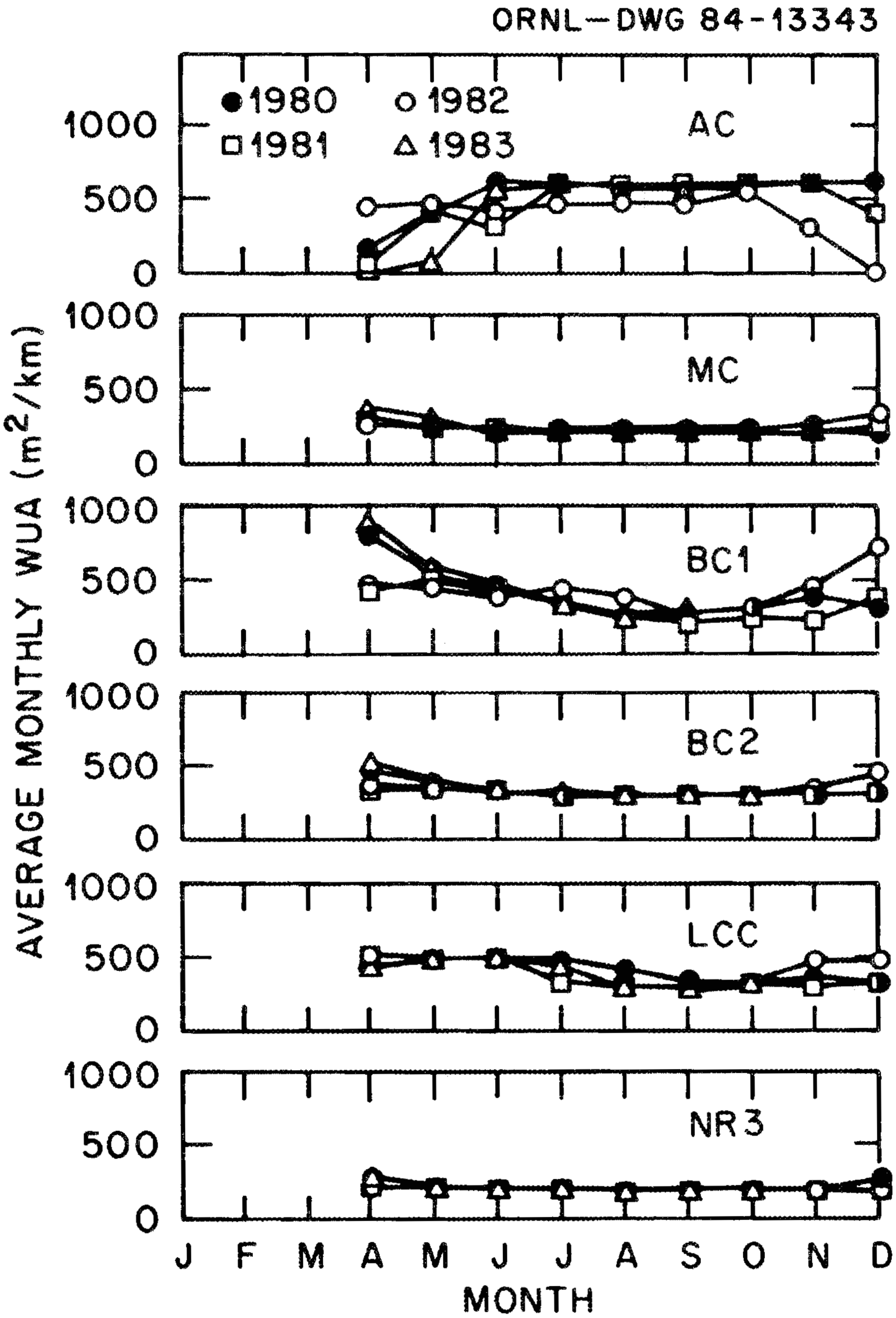

Fig. H-3. Annual habitat regimes for rainbow trout fry based on average monthly flows, 1980-1983.

