

ENVIRONMENTAL FACTORS RELATED TO THE
ABUNDANCE AND DISTRIBUTION OF
BROOK TROUT (Salvelinus fontinalis) AND BROWN TROUT
(Salmo trutta) AND SEASONAL MOVEMENTS OF
BROWN TROUT IN SELECTED VIRGINIA STREAMS

by

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(ABSTRACT)

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The relationships between brook trout (Salvelinus fontinalis), brown trout (Salmo trutta), non-game fish populations and selected physical and chemical parameters were investigated in four streams draining the Blue Ridge Mountains in north-central Virginia during low flow conditions in August, 1981 and 1982. Multiple regression and discriminant function analysis identified average stream width and maximum stream temperature as the main environmental factors related to brook and brown trout abundance and distribution. Furthermore, consistent fish species assemblages relative to brown trout distribution were observed in the study streams.

The movements of tagged brown trout in two streams were assessed for the period from June 1981 to July 1982. Most brown trout remained within 200 m of original tagging sections, 98.7% in the Conway River (73 out of 79) and 71.4%

in the North Fork Thornton River (7 out of 9). The 1979, 1978 and 1977 year class fish (ages 2+, 3+ and 4+) exhibited extremely restricted movements and were invariably recaptured at original capture locations while the 1980 year class (age 1+) displayed small net upstream movements (<80 m) throughout the period. Two 1980 year class individuals displayed extensive movements (17.0 km downstream and 1.2 km upstream). These movements were characteristic of other stream resident brown trout populations.

Results of this study suggest that brown trout may expand their range upstream into currently allopatric brook trout zones. It would likely be a slow but steady process which could be accelerated by infrequent long-range movements. The potential for establishment of reproducing brown trout populations and impacts of brown trout on native brook trout populations can be assessed utilizing fish species assemblages, average stream width and maximum stream temperature prior to further brown trout introductions in this region of Virginia.

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INTRODUCTION

Salmonid Introductions

The distributions of numerous fish species have been extended through introductions into aquatic systems beyond their native ranges (Krebs 1978). These introductions have frequently resulted in the establishment of "naturalized" or reproducing populations (Vooren 1972). Though often labeled successful, the establishment of an exotic fish species may be detrimental to the native fish fauna (McDowall 1968).

Exotic salmonid introductions have resulted in the establishment of reproducing populations throughout the world. Losses of native fish species have resulted from introductions of brown trout (Salmo trutta) and rainbow trout (Salmo gairdneri) in New Zealand rivers (McDowall 1968) and in the Great Smoky Mountains National Park, North Carolina (Kelly et al. 1978). Successful introductions of brown trout into many lotic systems inhabited by native brook trout (Salvelinus fontinalis) have occurred across the North American continent (MacCrimmon and Marshall 1968). Brown trout have been implicated in the decline of native brook trout populations in some of these systems through competition and predation (Bean 1906, Brynildson et al. 1973). The extent to which brown trout impact brook trout populations is related to the biology of these species and historical changes in the lotic systems which they co-

inhabit.

Historical Overview

Brook trout are indigenous to eastern North America, ranging as far west as the Canadian province of Manitoba and south into the state of Georgia. The species is restricted to headwater streams in the Appalachian region of the southeastern United States (MacCrimmon and Campbell 1969) and is the only salmonid species native to Virginia.

The native range of the brook trout has been reduced due to degradation of both lentic and lotic cold water habitats (MacCrimmon and Campbell 1969). Land use practices such as logging operations, agriculture and watershed development (Schuder 1974) have all contributed to siltation and increased stream temperatures which are not tolerated by brook trout (Kelly et al. 1978). The latter is the most important factor limiting brook trout distribution when sufficient precipitation and spawning gravel are available for reproduction (MacCrimmon and Campbell 1969). Species of the genus Salvelinus prefer temperatures in the range of 9.0-11.5 °C (Peterson et al. 1979) and brook trout are not normally found in lotic systems in which temperatures exceed 19.0-20.0 °C for any extended period of time (Burton and Odum 1945, Dymond 1953).

During the early 1900's, declines in brook trout populations led to reduced angling opportunities throughout

North America. Fishery managers began to stock exotic rainbow and brown trout to supplement trout fishing opportunities (MacCrimmon and Marshall 1968).

Brown trout were first introduced to North America in 1883 into the Pere Marquette River, Michigan and were subsequently stocked in other waters throughout the United States and Canada (MacCrimmon and Marshall 1968). Brown trout were more tolerant of higher stream temperatures than brook trout (MacCrimmon and Campbell 1969, Brynildson et al. 1973), prefer temperatures of 13.0-15.0 °C (Peterson et al. 1979) and have subsequently been found at temperatures exceeding 28.0 °C for short periods of time in well-oxygenated waters (Davis 1965, Calhoun 1966). A survey of state agencies in 1967 indicated that 45 of 50 states had introduced brown trout (Marshall and MacCrimmon 1970). Today, brown trout stocked in streams considered marginal for native salmonids have established reproducing populations across North America (MacCrimmon and Marshall 1968).

Brown trout inhabit lotic systems in Europe characterized by cold temperatures, high gradients, rapid flows and bottoms composed of boulders, rubble and gravel (Jones 1948, Nilsson 1957, Huet 1959, Egglisshaw 1970, LeCren 1973, Mortensen 1977, Jonsson and Sandlund 1979). This habitat description closely approximates the habitat of many

brook trout streams in the southeastern United States. Although brown trout predominate in the lower reaches of these southeastern streams (Kelly et al. 1978), the overlap in habitat preference with brook trout results in sympatric zones inhabited by both species.

Brook and Brown Trout Interactions

Bean (1906) first attributed declines of the brook trout population in the Beaverkill River, New York to brown trout introductions. Brown trout have subsequently been implicated in the displacement of brook trout from a number of lotic systems in North America. Typically, brown trout predominate in the lower reaches of streams while brook trout are restricted to smaller headwater reaches. Both species generally co-occur in sympatric zones located between the headwaters and lower reaches of these streams (Brynildson et al. 1973). This phenomenon has been described in the Kanaskis River system, Alberta (Nelson 1965), Little South Poudre River drainage, Colorado (Vincent and Miller 1969), Waterford River, Newfoundland (Nyman 1970), Sagehen Creek, California (Gard and Flittner 1974) and Firehole River, Wyoming (Kaeding 1980).

Competitive interactions may occur between brook and brown trout in the zones of sympatry in streams. Newman (1956) specified the following behavioral requirements for interspecific competition: (1) species occupy the same or

overlapping habitats, (2) species aggressively respond to each other and (3) periods or rhythms of aggressive activity overlap. Further, species which have evolved in isolation and live as ecological equivalents are potentially their own greatest competitors. The ecological demands of brook and brown trout are similar (Nyman 1970), satisfying the criteria for interspecific competition. Therefore, competition could occur if brook and brown trout simultaneously demanded a limited stream resource such as food or cover.

Brown Trout Impacts on Brook Trout Populations

The mechanisms by which brown trout may displace brook trout are not fully understood. Four possible causes for the reported declines in brook trout populations in the presence of brown trout were cited by Fausch and White (1981): (1) predation of brown trout on young brook trout, (2) differential angling vulnerability, (3) territorial behavior and/or (4) differential response to environmental factors.

Predation

Brown trout prey selectively on young brook trout (Alexander 1977) and rainbow trout (Hannuksela 1969) in some streams. Garman and Nielsen (1982) found that brown trout greater than 280 mm were primarily piscivorous. Thus, this size group of brown trout could significantly impact brook

trout populations.

Angling Vulnerability

Brook trout are more vulnerable to angling than brown trout (Cooper 1951, Marshall and MacCrimmon 1970), thus enhancing brown trout dominance through selective removal of brook trout. Brown trout apparently have an inherent ability to avoid capture by anglers not equally possessed by the brook trout (Cooper 1951).

Behavior

In general, stream salmonids are characterized by intense competition for a limited supply of space, food, shelter and spawning gravel (McFadden 1969). Thus salmonids are strongly territorial in a stream which can support a finite density of fish and number of territories (Allen 1969). The acquisition of optimal territories is of survival benefit to both the individual and the population (Chapman 1966).

Larger size confers a competitive advantage to salmonids in the establishment and defense of territories (Newman 1956). Jenkins (1969) observed that weight was the primary factor relating to success in agonistic encounters between brown and rainbow trout. Prior residence also confers an advantage to individuals (Newman 1956), leading to greater success in agonistic encounters (Jenkins 1969). Wild brown trout generally attain larger sizes than brook

trout due to greater longevity and the piscivorous nature of older age classes. Thus, brown trout gain a competitive size advantage over brook trout for limited stream resources (Brynildson et al. 1973). In competition for resting positions in the Au Sable River, Michigan, brown trout of equal and greater size than brook trout excluded brook trout from these critical areas (Fausch and White 1981).

Environmental Response

Differential response to the physical and chemical environment could influence the abundance and distribution of brook and brown trout in streams. Chapman (1966) states that the physical and chemical environment sets the framework within which density is governed in streams. Physical and chemical properties change along the length of a watercourse with subsequent changes in fish populations (Hynes 1970, Cummins 1977, Platts 1979). The fact that there is an upstream limit to brown trout in streams with brook trout present (Vincent and Miller 1969, Nyman 1970, Gard and Flittner 1974, Kaeding 1980) suggests that one or more physical and/or chemical parameters could act to regulate and limit the abundance and distribution of brown trout.

Researchers have postulated a wide spectrum of parameters which could limit the longitudinal distribution of salmonids in streams. The most frequently discussed

parameters are temperature (Burton and Odum 1945, Vincent and Miller 1969, Gard and Flittner 1974), gradient (Huet 1959, MacPhee 1966, Griffith 1972, Gard and Flittner 1974) and stream size (Huet 1959, Sheldon 1968, Gard and Flittner 1974).

Temperature

Burton and Odum (1945) suggested that the downstream limit of brook trout occurs in areas of streams exceeding 19.0 °C for an extended period of time. Vincent and Miller (1969) proposed that a mean five-day maximum temperature of 13.0-15.0 °C acts to limit the upstream distribution of brown trout in streams with brook trout present.

Gradient

The role of gradient in controlling the distribution of fishes in streams is confounded by the fact that it is interrelated with many other stream characteristics. Gradient affects current, pool to riffle ratio, bottom substrate, macrofauna and temperature (Gard and Flittner 1974). Gradient appears to be important because of its influence on a wide range of stream characteristics important to fish.

Stream Size

Stream size relates to depth and width. Upstream areas and stream margins are most suitable for small fish while downstream reaches are best for larger fish requiring deeper

and faster water (Chapman 1966). Hypothetically, the smaller body size of brook trout could enable them to successfully compete with brown trout in smaller headwater reaches of streams (R.J. White pers. comm.).

Brown Trout Movements

Brown trout movements are important in understanding displacement of brook trout because these movements result in distributional changes and range expansion of brown trout. Kaeding (1980) stated that the extent to which brown trout successfully compete with brook trout may depend upon seasonal movements of brown trout into stream reaches occupied only by brook trout. Previous movement studies have demonstrated that brown trout tend to remain within one mile of original marking sites; 91% over a one year study period (Schuck 1943), 92% over a one year study period (Allen 1951), 85% over a thirty-three year study period (Shetter 1968) and 81% over a one year study period (Mense 1975). These studies indicate that many stream resident brown trout populations maintain relative distributional stability through time (Mense 1975) and support the conclusion of Gerking (1953) that home ranges established by stream fishes will normally remain throughout their lives. Bachman (1932) proposed that restricted movements are related to an energetic optimization strategy.

Despite the sedentary nature of most stream resident

brown trout, all studies noted some individuals that made long upstream or downstream movements (Schuck 1943, Allen 1951, Shetter 1968, Mense 1975). Jenkins (1969) described those trout that tended to move as transients. Gerking (1953) pointed out the importance of transients as a reserve supply which could repopulate decimated areas in streams. In addition, these transients could be responsible for brown trout range expansion into previously unoccupied areas.

Resident salmonids often display seasonal movements, typically characterized by downstream movements during the fall, winter and spring with upstream movements in the spring and summer (Bjornn and Mallet 1964, Bjornn 1971). Brown trout associate strongly with bottom substrate during the winter, both in the laboratory (Hartman 1963) and in the field (Bjornn 1971). Chapman (1966) postulated that if density is regulated in the winter it is related to cover necessary to escape downstream displacement or damage by current and ice. Schuck (1943) observed fall spawning runs upstream in Crystal Creek, New York with brown trout later returning to "home sites" downstream.