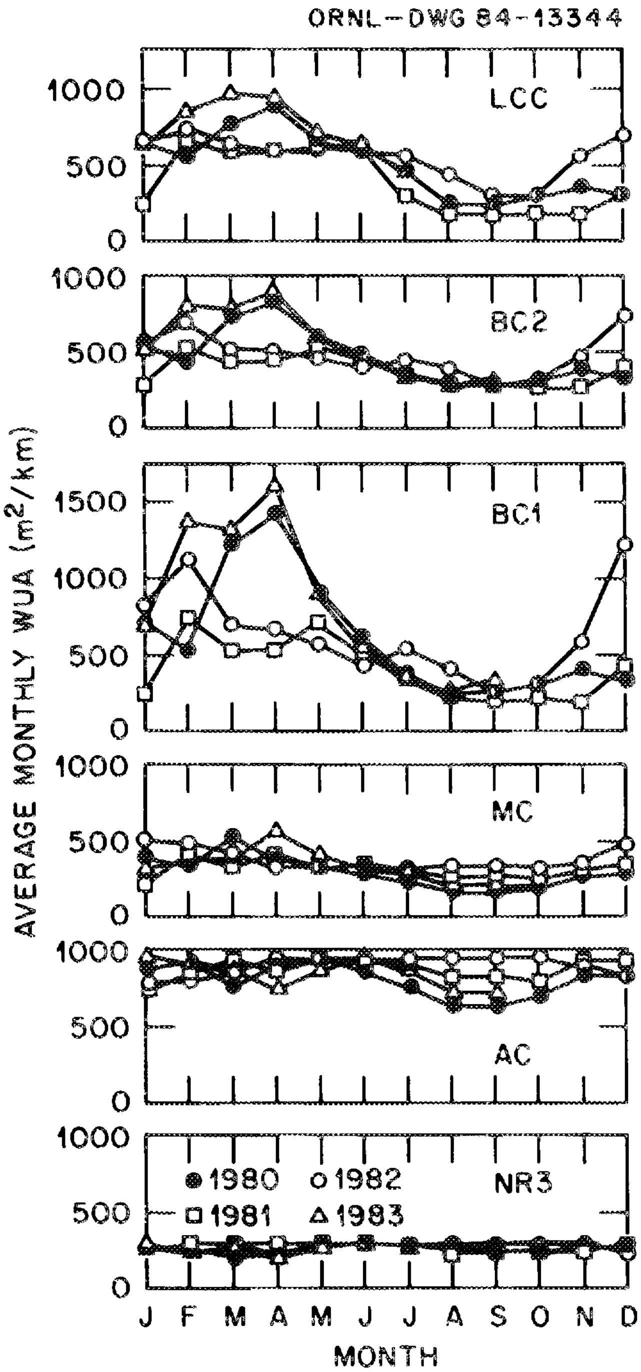

Fig. H-4. Annual habitat regimes for juvenile rainbow trout based on average monthly flows, 1980-1983.

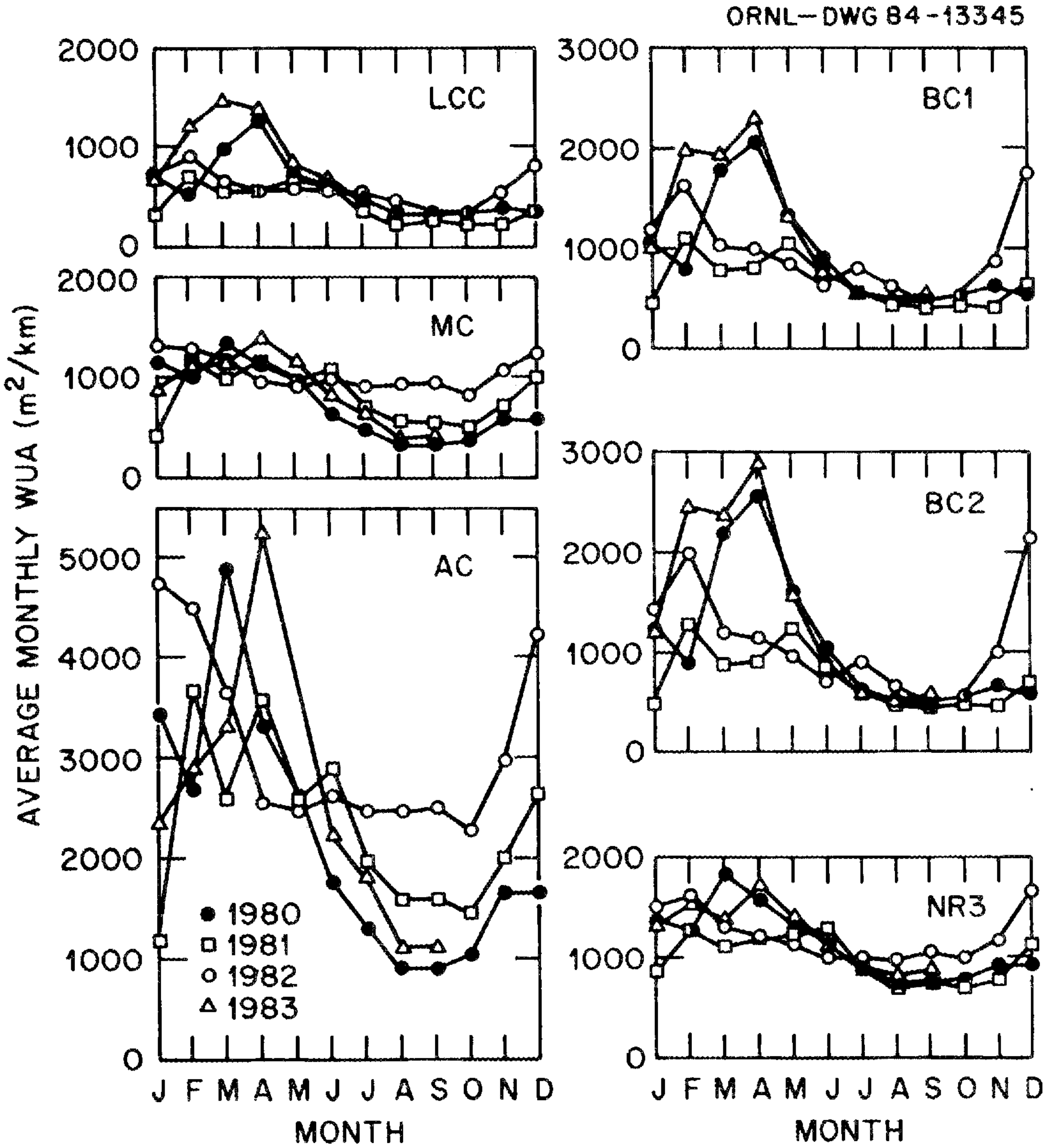

Fig. H-5. Annual habitat regimes for adult rainbow trout based on average monthly flows, 1980-1983.