Chapman and Bjornn (1969) stated that salmonids occupy stream depths and velocities appropriate to their body size. As a fish grows, its environmental requirements change and spatial needs increase. This could be responsible for the pronounced downstream movement of larger brown trout

(greater than 330 mm) documented by Shetter (1968) in the Au Sable River, Michigan.

Problem Statement

The historical range of native brook trout in Virginia has progressively receded since colonial settlement began over 350 years ago. Loss of native range has occurred primarily from channelization, deforestation, mining and watershed development with subsequent degradation of cold water habitat. Consequently, brook trout have become limited to headwater streams in the mountainous regions of the Blue Ridge and Appalachian Plateau (Schuder 1974). Droughts, floods and anchor ice frequently occur and cause heavy density-independent brook trout mortality in these streams (Sadowski 1978, LaRoche and Pardue 1980); however, resilient brook trout populations usually recover quickly (Lennon 1961). Due to the strong influence of climatic factors, Lennon (1961) concluded that these streams provide marginal habitat for brook trout.

Viable brook trout populations exist in numerous streams which originate within the borders of the Shenandoah National Park in north-central Virginia (Lennon 1961). Reproducing populations of brown trout have become established in several of these streams following introductions which began in 1963 (J. Kauffman pers. comm.). Virginia Commission of Game and Inland Fisheries (VCGIF) and

Shenandoah National Park personnel are concerned that brown trout may expand their range in these streams and displace portions of already limited brook trout populations. Determination of those environmental factors which are important in regulating and limiting the abundance and distribution of brook and brown trout is necessary to evaluate this perceived problem.

Several investigations of brook and brown trout populations have been conducted but specific differences in the ecological requirements of the two species have not been adequately defined (MacCrimmon and Marshall 1968). A large gap exists between detailed laboratory data and adequate field data to describe mechanisms of salmonid population regulation and limitation (McFadden 1969). Simultaneous measurement of selected physical, chemical and biological parameters is necessary to properly evaluate their relationship to the abundance and distribution of brook and brown trout. Coincident with measurement of the physical, chemical and biological parameters, an assessment of brown trout movements provides further insights into the dynamics of the brown trout populations and their potential effects on native brook trout populations.

This study was initiated to address concerns expressed by state fishery biologists and park officials regarding the impact of exotic brown trout on native brook trout

populations. Brook and brown trout populations and selected habitat parameters were investigated with the following specific objectives:

(1) To determine the relationships between the abundance and distribution of brook and brown trout and selected physical, chemical and biological parameters in four Virginia streams.

(2) To monitor and evaluate the seasonal movements of brown trout in two Virginia streams.

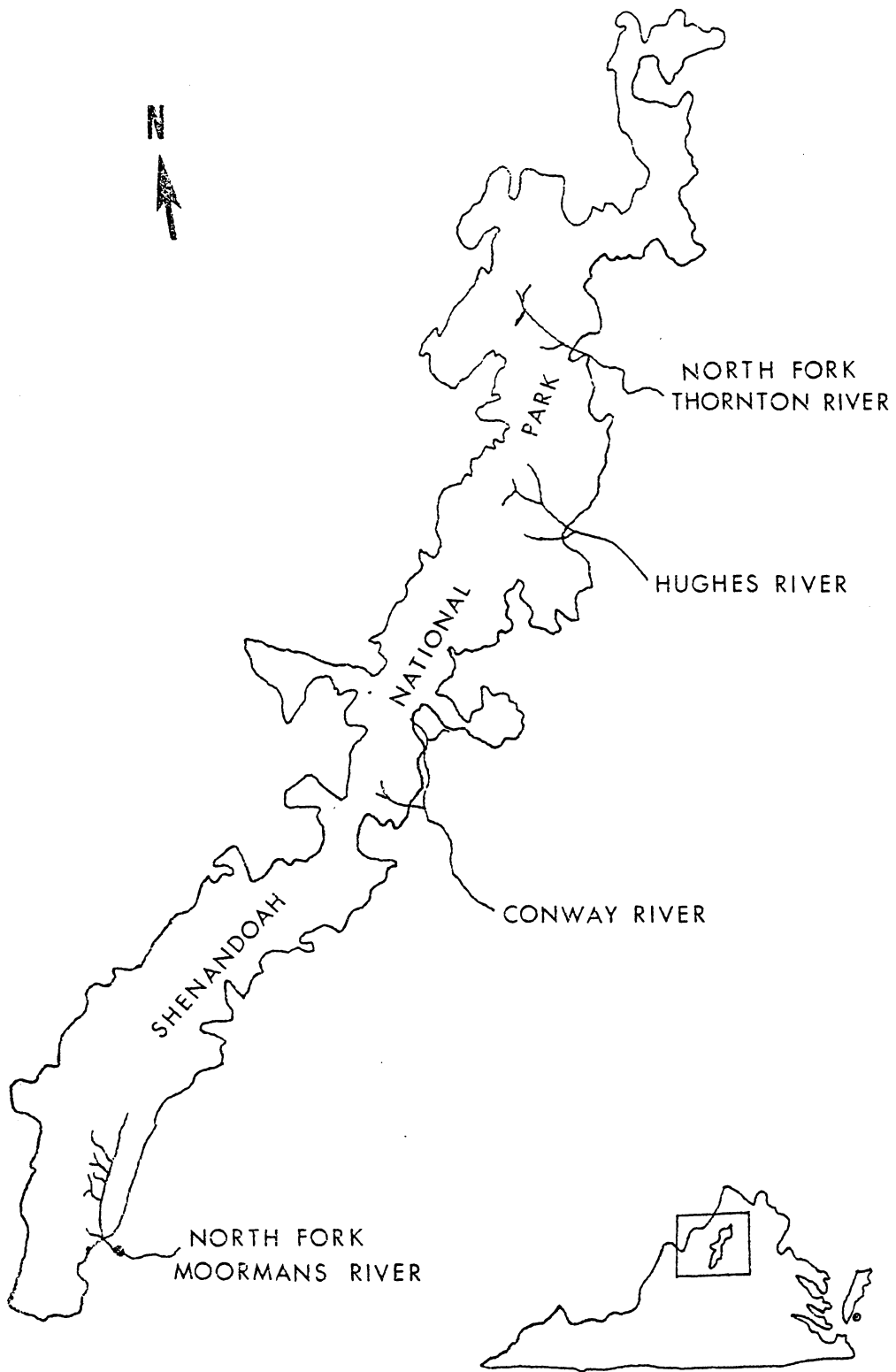
MATERIALS AND METHODS

Study Area

Four streams which drain the eastern slope of the Blue Ridge Mountains and originate within the borders of the Shenandoah National Park in north-central Virginia were selected for this study. The streams were the Conway River (Greene County; 38°42' N, 78°27' W; USGS - Fletcher), North Fork Thornton River (Rappahannock County; 38°42' N, 78°17' W; USGS - Thornton Gap), North Fork Moormans River (Albermarle County; 38°10' N, 78°45' W; USGS - Browns Cove) and Hughes River (Madison County; 38°35' N, 78°17' W; USGS - Old Rag Mountain) (Figure 1). The watersheds of these streams have been protected from human disturbances (i.e. logging, agriculture and development) since 1930 when the Shenandoah National Park was established. Stream selection criteria included: (1) no impassable barriers to fish movement and (2) presence of resident populations of brook and brown trout.

The Shenandoah National Park is located in the northern section of the Blue Ridge geographic province of Virginia. The Blue Ridge in this area is composed of metamorphosed igneous rocks such as granites, greenstones and slates. The area was classified as an Oak-Chestnut region but is currently classified as an Oak-Hickory region. A boreal association occurs at higher elevations with yellow birch,

Figure 1. Locations of study streams draining the Shenandoah National Park in north-central Virginia.



sugar maple, beech and buckeye the predominate trees (Hoffman 1979).

The Shenandoah National Park is further characterized by steep ridges and peaks rising 304 to 912 meters above the Piedmont Plateau. Consequently, the streams draining the park generally are short, steep and small to medium in size. Streambeds are subject to extensive scouring during high water periods (Lennon 1961). Lennon (1961) further described these streams as clear, colorless and very soft with the following ranges of chemical properties: pH 6.0-7.0, conductivity 22-58 μ mhos/cm and methyl orange alkalinity 0-10 mg/L CaCO_3 .

Objective (1) : Salmonid Abundance and Distribution

Survey and Site Selection

Initial electrofishing surveys were conducted in the four streams using a BP-1C Coffelt backpack electrofishing unit (Coffelt Electronics Company, Inc.). Through these surveys and Virginia Commission of Game and Inland Fisheries trout stream surveys, the upstream limits of brown trout were approximated in the Conway River on 14 June 1981, the North Fork Thornton River on 3 June 1981, the North Fork Moormans River on 6 June 1981 and the Hughes River on 4 June 1981. Approximated upstream limits of brown trout were designated as reference points to delineate sampling sections.

Following the initial survey, seven 70-meter sections per stream were measured and flagged for sampling purposes. The 70-meter sections were located approximately 800 meters apart in the following manner: (1) one section immediately downstream of the determined upstream limit of brown trout (i.e. reference point), (2) three additional sections downstream of the reference point and (3) three sections upstream of the reference point. Spacing the study sections in this manner allowed assessment of changes in selected physical, chemical and biological parameters over 4.8 kilometers in each stream.

In 1982, the investigation of abundance and distribution of brook and brown trout focused on the Conway and North Fork Thornton Rivers, the two streams in which brown trout movements were being monitored. Seventeen 70-meter sections were delineated on the Conway River located approximately 400 meters apart in the following manner: (1) one section immediately downstream of the reference point, (2) six additional sections downstream of the reference point and (3) ten sections upstream of the reference point. Ten 70-meter sections were delineated on the North Fork Thornton River located approximately 800 meters apart in the following manner: (1) one section immediately downstream of the reference point, (2) six additional sections downstream of the reference point and

(3) three sections upstream of the reference point. Spacing the study sections in this manner allowed assessment of changes in selected physical, chemical and biological parameters over 6.4 kilometers of the Conway River and 7.2 kilometers of the North Fork Thornton River.

Reference points were located at the following elevations on the study streams: Conway River (1220 feet), North Fork Thornton River (1280 feet), North Fork Moormans River (1240 feet) and Hughes River (1200 feet). The study streams and sections are illustrated in Figures 2, 3, 4 and 5 for the Conway, North Fork Thornton, North Fork Moormans and Hughes Rivers, respectively. Elevations of each study section are given in Table 1.

Quantitative Electrofishing

Quantitative electrofishing was conducted on the Conway River on 3-4 August 1981, the North Fork Thornton River on 12-13 August 1981, the North Fork Moormans River on 5-6 August 1981 and the Hughes River on 10-11 August 1981. Quantitative electrofishing was repeated on the Conway River on 2-5 August 1982 and the North Fork Thornton River on 9-10 August 1982.

Populations of brook and brown trout were estimated in each 70-meter section. Populations of non-game fishes were estimated in 30-meter subsections of each 70-meter section. All population estimates were determined by three run

Figure 2. Location of study sections on the Conway River (* indicates the approximated upstream limit of brown trout).