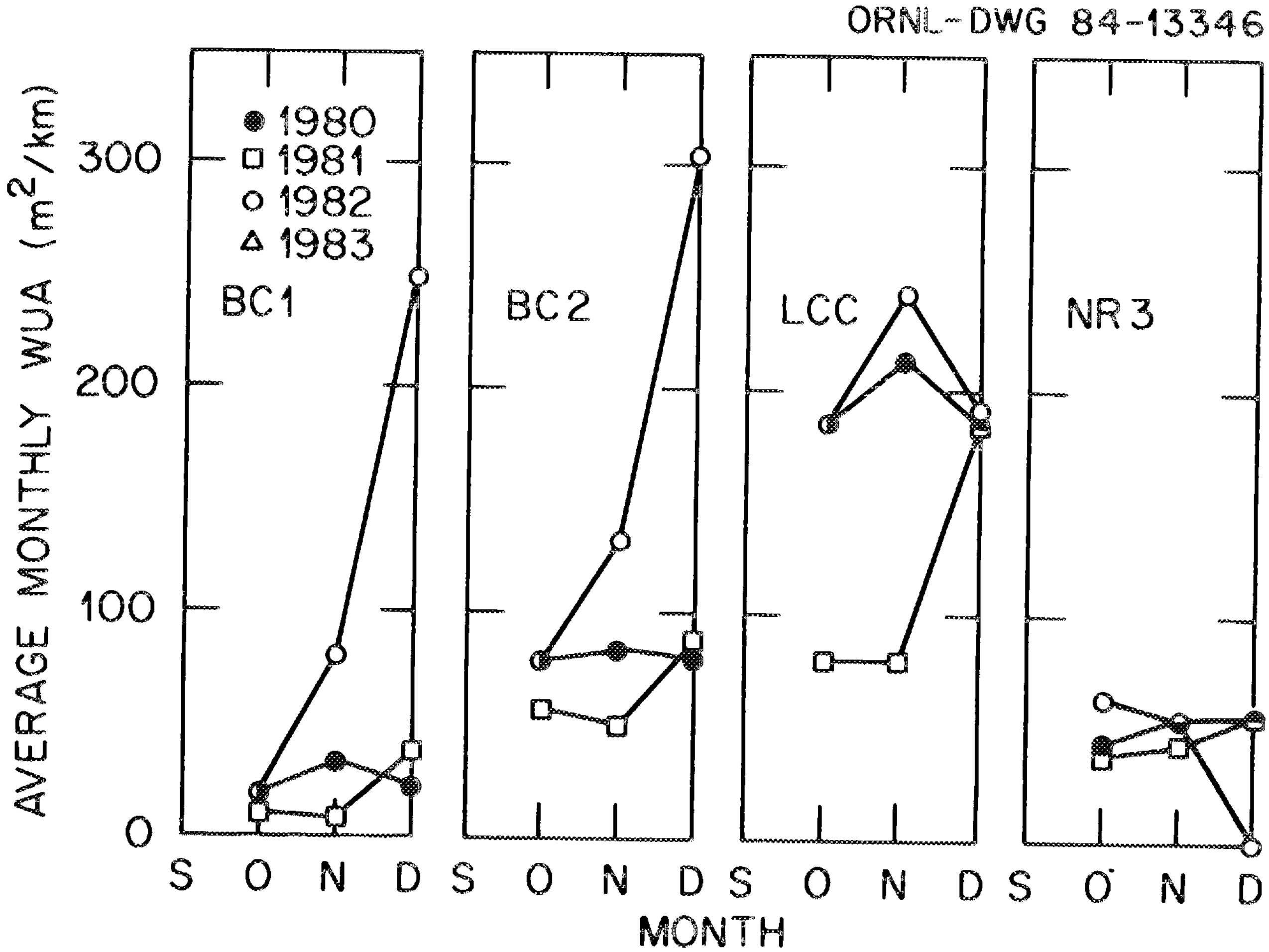

Fig. H-6. Annual habitat regimes for brown trout spawning based on average monthly flows, 1980-1983.

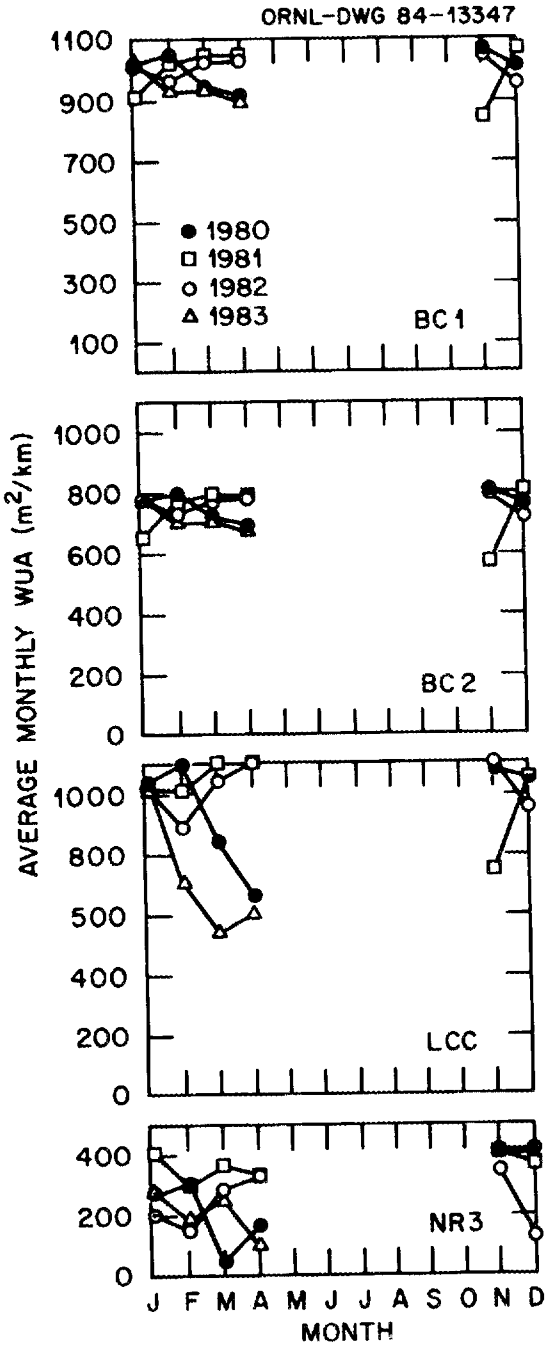

Fig. H-7. Annual habitat regimes for brown trout incubation based on average monthly flows, 1980-1983.

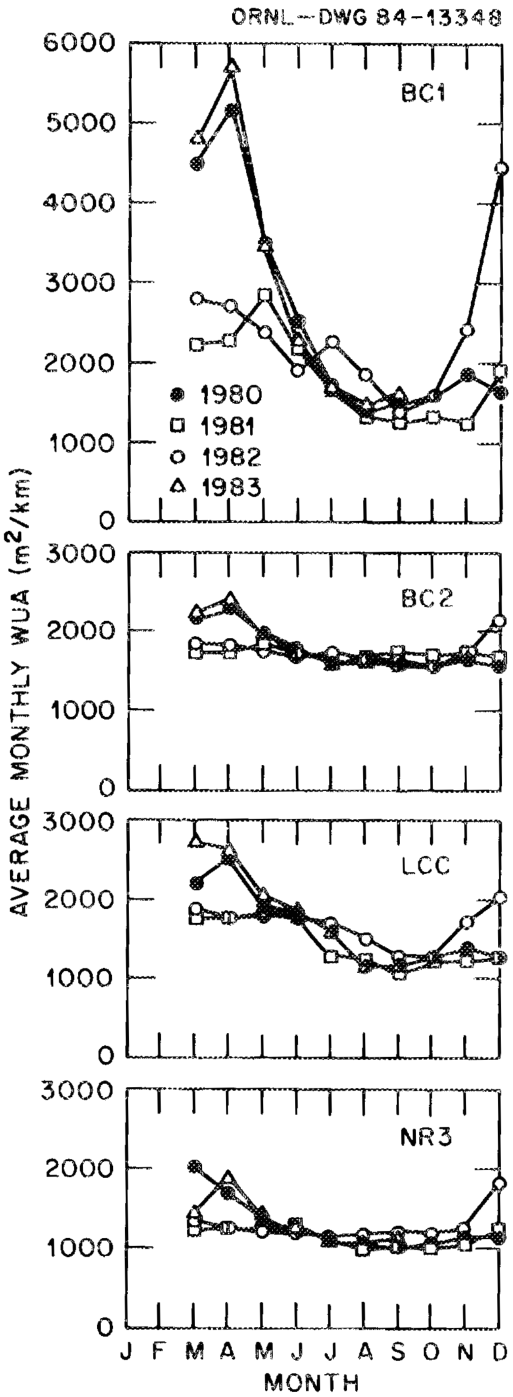

Fig. H-8. Annual habitat regimes for brown trout fry based on average monthly flows, 1980-1983.