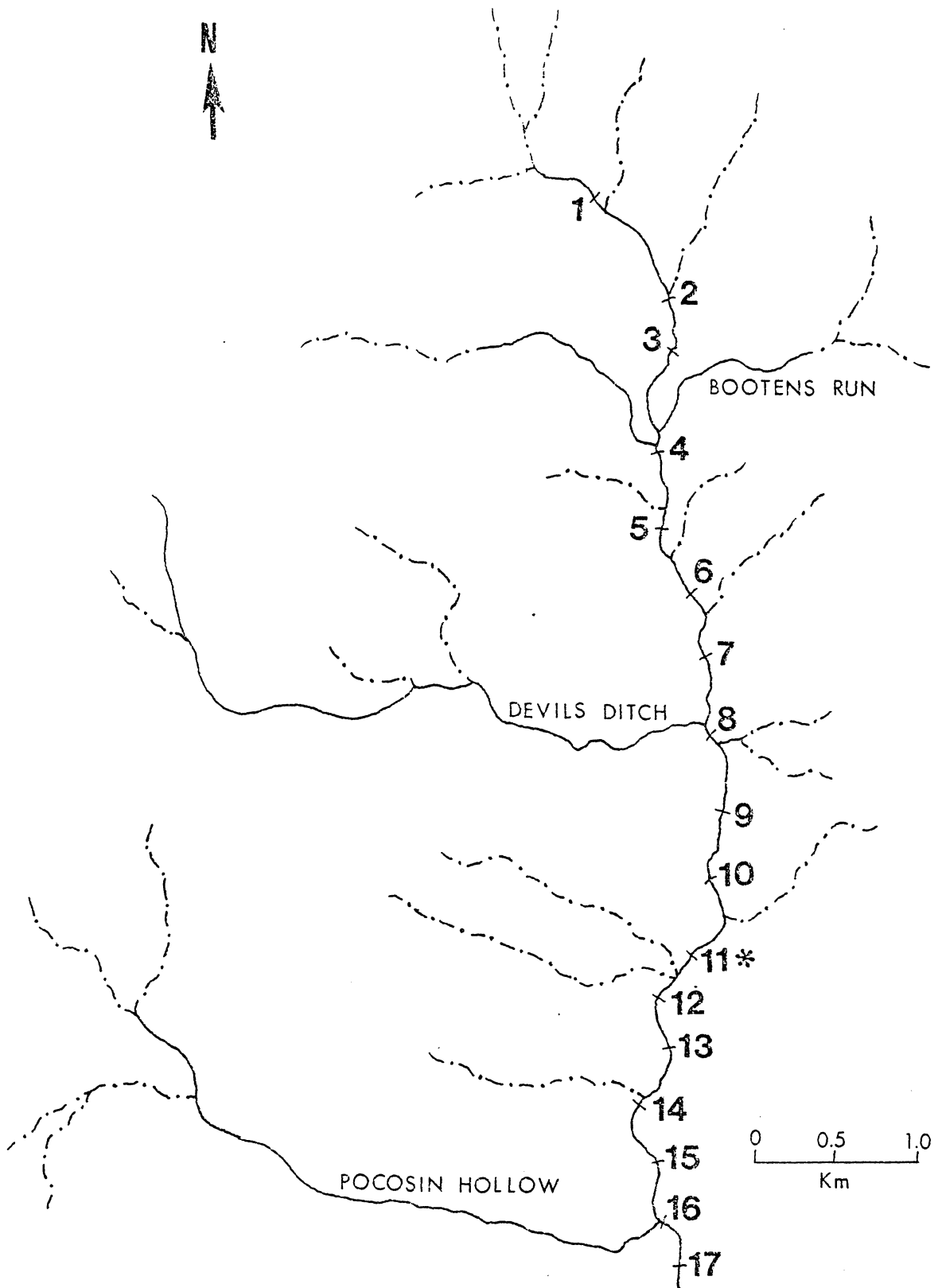


Figure 3. Location of study sections on the North Fork Thornton River (* indicates the approximated upstream limit of brown trout).

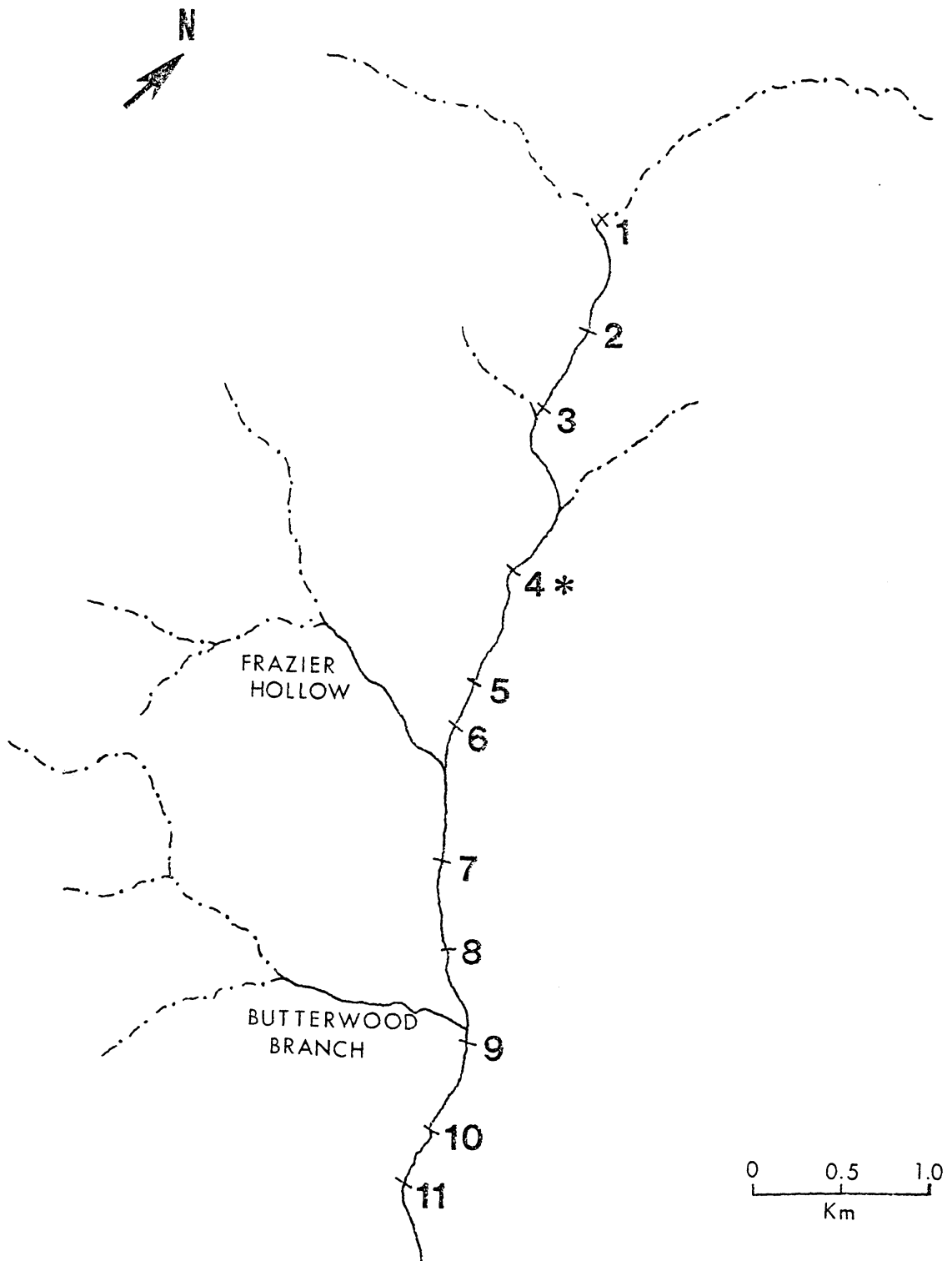
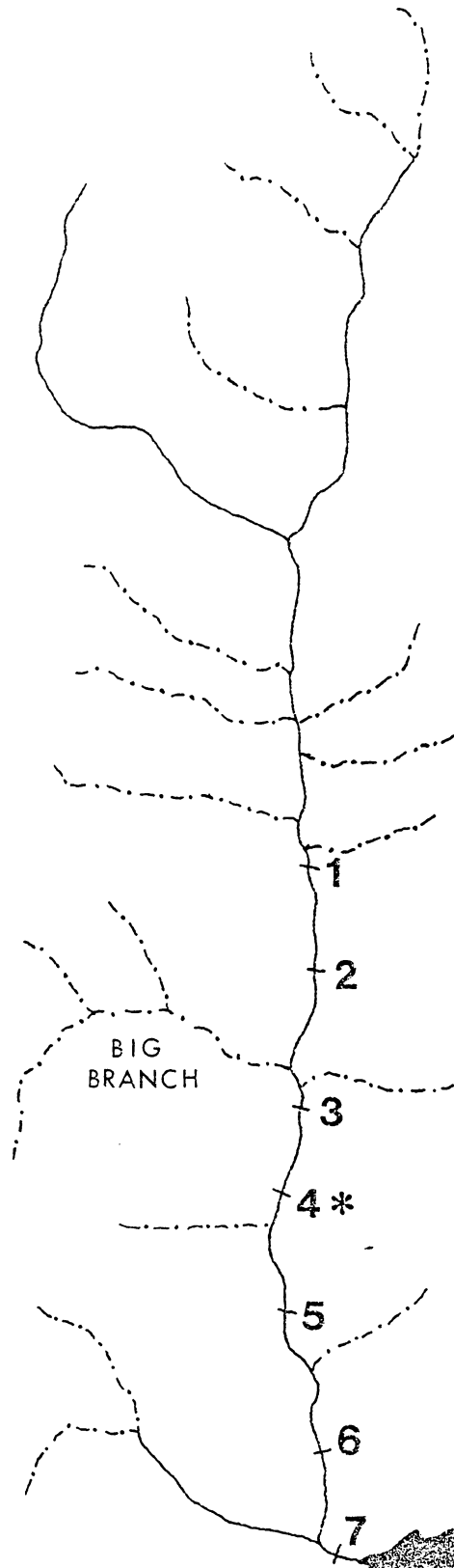


Figure 4. Location of study sections on the North Fork Moormans River (* indicates the approximated upstream limit of brown trout).

25



0 0.5 1.0
Km

CHARLOTTESVILLE
RESERVOIR

Figure 5. Location of study sections on the Hughes River (* indicates the approximated upstream limit of brown trout).

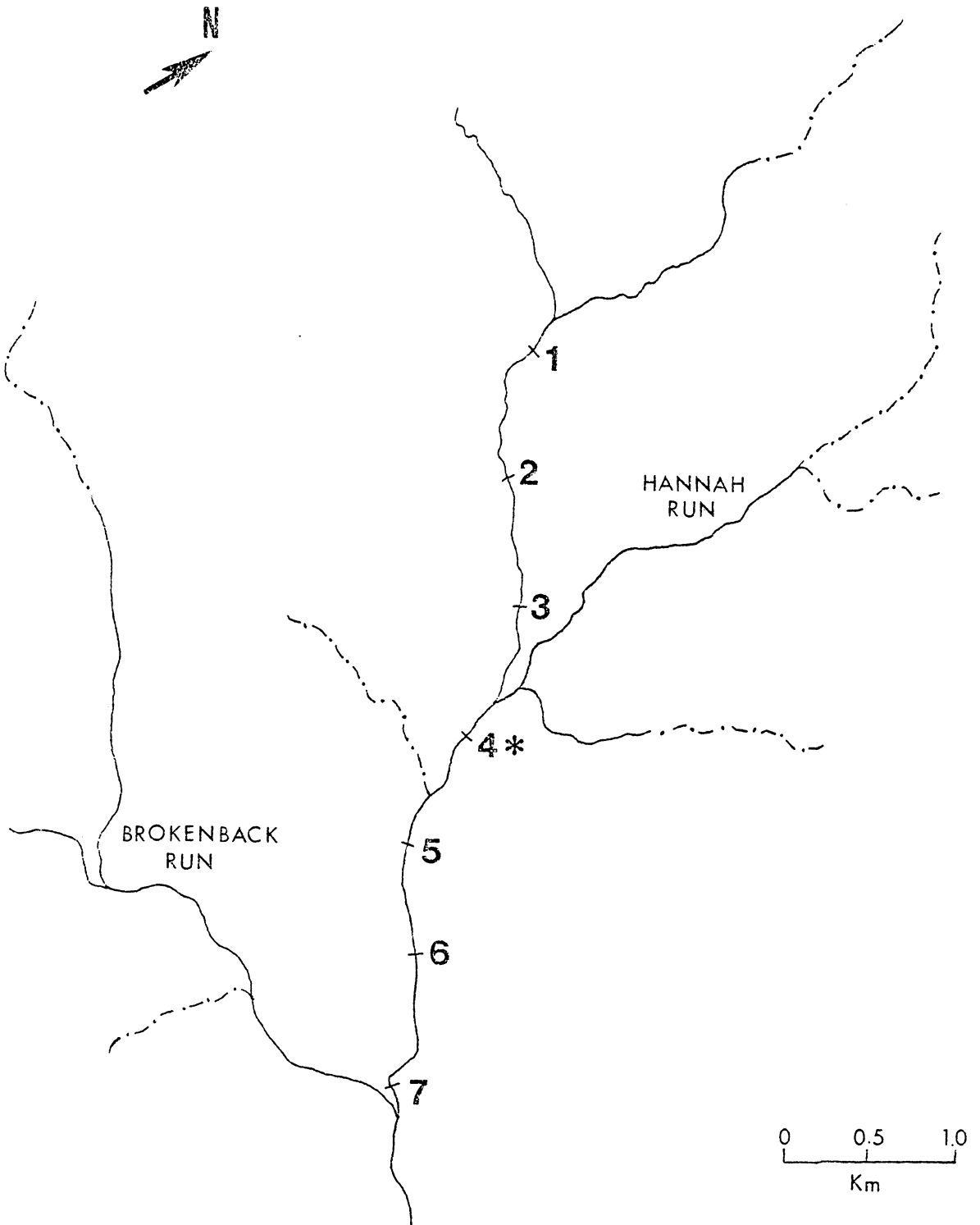


Table 1. Elevations (ft) of study sections on the four streams draining the Shenandoah National Park.

STUDY SECTION ¹	CONWAY	NORTH FORK THORNTON	NORTH FORK MOORMANS	HUGHES
1	2100	1680	1560	1880
2	1920	1520	1460	1640
3	1840	1420	1360	1360
4	1700	1280	1240	1200
5	1620	1220	1170	1100
6	1550	1180	1040	1000
7	1460	1140	1000	900
8	1380	1080		
9	1300	1020		
10	1260	980		
11	1220	960		
12	1180			
13	1140			
14	1100			
15	1060			
16	1030			
17	1020			

¹ Refer to Figures 2, 3, 4 and 5.

depletions (Carle and Strub 1978) using a Coffelt BP-1C backpack electroshocking unit.

Prior to electrofishing, block nets were placed at the upstream and downstream boundaries of a section to prevent fish movement into or out of the section. An attempt was made to capture all fish species in the first 30 meters and all salmonids in the last 40 meters of a section. After each shocking run, captured fish were placed in separately screened live-buckets. Each fish was subsequently identified and separated according to species.

Fish were anesthetized with tricaine methanesulfonate (MS-222) to facilitate ease of handling and processing. Total lengths were measured to the nearest 1.0 mm and weights to the nearest 0.1 g for salmonids and non-game fishes. Scale samples were removed from salmonids for age determination. All processed fish were returned to the live-buckets and then released after recovery.

Standing stocks (g/m^2) of each salmonid year class were determined for each section. Salmonids were aged with the aid of length-frequency distributions and scale reading techniques (Everhart et al. 1975). The numbers of each year class per shocking run were tabulated and population estimates were determined using a computer package developed by Carle and Strub (1978). Average weights for each year class were calculated and standing stocks were derived by

the following formula:

$$SS = NW/A$$

where: SS = standing stock (g/m² wet weight)

N = depletion population estimate (Carle and Strub 1978)

W = average weight (g)

A = area of the section (m²)

Surface area was calculated as the length multiplied by the average width of a given section.

Standing stocks of non-game fishes were determined for each 30-meter subsection, for all ages combined. The same procedure and formula given above was used to calculate non-game standing stocks.

Physical and Chemical Measurements

Selected physical and chemical parameters were measured in each 70-meter section. The parameters measured included: depth, width, gradient, discharge, pool to riffle ratio, instream cover, canopy cover, available spawning substrate, bottom substrate composition, pH, conductivity, alkalinity, maximum temperature and pool classification. All measurements were made simultaneously in late summer, a critical period for stream salmonids because of low flows and high water temperatures (Duff and Cooper 1976).

Physical and chemical measurements were made in the Conway River on 17-18 August 1981, the North Fork Thornton

River on 25-26 August 1981, the North Fork Moormans River on 19 August 1981 and the Hughes River on 27-28 August 1981. The same measurements were repeated on the Conway River on 16-18 August 1982 and the North Fork Thornton River on 19 August 1982.

Depth

Fifteen transects per 70-meter section were delineated and spaced approximately 4.5 meters apart. Depth (m) was measured at 0.5 meter intervals across each transect with a meter stick. Average depth was calculated as:

$$\text{Average Depth} = \Sigma D/n$$

where: ΣD = summation of depth measurements (m)

n = total number of observations

Width

Fifteen transects spaced approximately 4.5 meters apart were measured with a 30 meter tape to determine the width of each transect. Average width was calculated as:

$$\text{Average Width} = \Sigma W/n$$

where: ΣW = summation of width measurements (m)

n = total number of observations

Gradient

The average gradient of each section was determined using topographic maps (scale 1:24000). The distance between each 40 foot (12.2 m) contour line was measured and the gradient between each pair of contour lines was

calculated as:

$$\text{Gradient} = 40 \text{ ft/d}$$

where: Gradient = change in elevation over distance
(ft/mile)

d = distance between two 40 foot contour lines
(mile)

The distance between contour lines was measured with a map wheel. Thus, the gradient for each section is represented by the average gradient of the stream within which the section is located.

Discharge

Discharge for each section was determined by the following equation (Hynes 1970):

$$Q = WDV$$

where: Q = discharge (m^3/s)

W = width (m)

D = mean depth (m)

V = mean velocity measured at 0.6 depth from water surface (m/s)

Velocity was measured with the aid of a Pigmy Gurley Meter (Gurley Hydrological Instruments).

Pool to Riffle Ratio

The pool to riffle ratio was determined from measurements of pool lengths with a 30-meter tape. This parameter is expressed as percent pool which was calculated

as:

$$\text{Percent Pool} = (\Sigma L / SL) \times 100\%$$

where: ΣL = summation of pool lengths (m)

SL = section length (m)

Instream Cover

Percent instream cover was determined according to Lewis (1969) with modifications to include pools and riffles. Instream cover (i.e. debris, turbulence, boulders, overhanging vegetation and undercut banks), sufficient for fish >120 mm in length, was measured with a meter stick to determine total cover (m^2). Percent instream cover was calculated as:

$$\text{Percent Instream Cover} = (TC / SA) \times 100\%$$

where: TC = total cover (m^2)

SA = surface area of section (m^2)

Canopy Cover

Canopy cover was defined as the area of the stream channel shaded directly overhead by the canopy of streamside vegetation. The percent canopy cover was determined by visual estimation.

Available Spawning Substrate

Spawning substrate was defined as fine gravel (2.54-25.4 mm diameter) and coarse gravel (25.4-76.2 mm diameter) (Duff and Cooper 1976). The surface areas of pockets of spawning gravel ($>0.09 m^2$) were measured with a

meter stick to determine the total available spawning substrate (m^2). Percent available spawning substrate was calculated as:

$$\text{Percent Available Spawning Substrate} = (\text{TASS}/\text{SA}) \times 100\%$$

where: TASS = total available spawning substrate (m^2)

SA = surface area of section (m^2)

Bottom Substrate Composition

The bottom substrate was classified according to Platts (1979) as follows:

Particle Diameter (mm)	Material
Greater than 304.7	Boulder
76.1-304.7	Rubble
4.7-76.1	Gravel
Less than 4.7	Fine Sediment

For each transect across the stream channel, the dominant bottom material was identified at each 0.5 meter interval. Percent of each bottom type was calculated as:

$$\text{Percent Bottom Type} = (\Sigma \text{BT}/n) \times 100\%$$

where: ΣBT = summation of observations of a bottom type

n = total number of observations of all bottom substrate types

pH

One water sample was collected from each section for pH analysis. The pH was measured with a Corning Model 12 Research pH Meter (Corning Scientific Instruments) in the laboratory.

Conductivity

The same water sample collected for pH analysis was used for analysis of conductivity ($\mu\text{mhos/cm}$). Conductivity was measured with a Yellow Springs Instrument Model 33 S-C-T Meter (Simpson Electric Company) in the laboratory.

Alkalinity

The same water sample collected for pH and conductivity analysis was used for analysis of alkalinity (mg/L CaCO_3). Alkalinity was determined with a DR-EL/1 Hach Kit (Hach Chemical Company 1977) in the laboratory.

Maximum Temperature

Ambient water temperatures ($^{\circ}\text{C}$) were monitored with Taylor Maximum-Minimum thermometers to determine maximum temperatures in August and September. Temperatures were monitored in the Conway River from 3 August - 14 September 1981, the North Fork Thornton River from 12 August - 13 September 1981, the North Fork Moormans River from 5 August - 15 September 1981 and the Hughes River from 10 August - 14 September 1981. Measurements were repeated in the Conway River and the North Fork Thornton River from 29 July - 28

September 1982.

Pool Classification

Pools in each section were rated and classified by modifying the guidelines established by Duff and Cooper (1976). Pool rating was based on size, depth and cover associated with a pool as follows:

Size (m)	Size Rating	Depth (m)	Depth Rating	Cover	Cover Rating
.00-.09	1	0-1.9	1	Exposed	2.5
.10-.19	2	2-3.9	2	Exposed	2.5
.20-.29	3	4-5.9	3	Exposed	2.5
.30-.39	4	6-7.9	4	Exposed	2.5
.40-.49	5	8-9.9	5	Partial	6.5
.50-.59	6	10-11.9	6	Partial	6.5
.60-.69	7	12-13.9	7	Partial	6.5
.70-.79	8	14-15.9	8	Partial	6.5
.80-.89	9	16-17.9	9	Abundant	10.5
.90-.99	10	18-19.9	10	Abundant	10.5
1.00-1.09	11	20-21.9	11	Abundant	10.5
>1.10	12	22-23.9	12	Abundant	10.5

Pool Class	*Total Rating
1	28.5-34.5
2	22.5-28.4
3	16.5-22.4
4	10.5-16.4
5	4.5-10.4

*Total Rating = Size Rating + Depth Rating + Cover Rating

The size category refers to width and length of a pool (m) and the largest value was used to determine the rating.

Statistical Analysis

Collected data was statistically analyzed to determine: (1) relationships between brook and brown trout abundance and the selected parameters with multiple regression procedures (Draper and Smith 1966) and (2) relationships between brook and brown trout distribution and the selected parameters with discriminant function procedures (Kleinbaum and Kupper 1978).

Abundance : Multiple Regression Analysis

Pearson's product moment correlation coefficients (Draper and Smith 1966) were calculated for all the

dependent and independent variables to assess correlations among those parameters. Multiple regression procedures were then used to derive predictive equations for trout standing stocks (Draper and Smith 1966). The standing stocks of brook, brown and total trout represented abundance and were the dependent variables. Eighteen selected physical, chemical and biological parameters included non-game fish standing stocks, average depth, average width , gradient, discharge, percent pool, percent cover, percent spawning substrate, percent bedrock, percent boulder, percent rubble, percent gravel, percent silt, pH, conductivity, alkalinity and maximum temperature as the independent variables (Table 2).

Maximum R-square, backward elimination and stepwise multiple regression procedures were used to develop and select several models based on a decision level of 0.05 for tests on the beta coefficients (i.e. the partial slopes for each independent variable). The models were then analyzed with general linear model procedures with tests on the beta coefficients at a decision level of 0.05. The general linear model procedures were carried out with and without y-intercepts (Draper and Smith 1966), in order to develop the "best" models using the following criteria. Models were selected for simplicity (number of variables), fit (mean square error and R-square) and prediction (PRESS statistic -

Table 2. List of dependent (Y) and independent (X) variables used in multiple regression and discriminant function analysis.

SYMBOL	VARIABLE	UNIT
Y1	Brook Trout Standing Stock	g/m ²
Y2	Brown Trout Standing Stock	g/m ²
Y3	Total Trout Standing Stock	g/m ²
X1	Non-game Fish Standing Stock	g/m ²
X2	Average Depth	m
X3	Average Width	m
X4	Gradient	ft/mile
X5	Discharge	m ³ /sec
X6	Percent Pool	%
X7	Percent Instream Cover	%
X8	Percent Canopy Cover	%
X9	Percent Spawning Substrate	%
X10	Percent Bedrock	%
X11	Percent Boulder	%
X12	Percent Rubble	%
X13	Percent Gravel	%
X14	Percent Silt	%
X15	pH	pH units
X16	Conductivity	µmhos/cm
X17	Alkalinity	mg/L CaCO ₃
X18	Maximum Temperature	°C

Prediction Error Sum of Squares). A ranking system was used in which (1) the highest R-square and (2) the lowest error mean square and PRESS statistic values received the highest ranks. The model with the highest total ranking was designated as the "best" predictive model.

Distribution : Discriminant Function Analysis

Discriminant function analysis procedures (Klienbaum and Kupper 1978) were utilized to analyze relationships of brook and brown trout longitudinal distribution to selected physical, chemical and biological parameters. Each study section was classified according to the percentage of brook and brown trout standing stocks as follows: (1) 75-100% brook trout and 0-24% brown trout, (2) 25-74% brook and brown trout and (3) 0-24% brook trout and 75-100% brown trout.

Backward elimination and stepwise discriminant function procedures were used to derive the best predictive discriminant functions with a decision level of 0.05 for tests on the coefficients. Several functions were selected based on p-values for tests on the coefficients. These functions were then analyzed with a discriminant function procedure which derived the "best" model by validation of the functions with the original data set (Kendall and Stuart 1978).

The models developed by the multivariate screening

techniques allowed an assessment of the main relationships between brook and brown trout abundance and distribution and the selected parameters for (1) all streams sampled in August 1981 and (2) all streams sampled in August 1982. Statistical procedures performed for the described analyses are contained in the Statistical Analysis System package (Statistical Analysis System 1979) at Virginia Polytechnic Institute and State University.