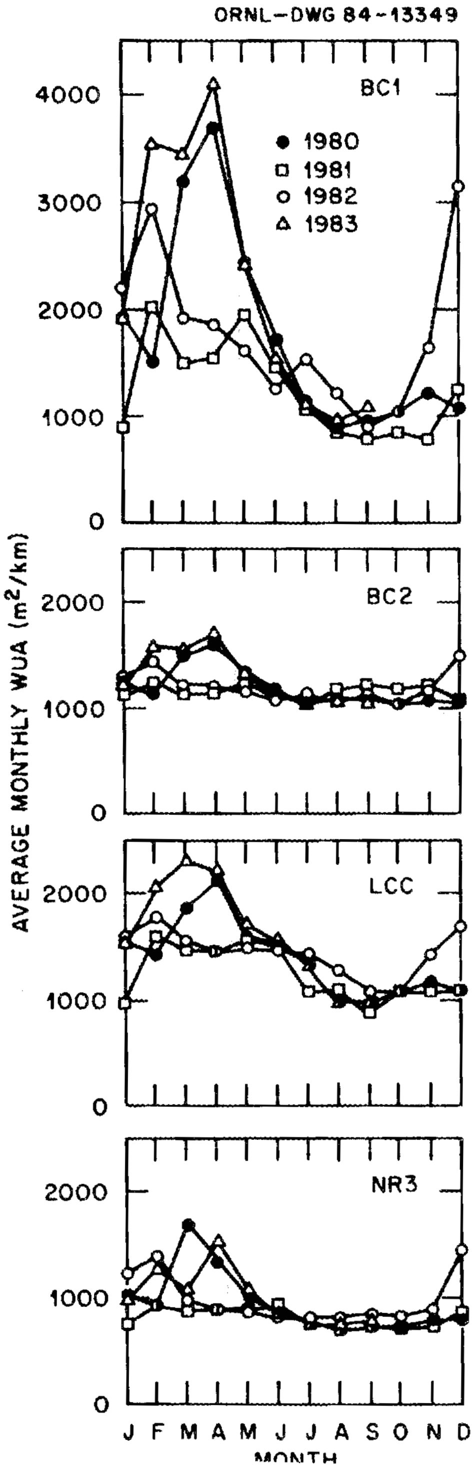

Fig. H-9. Annual habitat regimes for juvenile brown trout based on average monthly flows, 1980-1983.