Fish Species Associations

The associations between brown trout and other fish species were examined for the Conway, North Fork Thornton, North Fork Moormans, Hughes, Rose and St. Mary's Rivers. VCGIF quantitative electrofishing surveys provided the necessary information for the Rose and St. Mary's Rivers, both of which drain the Blue Ridge Mountains and originate within the Shenandoah National Park. Associations were analyzed by pooling data collected in August 1981 and 1982 in the Conway and North Fork Thornton Rivers, August 1981 in the North Fork Moormans and Hughes Rivers and June 1976 in the Rose and St. Mary's Rivers for a total sample size of 66 study sections.

Fish species associations were analyzed with a chi-square test for independence based on presence and absence criteria (Hurlbert 1969, Krebs 1978). The null hypothesis states that two species are not associated and the alternate

hypothesis is that the species are associated. The formulas for the chi-square statistic (X^2) and coefficient of association (V) are:

$$X^2 = n(ad-bc)^2 / ((a+b)(c+d)(a+c)(b+d))$$

$$V = (ad-bc) / \sqrt{((a+b)(c+d)(a+c)(b+d))}$$

where: n = total number of sections

a = number of sections where species X is present
and species Y is present

b = number of sections where species X is absent
and species Y is present

c = number of sections where species X is present
and species Y is absent

d = number of sections where species X is absent
and species Y is absent

The degrees of freedom equal 1. At a decision level of 0.05, the critical chi-square test statistic value is 3.84.

Objective (2) : Brown Trout Movements

Movement Assessment

Upstream limits of brown trout were approximated in the Conway and North Fork Thornton Rivers in June 1981. Sixteen consecutive 100-meter sections were delineated immediately downstream from the upstream limit of brown trout in each stream.

A total of four samples were taken on both the Conway and North Fork Thornton Rivers during the period June 1981

through July 1982. This information allowed assessment of brown trout movements over approximately a 13 month period at intervals of (1) 5 months (June 1981 - October 1981), 10 months (June 1981 - April 1982), 13 months (June 1981 - July 1982) beginning in June 1981, (2) 6 months (October 1981 - April 1982), 9 months (October 1981 - July 1982) beginning in October 1981 and (3) 4 months (April 1982 - July 1982) beginning in April 1982.

The 1600-meter study areas were initially sampled in the Conway River on 15-17 June 1981 and the North Fork Thornton River on 11-13 June 1981. Each 100-meter section was electrofished with a Coffelt BP-1C backpack electroshocking unit beginning at the most downstream section. Effort was made to capture all brown and brook trout shocked on one electrofishing run per section. Sections were not blocked with nets. After shocking each section, trout were anesthetized in MS-222 to facilitate efficient handling and processing. Each trout was measured to the nearest 1.0 mm, weighed to the nearest 0.1 g and a scale sample was taken for age determination. The adipose fins of all captured trout were excised. Brown trout greater than 160 mm were tagged with serially numbered, circular pennant tags (6.0 mm diameter); fish less than 160 mm were considered too small for tags. Tags were secured with fine gauge (0.148 mm diameter) wire by inserting a

hypodermic needle through the dorsal musculature in a position posterior to the dorsal fin and anterior to the adipose fin (Figure 6). After processing, each fish was placed in a screened live-bucket to recover from handling. Upon recovery, all trout were released back into the middle of the section.

The initial marking of fish was completed in two days on each stream. On the third day, a recapture run through the 1600-meter study area of each stream was conducted to obtain a mark-recapture estimate of the brook and brown trout populations (Everhart et al. 1975). All previously untagged brown trout were processed and tagged during this recapture run. Peterson mark-recapture estimates were calculated as:

$$N = MC/R$$

where: N = population estimate

M = total number of marked fish at large

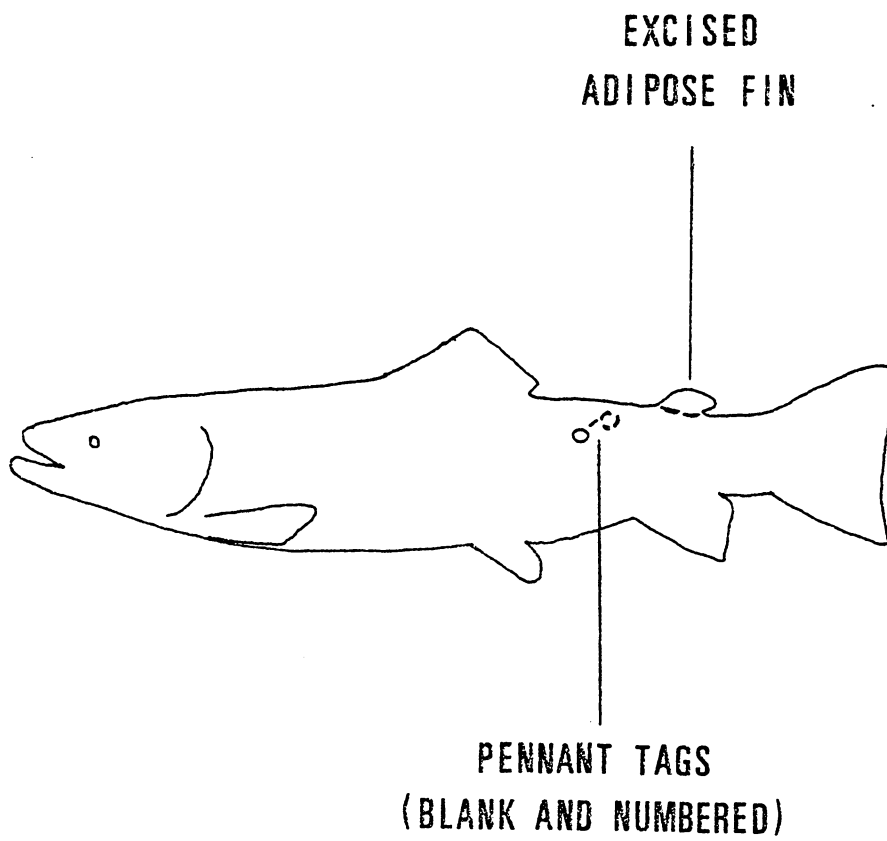
C = total catch on recapture run

R = total number of marked fish recaptured

The population estimates provided information about the relative abundance of brook and brown trout in the study areas.

In late October 1981, the original sixteen 100-meter sections plus an additional eight 100-meter sections immediately upstream from the original sixteen sections were

Figure 6. Marking scheme for brown trout using adipose fin clips and pennant tags.



sampled. The eight sections were added to assess upstream movements and to increase the length of the study area. The Conway River was sampled on 24-25 October 1981 and the North Fork Thornton River on 30 October 1981.

Each 100-meter section was sampled with one electrofishing run beginning at the furthest downstream section and proceeding upstream through the entire 2400-meter study area. After sampling a section, each captured brown trout was anesthetized in MS-222, measured to the nearest 1.0 mm and weighed to the nearest 0.1 g. The brown trout were then inspected for pennant tags and/or excised adipose fins. All untagged brown trout (>160 mm) were tagged, the adipose fins excised and scale samples taken for age determination. Trout were then placed in screened live-buckets to recuperate. Upon recovery, all trout were released into the middle of the section.

In April 1982, the 2400-meter study areas of each stream were again sampled to assess brown trout movements. The same procedures described for the October 1981 samples were repeated except that (1) no weights were recorded and (2) no newly tagged brown trout were released in the Conway River. The Conway River was sampled on 10 April 1982 and the North Fork Thornton River on 24 April 1982.

In July 1982, the 2400-meter study areas of each stream were sampled to assess brown trout movements. The same

procedures described for the October 1981 samples were repeated except that no newly tagged brown trout were released in either stream. The Conway River was sampled on 12 July 1982 and the North Fork Thornton River on 13 July 1982.

Analysis

Movements

Movements of individual year classes of brown trout were analyzed for each time interval. Net movements for each year class were determined as the average movement away from original capture sections for a given time interval. Movements were measured by sections (100 m increments). Upstream and downstream movements were assigned positive and negative values, respectively.

Tag Retention

Tag retention was determined using recapture data for specific time intervals. Percent tag retention was calculated as follows:

$$\text{Percent Tag Retention} = (T/A) \times 100\%$$

where: T = total tags recaptured

A = total adipose clips recaptured

Tag Recovery

Tag recovery was analyzed for each time interval. Corrected tags available (i.e. corrected for tag retention) was calculated as tags at large multiplied by percent tag

retention for a given time interval. The percent tags recovered was calculated as:

$$\text{Percent Tags Recovered} = (T/CTA) \times 100\%$$

where: T = total tags recovered

CTA = corrected tags available

Tag Effects

Tagging effects were analyzed by comparing condition factors of tagged and untagged 1980 year class brown trout. The condition factors of tagged and untagged fish from the October 1981 and July 1982 samples from the Conway River were analyzed with one-sided, unpaired t-tests at a decision level of 0.05.

RESULTS

Objective (1) : Salmonid Abundance and Distribution

Fish Populations

Twenty-four fish species and one hybrid were collected in the August 1981 and 1982 electrofishing samples. These species were members of a diverse group of families which included Salmonidae, Cyprinidae, Catostomidae, Cottidae, Ictaluridae, Percidae, Centrarchidae and Anguillidae (Table 3).

Brook trout predominated in the uppermost study sections and progressively decreased in abundance in downstream sections. The opposite distribution pattern was observed for brown trout, which were most abundant in downstream sections and progressively decreased in abundance in upstream sections (Tables 4,5). In general, the distribution patterns of brook and brown trout were characterized by: (1) an allopatric brook trout zone in the uppermost sections and (2) an extensive sympatric zone grading from predominately brook trout to predominately brown trout in a downstream direction. Only the lowermost section in the Conway River in August 1981 was characterized as an allopatric brown trout zone. The distribution pattern of brook and brown trout in the Conway River on 2-5 August 1982 typifies that of all streams investigated (Figure 7).

There was no evidence of reproducing rainbow trout

Table 3. Species list of fish collected in Shenandoah National Park waters in August, 1981 and 1982.

SCIENTIFIC NAME	COMMON NAME
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Family Salmonidae	
<u>Salmo gairdneri</u>	Rainbow trout
<u>Salmo trutta</u>	Brown trout
<u>Salvelinus fontinalis</u>	Brook trout
Brook x Brown trout hybrid.....	Tiger trout
Family Cyprinidae	
<u>Campostoma anomalum</u>	Stoneroller
<u>Clinostomus funduloides</u>	Rosyside dace
<u>Exoglossum maxillingua</u>	Cutlips minnow
<u>Notropis cornutus</u>	Common shiner
<u>Nocomis leptocephalus</u>	Bluehead chub
<u>Nocomis micropogon</u>	River chub
<u>Phoxinus oreas</u>	Mountain redbelly dace
<u>Rhinichthys atratulus</u>	Blacknose dace
<u>Rhinichthys cataractae</u>	Longnose dace
<u>Semotilus atromaculatus</u>	Creek chub
<u>Semotilus corporalis</u>	Fallfish
Family Catostomidae	
<u>Catostomus commersoni</u>	White sucker
<u>Hypentelium nigricans</u>	Northern hog sucker
<u>Moxostoma rhothoecum</u>	Torrent sucker
Family Cottidae	
<u>Cottus bairdi</u>	Mottled sculpin
Family Ictaluridae	
<u>Noturus insignis</u>	Margined madtom
Family Percidae	
<u>Etheostoma flabellare</u>	Fantail darter
<u>Etheostoma nigrum</u>	Johnny darter
Family Centrarchidae	
<u>Ambloplites rupestris</u>	Rock bass
<u>Micropterus dolomieu</u>	Smallmouth bass
Family Anguillidae	
<u>Anguilla rostrata</u>	American eel