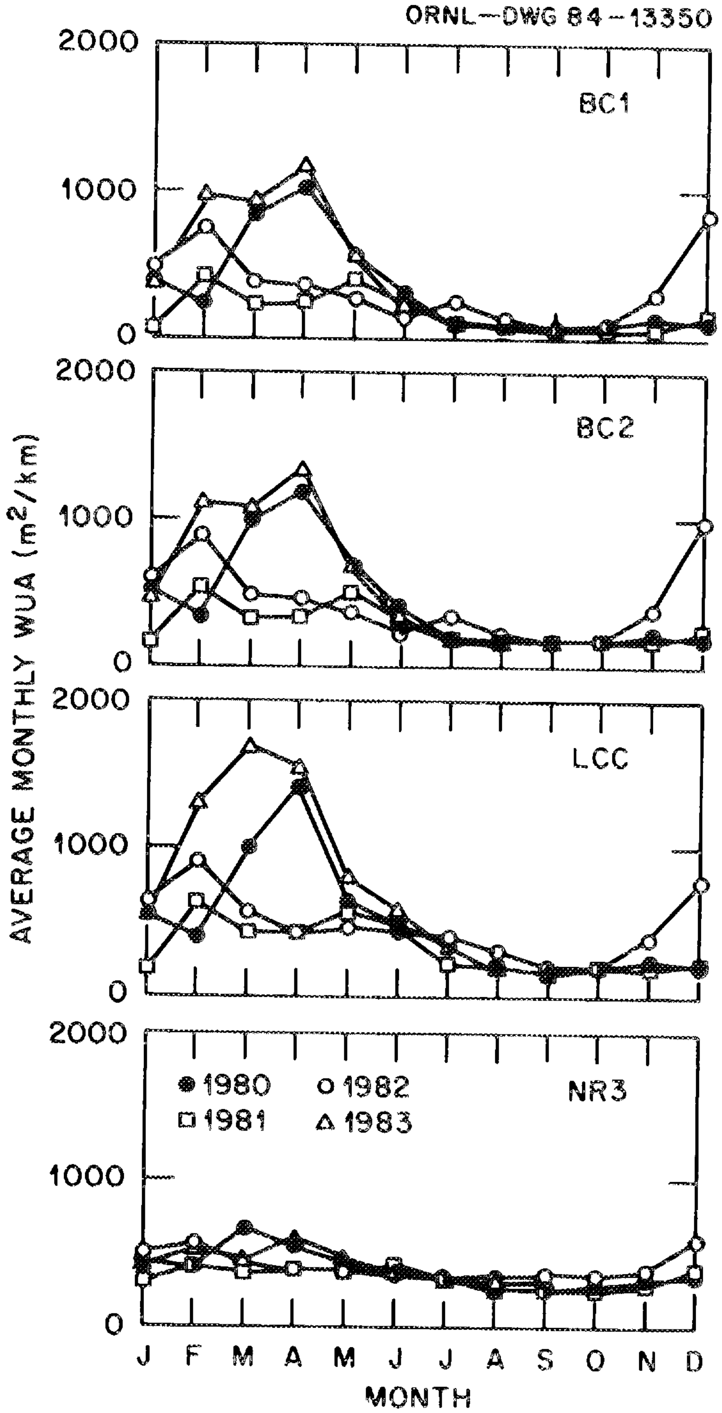

Fig. H-10. Annual habitat regimes for adult brown trout based on average monthly flows, 1980-1983.

APPENDIX I

Invertebrate Drift Taxa

Table I-1. Total number, percent of total, mean density, and frequency of occurrence of aquatic and terrestrial organisms found in 54 drift samples during 1982. All sites and dates pooled.

Taxon	Total number collected	Percent of total	Mean density[a] (number per 1000 m^3)	Frequency[b]
Ephemeroptera				
Baetis	15	2.0	0.60	11
Baetis exuviae	3	0.4	0.12	3
Pseudocleon	14	1.8	0.56	10
Pseudocleon exuviae	1	0.1	0.04	1
Baetidae	2	0.3	0.08	2
Baetidae exuviae	21	2.8	0.84	5
Baetisca exuviae	1	0.1	0.04	1
Ephemerella	19	2.5	0.76	6
Ephemerella exuviae	15	2.0	0.60	11
Epeorus	15	2.0	0.60	5
Epeorus exuviae	4	0.5	0.16	4
Stenonema	5	0.7	0.20	5
Stenonema exuviae	2	0.3	0.08	2
Cinygmula	2	0.3	0.08	2
Cinygmula adult	1	0.1	0.04	1
Heptageniidae	3	0.4	0.12	1
Heptageniidae exuviae	7	0.9	0.28	5
Isonychia exuviae	2	0.3	0.08	2
Paraleptophlebia	4	0.5	0.16	2
Paraleptophlebia exuviae	3	0.4	0.12	1
Unidentified	1	0.1	0.04	1
Total	140	18.5		
Mean			0.27	
Plecoptera				
Chloroperla	2	0.3	0.08	2
Chloroperlidae	5	0.7	0.20	4
Chloroperlidae exuviae	1	0.1	0.04	1
Leuctra	9	1.2	0.36	7
Leuctra exuviae	1	0.1	0.04	1
Peltoperla	6	0.8	0.24	5
Peltoperla exuviae	19	2.5	0.76	7
Acroneuria	3	0.4	0.12	3
Acroneuria exuviae	3	0.4	0.12	1
Perlidae exuviae	1	0.1	0.04	1
Isoperla	8	1.1	0.32	6
Isoperla exuviae	3	0.4	0.12	2

Table I-1 (continued)