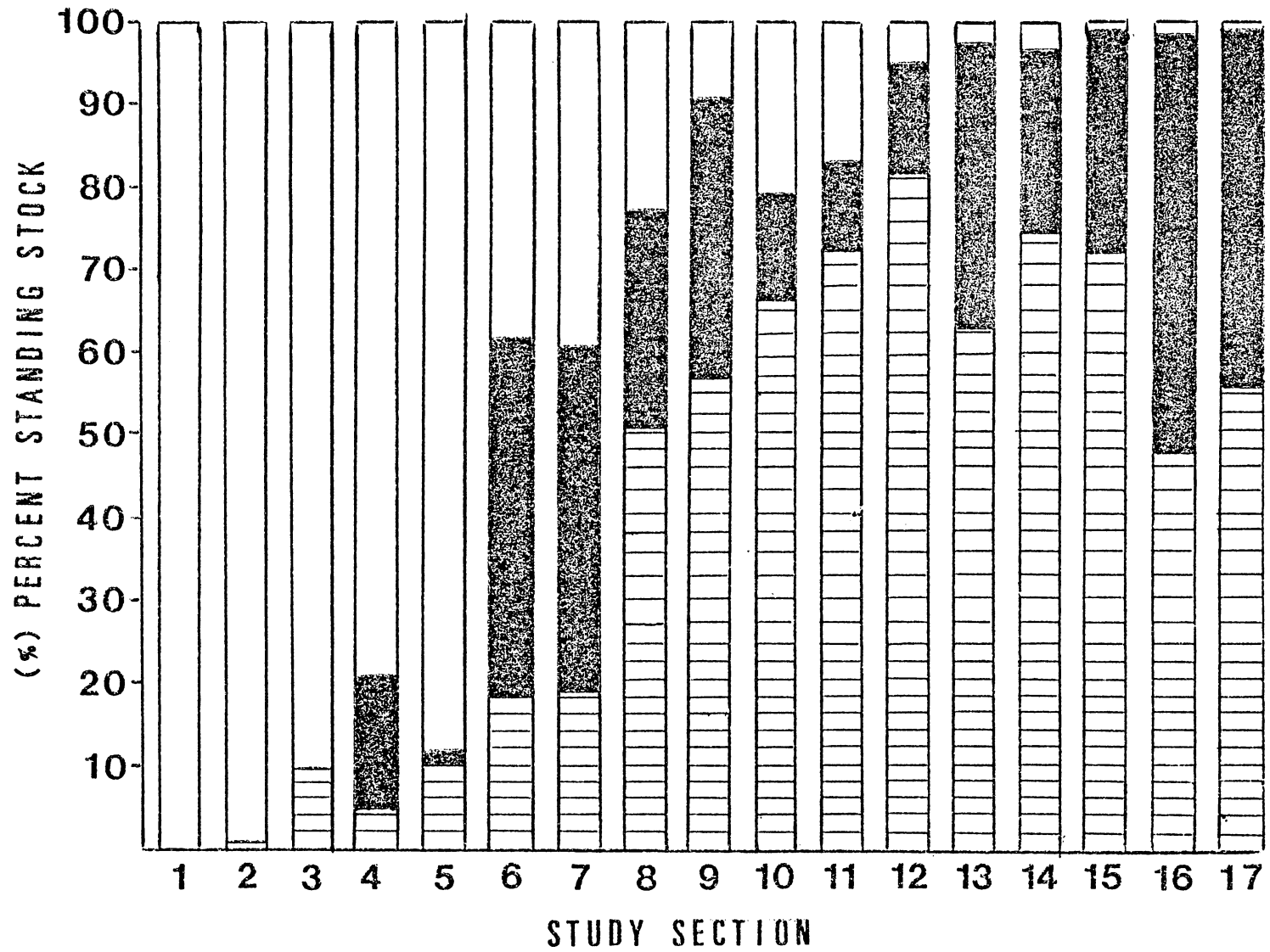
Table 4. Standing stocks (g/m²) and population estimates (in parentheses) of brook trout, brown trout and non-game fish in August 1981.

STREAM	STUDY SECTION	BROOK TROUT	BROWN TROUT	NON-GAME FISH
CONWAY RIVER	5	4.77 (140)	0.46 (2)	1.15 (22)
	7	2.42 (83)	0.99 (7)	4.02 (105)
	9	0.40 (12)	3.02 (12)	6.92 (86)
	11	0.29 (9)	0.11 (4)	2.71 (82)
	13	0.17 (4)	2.41 (15)	3.20 (90)
	15	0.01 (1)	7.46 (24)	6.00 (209)
	17	0.00 (0)	3.31 (8)	8.26 (175)
NORTH FORK THORNTON RIVER	1	2.64 (22)	0.00 (0)	2.53 (51)
	2	4.78 (25)	0.00 (0)	1.00 (22)
	3	3.19 (58)	0.00 (0)	2.22 (54)
	4	5.65 (58)	0.22 (1)	3.88 (67)
	6	12.00 (152)	1.84 (5)	20.01 (208)
	8	0.59 (39)	1.85 (2)	4.27 (133)
	9	3.35 (27)	3.53 (3)	7.13 (232)
NORTH FORK MOORMANS RIVER	1	2.45 (47)	0.00 (0)	2.61 (36)
	2	3.67 (152)	0.00 (0)	2.73 (81)
	3	5.08 (74)	0.34 (1)	2.78 (56)
	4	3.46 (80)	2.09 (4)	17.92 (128)
	5	1.17 (9)	1.41 (4)	6.39 (129)
	6	0.01 (1)	0.00 (0)	10.69 (219)
	7	0.00 (0)	0.00 (0)	10.13 (257)
HUGHES RIVER	1	11.35 (107)	0.00 (0)	0.00 (0)
	2	5.81 (68)	0.00 (0)	0.00 (0)
	3	4.97 (54)	0.00 (0)	0.00 (0)
	4	2.58 (28)	0.27 (5)	1.98 (82)
	5	0.93 (22)	0.17 (2)	1.00 (56)
	6	1.20 (50)	0.94 (5)	4.67 (186)
	7	0.42 (5)	2.22 (3)	9.36 (262)

Table 5. Standing stocks (g/m^2) and population estimates (in parentheses) of brook trout, brown trout and non-game fish in August 1982.

STREAM	STUDY SECTION	BROOK TROUT	BROWN TROUT	NON-GAME FISH
CONWAY RIVER	1	7.59 (170)	0.00 (0)	0.00 (0)
	2	6.05 (101)	0.00 (0)	0.02 (1)
	3	5.66 (124)	0.00 (0)	0.62 (17)
	4	4.05 (107)	0.74 (19)	0.28 (7)
	5	4.08 (89)	0.02 (1)	0.48 (13)
	6	2.25 (31)	2.46 (2)	1.09 (29)
	7	2.88 (94)	3.04 (5)	1.40 (40)
	8	1.22 (36)	1.40 (7)	2.63 (48)
	9	0.88 (29)	3.08 (13)	5.28 (52)
	10	0.85 (17)	0.54 (6)	2.77 (71)
	11	0.79 (18)	0.48 (16)	3.37 (78)
	12	0.11 (3)	0.28 (14)	1.78 (71)
	13	0.13 (1)	1.92 (14)	3.51 (55)
	14	0.23 (2)	1.50 (13)	5.06 (111)
	15	0.06 (1)	1.77 (20)	4.83 (104)
	16	0.11 (1)	4.16 (9)	3.98 (77)
	17	0.05 (1)	2.33 (20)	2.93 (97)
NORTH FORK THORNTON RIVER	1	5.74 (45)	0.00 (0)	1.26 (33)
	2	8.57 (36)	0.00 (0)	0.74 (26)
	3	5.11 (54)	0.00 (0)	1.55 (35)
	4	8.66 (76)	0.00 (0)	1.74 (36)
	5	3.36 (47)	0.22 (1)	1.55 (44)
	7	5.35 (89)	0.20 (6)	1.59 (60)
	8	1.10 (34)	2.35 (6)	4.17 (84)
	9	1.73 (32)	0.00 (0)	6.39 (100)
	10	1.45 (16)	2.29 (6)	2.41 (60)
	11	1.02 (6)	2.19 (3)	26.80 (54)

Figure 7. Percent composition of standing stocks of brook trout (white bars), brown trout (black bars) and non-game fish (hatched bars) in the Conway River on 2-5 August 1982.



populations but two rainbow trout were collected in the North Fork Moormans River in August 1981. The fish were captured in study section 6 and had been stocked in the spring of 1981 by VCGIF fishery personnel.

The only other salmonids collected were two age 1+ tiger trout (brook x brown trout hybrid) in the Conway River in August 1981. The hybrids were a product of natural reproduction since no stockings of hatchery fish have occurred in the Conway River for several years. These natural hybrids provided evidence that hybridization between brook and brown trout occasionally occurs in streams but the extremely low numbers encountered suggests this is an uncommon event.

The most abundant age groups of brook trout were ages 0+ and 1+. Relatively fewer age 2+ fish were encountered and age 3+ and 4+ fish were rare. The abundance of the age groups in each section generally followed the decreasing order of age 0+, 1+, 2+, 3+ and 4+ (Appendix Tables 1,2) for both years.

The most abundant age groups of brown trout were also ages 0+ and 1+. Greater numbers of age 2+, 3+ and 4+ brown trout were encountered than was the case for brook trout. The majority of age 2+, 3+ and 4+ brown trout were found in the lowermost study sections. These older age groups were occasionally found in some of the uppermost study sections,

notably the Conway River (Appendix Tables 3,4).

Brown trout were larger than brook trout at any given age in all streams (Appendix Tables 5,6). Average total lengths at age for brook and brown trout are represented by the relationships which existed in the Conway River on 2-5 August 1982 (Figure 8).

The abundance of non-game species increased in downstream sections (Tables 4,5). Non-game fishes also contributed a greater proportion to the total abundance and density of all fish species in downstream sections (Figure 7). The abundances and densities of individual non-game fish species in each study section are given in the Appendix (Tables 7,8,9,10,11,12).

Fish Species Associations

Three categories were designated to describe the occurrence of fish species relative to the distribution of brown trout. The categories were defined as follows: (1) species with no occurrence above the upstream limit of brown trout, (2) species with infrequent occurrence above the upstream limit of brown trout and (3) species with frequent occurrence above the upstream limit of brown trout. Each fish species was assigned to one of these categories (Table 6).

The fish species in category 3 typify the fish community composition of many headwater mountain streams

Figure 8. Average total length (mm) at age of brook trout (white bars) and brown trout (black bars) in the Conway River on 2-5 August 1982.

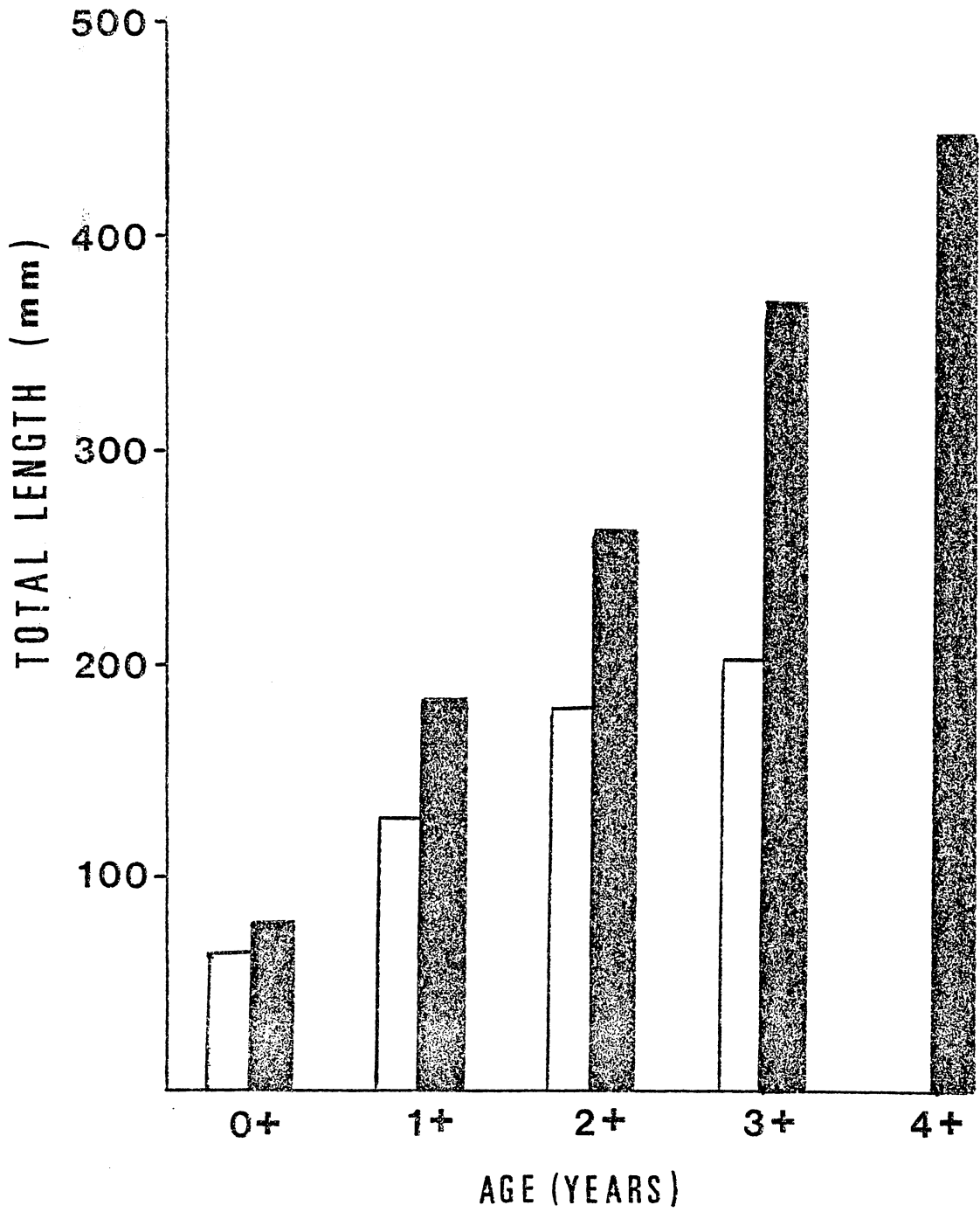


Table 6. Fish species groupings in relation to brown trout distribution in Shenandoah National Park waters.

CATEGORY 1 ¹	CATEGORY 2 ²	CATEGORY 3 ³
Mountain redbelly dace	Longnose dace	Brook trout
Stoneroller	Rosyside dace	Blacknose dace
White sucker	Torrent sucker	Mottled sculpin
Fallfish	Fantail darter	
Creek chub	Johnny darter	
River chub	American eel	
Bluehead chub		
Common shiner		
Margined madtom		
Northern hog sucker		
Cutlips minnow		
Rock bass		
Smallmouth bass		

¹ No occurrence above the upstream limit of brown trout.

² Infrequent occurrence above the upstream limit of brown trout.

³ Frequent occurrence above the upstream limit of brown trout.

throughout Virginia. Brown trout were not present in sections which were only occupied by brook trout, blacknose dace (Rhinichthys atratulus) and/or mottled sculpins (Cottus bairdi). Furthermore, these two non-game species were present in over 80 percent of the sections occupied by brown trout, indicating their widespread distribution in the study streams.

The fish species in category 1 were not found above the upstream limit of brown trout in any streams. Brown trout were present in 97 percent of the sections occupied by one or more of the category 1 species which included the mountain redbelly dace (Phoxinus oreas), stoneroller (Campostoma anomalum), white sucker (Campostoma commersoni), fallfish (Semotilus corporalis), creek chub (Semotilus atromaculatus), river chub (Nocomis micropogon), bluehead chub (Nocomis leptcephalus), common shiner (Notropis cornutus), margined madtom (Noturus insignis), northern hog sucker (Hypentelium nigricans), cutlips minnow (Exoglossum maxilllingua), rock bass (Ambloplites rupestris) and smallmouth bass (Micropterus dolomieu).

Of particular interest are the fish species in category 2. The occurrence of one or more of the category 2 species in 95 percent of the sections occupied by brown trout and infrequent occurrence above the upstream limit of brown trout may signify their value as indicators of a brown trout

transition zone. This transition zone is defined as the area in a stream where brown trout distribution becomes limited in an upstream direction. American eels (Anguilla rostrata) were not considered in the analysis because equal effort was not made to collect this species in quantitative electrofishing samples. Fantail darters (Etheostoma flabellare) and Johnny darters (Etheostoma nigrum) were also excluded from the analysis because of identification problems in the field which necessitated grouping these species under the heading of darter.

The associations between brown trout and the species in category 2, longnose dace (Rhinichthys cataractae), rosyside dace (Clinostomus funduloides) and torrent sucker (Moxostoma rhothoecum), were analyzed with a chi-square test for independence based on presence and absence criteria (Hurlbert 1969, Krebs 1978). Actual data for computation of the test statistics and coefficients of association is given in the Appendix (Table 13). The chi-square tests for independence provided strong evidence that significant associations exist between longnose dace (p-value <0.0005), rosyside dace (p-value <0.0005), torrent suckers (p-value <0.02) and brown trout. The coefficients of association were positive for longnose dace (+0.643), rosyside dace (+0.508) and torrent suckers (+0.403) (Table 7).

The described fish species assemblages occurred across

Table 7. Results of chi-square tests for independence of brown trout and non-game fish species associations in Shenandoah National Park waters.

SPECIES	SAMPLE SIZE	CHI-SQUARE STATISTIC	P-VALUE	ASSOCIATION COEFFICIENT
Longnose dace	66	27.322	<0.0005	+0.643
Rosyside dace	66	17.003	<0.0005	+0.508
Torrent sucker	37	6.010	<0.02	+0.403

six streams in different years including: (1) the Conway and North Fork Thornton Rivers in August 1981 and 1982, (2) the North Fork Moormans and Hughes Rivers in August 1981 and (3) the Rose and St. Mary's Rivers in June 1976. These assemblages are useful in identifying the presence or absence of brown trout due to their consistent occurrence relative to brown trout distribution.

Physical and Chemical Measurements

Five physical characteristics of the stream channels were measured: depth, width, gradient, discharge and percent pool. Ranges of these values (Table 8) and actual measurements for each study section (Appendix Tables 14,15) are given for August, 1981 and 1982. The sizes of the study streams, in increasing order of depth, width and discharge were the North Fork Thornton, North Fork Moormans, Hughes and Conway Rivers. The ranges of gradient and percent pool were similar for the four study streams.

Cover was measured as percent instream cover and percent canopy cover. Ranges of these measurements (Table 8) and actual measurements for each study section (Appendix Tables 16,17) are given for August, 1981 and 1982. The overall range for instream cover was 1.1 to 10.3 percent. Each stream displayed a range of percent instream cover encompassed by the overall range; i.e. streams had similar ranges of percent instream cover. The general trend was for

Table 8. Range of values for selected physical parameters and cover measurements among study sections in the Conway, North Fork Thornton, North Fork Moormans and Hughes Rivers in August 1981 and 1982.

STREAM	AVERAGE DEPTH (m)	AVERAGE WIDTH (m)	GRADIENT (ft/mile)	DISCHARGE (m ³ /sec)	POOL (%)	INSTREAM COVER (%)	CANOPY COVER (%)
CONWAY RIVER (1981)	0.14- 0.20	4.4- 6.5	124.2- 390.4	0.099- 0.252	35.5- 74.1	1.6- 9.1	30- 85
CONWAY RIVER (1982)	0.13- 0.22	4.3- 11.3	124.2- 460.1	0.069- 0.367	22.7- 80.4	2.3- 6.5	40- 80
NORTH FORK THORNTON RIVER (1981)	0.06- 0.17	2.2- 4.2	117.0- 429.3	0.003- 0.009	41.6- 81.1	2.0- 8.3	40- 90
NORTH FORK THORNTON RIVER (1982)	0.08- 0.20	2.5- 5.6	89.4- 429.3	0.002- 0.066	5.1- 83.1	1.6- 10.3	60- 90
NORTH FORK MOORMANS RIVER (1981)	0.08- 0.21	3.3- 4.6	184.0- 279.7	0.005- 0.057	41.6- 78.1	1.1- 5.5	50- 85
HUGHES RIVER (1981)	0.15- 0.28	3.7- 6.5	161.0- 643.9	0.022- 0.149	39.3- 69.1	2.0- 9.4	80- 85

percent canopy cover to decrease in the wider, downstream study sections.

Bottom substrate was measured as percent spawning substrate, bedrock, boulder, rubble, gravel and silt. Ranges of these measurements (Table 9) and actual measurements for each study section (Appendix Tables 18,19) are given for August, 1981 and 1982. Low percentages of spawning substrate were found in all study sections with an overall range of 0.0-3.0 percent. Bedrock was exposed in some sections. Silt did not exceed 30.0 percent in any section, probably due to the steep gradients and forested watersheds through which the streams flow. The predominant bottom materials were boulder, rubble and gravel.

The chemical properties measured were pH, conductivity and alkalinity. Ranges of these measurements (Table 10) and actual measurements for each study section (Appendix Tables 20,21) are given for August, 1981 and 1982. The streams displayed a narrow overall range of chemical properties: pH 6.4-7.3, conductivity 20-60 $\mu\text{mhos/cm}$ and alkalinity 10-40 mg/L CaCO_3 . These values characterize the streams as relatively infertile. There was little variation in chemical parameters within an individual stream but some variation existed among streams.

Ranges of maximum stream temperatures (Table 10) and actual measurements for each study section (Appendix Tables

Table 9. Range of values for percent bottom substrate types among study sections in the Conway, North Fork Thornton, North Fork Moormans and Hughes Rivers in August 1981 and 1982.

STREAM	SPAWNING SUBSTRATE (%)	BEDROCK (%)	BOULDER (%)	RUBBLE (%)	GRAVEL (%)	SILT (%)
CONWAY RIVER (1981)	0.0- 3.1	0.0- 0.0	28.9- 64.3	22.4- 51.3	9.0- 33.8	0.5- 5.6
CONWAY RIVER (1982)	0.2- 2.6	0.0- 32.2	30.2- 60.5	19.0- 42.6	11.4- 27.9	0.6- 9.9
NORTH FORK THORNTON RIVER (1981)	0.3- 3.0	0.0- 10.2	15.9- 31.0	12.9- 32.8	22.4- 59.7	7.7- 27.8
NORTH FORK THORNTON RIVER (1982)	0.7- 2.8	0.0- 7.5	7.3- 40.7	22.2- 55.7	13.8- 28.4	2.9- 10.4
NORTH FORK MOORMANS RIVER (1981)	0.2- 2.5	0.0- 7.1	17.1- 34.7	19.4- 37.1	29.9- 40.0	5.1- 11.6
HUGHES RIVER (1981)	0.5- 2.0	0.0- 0.0	26.9- 51.1	21.8- 34.4	19.0- 27.7	0.7- 8.7

Table 10. Range of values for chemical parameters and maximum temperatures among study sections in the Conway, North Fork Thornton, North Fork Moormans and Hughes Rivers in August 1981 and 1982.

STREAM	pH	CONDUCTIVITY (μ mhos/cm)	ALKALINITY (mg/L CaCO_3)	MAXIMUM TEMPERATURE ($^{\circ}\text{C}$)
CONWAY RIVER (1981)	6.4- 6.9	20- 28	25- 30	18.0- 21.0
CONWAY RIVER (1982)	6.5- 6.8	21- 28	15- 25	16.5- 22.0
NORTH FORK THORNTON RIVER (1981)	7.1- 7.3	40- 60	20- 30	19.0- 21.0
NORTH FORK THORNTON RIVER (1982)	6.9- 7.0	39- 51	30- 40	20.0- 21.5
NORTH FORK MOORMANS RIVER (1981)	7.0- 7.1	25- 31	25- 30	20.0- 21.0
HUGHES RIVER (1981)	6.8- 7.1	20- 25	10- 20	17.0- 20.0

20,21) are given for August, 1981 and 1982. The Conway River displayed a strong thermal gradient, 16.5 °C in the uppermost section to 22.0 °C in the lowermost section. The Hughes River had a weaker thermal gradient of 17.0-20.0 °C. There were stenothermal conditions in the North Fork Thornton and North Fork Moormans Rivers with maximum temperature ranges of 19.0-21.0 °C and 20.0-21.0 °C, respectively.

Class 3, 4 and 5 pools were the most abundant in all study sections in August 1981 and 1982. These lower quality pools occurred throughout the lengths of all streams with no apparent trends in frequency of occurrence in specific areas (i.e. upstream, downstream areas). Higher quality class 1 pools were rare and class 2 pools were relatively scarce. The Conway River had the greatest number of class 1 and 2 pools followed by the Hughes, North Fork Thornton and North Fork Moormans Rivers. Class 1 and 2 pools occurred throughout the Conway and Hughes Rivers but were restricted to the lowermost study sections in the North Fork Thornton River. Only two of these higher quality pools were found in the North Fork Moormans River (Tables 11,12).

Statistical Analysis

Abundance : Correlations and Regression Models

Pearson product moment correlation coefficients were determined between (1) each dependent variable and the

Table 11. Frequency of pool classes in the Conway, North Fork Thornton, North Fork Moormans and Hughes Rivers in August 1981.