Taxon	Total number collected	Percent of total	Mean density[a] (number per 1000 m^3)	Frequency[b]
Perlodidae	3	0.4	0.12	2
Pteronarcys exuviae	1	0.1	0.04	1
Taeniopteryx	5	0.7	0.20	3
Unidentified	1	0.1	0.04	1
Total	71	9.4		
Mean			0.18	
Trichoptera				
Brachycentrus	7	0.9	0.28	6
Micrasema	5	0.7	0.20	4
Glossosoma exuviae	1	0.1	0.04	1
Glossosomatidae exuviae	1	0.1	0.04	1
Hydropsyche	3	0.4	0.12	2
Cheumatopsyche	7	0.9	0.28	6
Cheumatopsyche exuviae	1	0.1	0.04	1
Diplectrona	1	0.1	0.04	1
Hydropsychidae	2	0.3	0.08	2
Hydropsychidae exuviae	4	0.5	0.16	2
Pycnopsyche	4	0.5	0.16	2
Limnephilidae	2	0.3	0.08	2
Dolophilodes	7	0.9	0.28	7
Dolophilodes exuviae	4	0.5	0.16	3
Psychomyia	1	0.1	0.04	1
Lype	1	0.1	0.04	1
Rhyacophila	9	1.2	0.36	9
Lepidostoma	3	0.4	0.12	3
Leptoceridae	1	0.1	0.04	1
Unidentified	9	1.2	0.36	3
Unidentified exuviae	20	2.6	0.80	11
Unidentified adult	1	0.1	0.04	1
Total	94	12.4		
Mean			0.17	
Coleoptera				
Optioservus	1	0.1	0.04	1
Promoresia	3	0.4	0.12	3
Elmidae	1	0.1	0.04	1
Hydrophilidae	1	0.1	0.04	1
Mycetophilidae	3	0.4	0.12	1

Table I-1 (continued)

Taxon	Total number collected	Percent of total	Mean density[a] (number per 1000 m^3)	Frequency[b]
Psephenus	1	0.1	0.04	1
Unidentified	4	0.5	0.16	4
Total	14	1.9		
Mean			0.08	
Diptera				
Palpomia	1	0.1	0.04	1
Tanypodinae	12	1.6	0.48	10
Tanypodinae exuviae	1	0.1	0.04	1
Chironomidae	53	7.0	2.12	18
Chironomidae exuviae	20	2.6	0.80	7
Empididae	2	0.3	0.08	2
Simulium	2	0.3	0.08	2
Simuliidae	4	0.5	0.16	3
Tetanoceridae	9	1.2	0.36	1
Atherix	1	0.1	0.04	1
Antocha	10	1.3	0.40	7
Antocha exuviae	2	0.3	0.08	1
Tipula	1	0.1	0.04	1
Eriocera	2	0.3	0.08	1
Tipulidae	11	1.5	0.44	7
Tipulidae exuviae	1	0.1	0.04	1
Chaoborus	1	0.1	0.04	1
Total	133	17.6		
Mean			0.31	
Hemiptera				
Rhagovelia	3	0.4	0.12	2
Unidentified	4	0.5	0.16	4
Total	7	0.9		
Mean			0.14	
Other Aquatic				
Isotomurus	6	0.8	0.24	1
Isotomidae	1	0.1	0.04	1
Odonata	1	0.1	0.04	1
Nigronia	2	0.3	0.08	2
Oligochaeta	7	0.9	0.28	7

Table I-1 (continued)

Taxon	Total number collected	Percent of total	Mean density[a] (number per 1000 m^3)	Frequency[b]
Urodela	1	0.1	0.04	1
Goniobasis	1	0.1	0.04	1
Ferrissia	3	0.4	0.12	3
Chrysomelidae	1	0.1	0.04	1
Etheostomatinae	2	0.3	0.08	2
Total	25	3.3		
Mean			0.10	
Terrestrials				
Asilidae	1	0.1	0.04	1
Aphididae	12	1.6	0.48	4
Araneida	13	1.7	0.52	9
Cicadellidae	3	0.4	0.12	3
Curculionidae	3	0.4	0.12	2
Dermaptera	1	0.1	0.04	1
Formicidae	55	7.3	2.20	4
Homoptera	69	9.1	2.76	14
Hymenoptera	8	1.1	0.32	4
Lepidoptera	7	0.9	0.28	3
Pentatomidae	1	0.1	0.04	1
Popillia	1	0.1	0.04	1
Psocoptera	33	4.4	1.32	9
Sciaridae	6	0.8	0.24	3
Tingidae	1	0.1	0.04	1
Diptera	58	7.7	2.32	11
Total	272	35.9		
Mean			0.68	

[a]Total number collected divided by total volume of water filtered (all samples combined).

[b]Total number of drift samples which contained that taxon.

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