STREAM	STUDY SECTION	POOL CLASS					Total
		1	2	3	4	5	
CONWAY RIVER	5	0	1	1	3	1	6
	7	0	1	3	5	0	9
	9	0	0	5	3	0	8
	11	0	0	1	2	2	5
	13	0	2	0	5	1	6
	15	0	0	4	6	1	11
	17	0	0	3	1	1	5
NORTH FORK THORNTON RIVER	1	0	0	0	5	4	9
	2	0	0	1	6	3	10
	3	0	0	1	5	1	7
	4	0	0	3	2	0	5
	6	1	0	0	2	2	5
	8	0	2	0	1	1	4
	9	0	0	1	7	0	8
NORTH FORK MOORMANS RIVER	1	0	0	0	2	4	6
	2	0	0	2	3	3	8
	3	1	0	3	2	1	7
	4	0	1	2	3	1	7
	5	0	0	2	6	2	10
	6	0	0	1	2	2	5
	7	0	0	0	6	3	9
HUGHES RIVER	1	0	2	2	2	0	6
	2	0	0	7	0	0	7
	3	0	1	1	4	0	6
	4	0	1	0	4	0	5
	5	0	1	3	2	0	6
	6	0	1	0	4	1	6
	7	0	0	2	1	1	4

Table 12. Frequency of pool classes in the Conway and North Fork Thornton Rivers in August 1982.

STREAM	STUDY SECTION	POOL CLASS					Total
		1	2	3	4	5	
CONWAY RIVER	1	0	0	0	2	1	3
	2	1	2	0	0	2	5
	3	0	1	1	3	0	5
	4	0	0	2	1	1	4
	5	0	1	1	2	1	5
	6	1	1	4	1	0	7
	7	0	1	4	3	0	8
	8	0	1	1	2	1	5
	9	0	2	2	4	0	8
	10	0	0	4	2	0	6
	11	0	0	1	2	0	3
	12	0	0	5	2	0	7
	13	0	1	5	1	1	8
	14	0	1	3	2	0	6
	15	0	2	3	3	0	8
	16	1	1	0	4	1	7
	17	0	0	4	2	2	8
NORTH FORK THORNTON RIVER	1	0	0	0	7	2	9
	2	0	0	3	4	1	8
	3	0	0	3	3	0	6
	4	0	0	1	3	0	4
	5	0	0	1	0	0	1
	7	0	1	0	3	0	4
	8	0	2	0	0	1	3
	9	0	0	2	6	0	8
	10	0	0	1	2	1	4
	11	1	1	0	1	0	3

independent variables and (2) each independent variable and the other independent variables. Significant correlations (p -value <0.05) existed between trout standing stocks and some of the independent variables in both August 1981 and August 1982. Brook trout standing stocks were positively correlated with the gradient variable (X4) and percent canopy cover (X8) and negatively correlated with average width (X3), discharge (X5) and maximum temperature (X18). Brown trout standing stocks were positively correlated with discharge (X5) and negatively correlated with percent canopy cover (X8) (Tables 13,14).

Significant correlations (p -value <0.05) existed between independent variables in both August 1981 and August 1982. Notably, positive correlations existed for (1) average width (X3) with average depth (X2) and discharge (X5) and (2) percent boulder (X11) with average depth (X2) and discharge (X5). The consistent positive correlations from year to year between average depth, average width and discharge indicates that these three variables represent a more general variable termed stream size. The correlation of percent boulder with average depth and discharge in both years indirectly relates this parameter to stream size. There is a high degree of inter-correlation among the independent variables especially substrate types (Tables 15,16).

Table 13. Matrix of significant (p-value <0.05) positive (+) and negative (-) correlations between dependent and independent variables in August 1981.

INDEPENDENT VARIABLE		DEPENDENT VARIABLE		
		BROOK TROUT (Y1)	BROWN TROUT (Y2)	TOTAL TROUT (Y3)
Non-game S.S.	(X1)	-	+	
Average Depth	(X2)			+
Average Width	(X3)	-		
Gradient	(X4)	+	-	
Discharge	(X5)	-	+	
Pool (%)	(X6)			
Instream Cover (%)	(X7)	+		+
Canopy Cover (%)	(X8)	+	-	
Spawning Substrate (%)	(X9)			
Bedrock (%)	(X10)			
Boulder (%)	(X11)			
Rubble (%)	(X12)			
Gravel (%)	(X13)			
Silt (%)	(X14)			
pH	(X15)		-	
Conductivity	(X16)			
Alkalinity	(X17)			
Maximum Temperature	(X18)	-	+	

Table 14. Matrix of significant (p-value <0.05) positive (+) and negative (-) correlations between dependent and independent variables in August 1982.

INDEPENDENT VARIABLE		DEPENDENT VARIABLE		
		BROOK TROUT (Y1)	BROWN TROUT (Y2)	TOTAL TROUT (Y3)
Non-game S.S.	(X1)			
Average Depth	(X2)	-	+	-
Average Width	(X3)	-	+	-
Gradient	(X4)	+		+
Discharge	(X5)	-	+	-
Pool (%)	(X6)	-	+	-
Instream Cover (%)	(X7)			
Canopy Cover (%)	(X8)	+	-	
Spawning Substrate (%)	(X9)	+		+
Bedrock (%)	(X10)	+		+
Boulder (%)	(X11)	-	+	
Rubble (%)	(X12)			
Gravel (%)	(X13)	+	-	
Silt (%)	(X14)			
pH	(X15)			
Conductivity	(X16)			+
Alkalinity	(X17)			
Maximum Temperature	(X18)	-		

Table 15. Matrix of significant (p-value <0.05) positive (+) and negative (-) correlations between independent variables in August 1981.

INDEPENDENT VARIABLE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Non-game S.S.	(X1)																		
Average Depth	(X2)		.																
Average Width	(X3)			+															
Gradient	(X4)		-																
Discharge	(X5)				+														
Pool (%)	(X6)																		
Instream Cover (%)	(X7)			+		+													
Canopy Cover (%)	(X8)						-												
Spawning Substrate (%)	(X9)																		
Bedrock (%)	(X10)																		
Boulder (%)	(X11)			+	+		+												
Rubble (%)	(X12)				+		+												
Gravel (%)	(X13)			-	-		-			+		-	-						
Silt (%)	(X14)			-	-		-					-	-	+					
pH	(X15)			-	-		-		+			-	-	+	+				
Conductivity	(X16)			-	-		-					-	-	+	+	+			
Alkalinity	(X17)			-	-		-					-				+			
Maximum Temperature	(X18)	+			-			-							+			+	

Table 16. Matrix of significant (p-value <0.05) positive (+) and negative (-) correlations between independent variables in August 1982.

INDEPENDENT VARIABLE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Non-game S.S.	(X1)																		
Average Depth	(X2)																		
Average Width	(X3)		+																
Gradient	(X4)	-																	
Discharge	(X5)		+	+															
Pool (%)	(X6)		+	+															
Instream Cover (%)	(X7)																		
Canopy Cover (%)	(X8)				+														
Spawning Substrate (%)	(X9)			-		-			+										
Bedrock (%)	(X10)				+														
Boulder (%)	(X11)		+	-		+	+												
Rubble (%)	(X12)				-							-							
Gravel (%)	(X13)		-	-		-						-							
Silt (%)	(X14)				-							-							
pH	(X15)		-	-		-						-	+		+				
Conductivity	(X16)		-	-		-						-	+	+	+	+			
Alkalinity	(X17)		-	-		-						-		+	+	+	+		
Maximum Temperature	(X18)				+						+				+	+	+		

Multiple regression procedures were used to develop several models which were evaluated with three criteria: mean square error (MSE), R-square and PRESS statistic. The best models were selected for each dependent variable for August, 1981 and 1982, based on the above criteria (Appendix Tables 22,23). The models developed for August 1981 and 1982 were each based on 27 observations (i.e. study sections). Section 6 on the North Fork Thornton River was excluded from the analysis for development of the August 1981 models. Large numbers of salmonid and non-game fish species were crowded into one large pool in this section. Areas upstream and downstream from the section were practically dewatered which undoubtedly forced many fish into the section to create an atypical situation.

The best predictive models for brook trout standing stocks (Y1) were:

$$(1) \quad Y1 = -0.13(X1) + 19.33(X2) - 0.73(X3) + 0.04(X6) + 0.54(X7) \\ + 0.04(X8) - 0.06(X11) - 0.05(X16)$$

$$(2) \quad Y1 = 6.66 - 21.65(X2) - 0.52(X3) + 0.01(X4)$$

for 1981 and 1982, respectively (Table 17). The R^2 values were 0.9134 for the 1981 model and 0.8058 for the 1982 model. Independent variables common to both models were average depth (X2) and average width (X3). However, the sign of the beta coefficient is only consistent in both

Table 17. The "best" predictive regression models for brook trout (Y1), brown trout (Y3) and total trout (Y3) standing stocks in August 1981 and 1982.

YEAR	DEPENDENT VARIABLE	INDEPENDENT VARIABLE	COEFFICIENT	R-SQUARE	
1981	Brook Trout (Y1)	Non-game S.S.	(X1)	-0.13	0.9134
		Average Depth	(X2)	19.33	
		Average Width	(X3)	-0.73	
		Pool (%)	(X6)	0.04	
		Instream Cover (%)	(X7)	0.54	
		Canopy Cover (%)	(X8)	0.04	
		Boulder (%)	(X11)	-0.06	
		Conductivity	(X16)	-0.05	
	Brown Trout (Y2)	Discharge	(X5)	19.19	0.7769
		Pool (%)	(X6)	0.07	
		Rubble (%)	(X12)	-0.05	
		pH	(X15)	-1.70	
		Conductivity	(X16)	0.05	
		Maximum Temperature	(X18)	0.40	
	Total Trout (Y3)	Average Depth	(X2)	22.47	0.7622
		Average Width	(X3)	-0.84	
		Discharge	(X5)	11.65	
		Pool (%)	(X6)	0.07	
Instream Cover (%)		(X7)	0.48		
Boulder (%)		(X11)	-0.07		
1982	Brook Trout (Y1)	Y-Intercept		6.66	0.8058
		Average Depth	(X2)	-21.65	
		Average Width	(X3)	-0.52	
		Gradient	(X4)	0.01	
	Brown Trout (Y2)	Y-Intercept		-34.89	0.7701
		Average Depth	(X2)	25.01	
		Pool (%)	(X6)	-0.03	
		Canopy Cover (%)	(X8)	-0.03	
		Boulder (%)	(X11)	0.06	
		pH	(X15)	4.22	
		Maximum Temperature	(X18)	0.24	
	Total Trout (Y3)	Y-Intercept		3.25	0.7185
		Average Width	(X3)	-0.37	
		Gradient	(X4)	0.01	
		Silt (%)	(X14)	-0.20	
Conductivity		(X16)	0.07		

models for average width (i.e. negative). Other variables in the models were non-game fish standing stocks (X1), gradient (X4), percent pool (X6), percent instream cover (X7) and percent canopy cover (X8), percent boulder (X11) and conductivity (X16).

The best predictive models for brown trout standing stocks (Y2) were:

$$(1) \quad Y2 = 19.19(X5) + 0.07(X6) - 0.05(X12) - 1.70(X15) \\ + 0.05(X16) + 0.40(X18)$$

$$(2) \quad Y2 = -34.89 + 25.01(X2) - 0.03(X6) - 0.03(X8) + 0.06(X11) \\ + 4.22(X15) + 0.24(X18)$$

for 1981 and 1982, respectively (Table 17). The R^2 values were 0.7769 for the 1981 model and 0.7701 for the 1982 model. Independent variables common to both models were percent pool (X6), pH (X15) and maximum temperature (X18). The sign of the beta coefficient is only consistent in both models for maximum temperature (i.e. positive). Other variables in the models were average depth (X2), discharge (X5), percent canopy cover (X8), percent boulder (X11), percent rubble (X12) and conductivity (X16).

The best predictive models for total trout standing stocks (Y3) were:

$$(1) \quad Y3 = 22.47(X2) - 0.84(X3) + 11.65(X5) + 0.07(X6) + 0.48(X7) - 0.07(X11)$$

$$(2) \quad Y3 = 3.25 - 0.37(X3) + 0.01(X4) - 0.20(X14) + 0.07(X16)$$

for 1981 and 1982, respectively (Table 17). The R^2 values were 0.7622 for the 1981 model and 0.7185 for the 1982 model. The independent variable common to both models was average width (X3). The sign of the beta coefficient is consistent in both models for average width (i.e. negative). Other variables in the models were average depth (X2), gradient (X4), discharge (X5), percent pool (X6), percent instream cover (X7), percent boulder (X11), percent silt (X14) and conductivity (X16).

The predictive capabilities of the multiple regression models were examined using plots of (1) observed standing stocks in 1981 versus predicted standing stocks using the 1982 models and (2) observed standing stocks in 1982 versus predicted standing stocks using 1981 models. These plots demonstrate the poor predictive capabilities of the models for brook trout (Figure 9), brown trout (Figure 10) and total trout (Figure 11) from year to year.

Distribution : Discriminant Function Models

Discriminant function analysis procedures were used to develop the best predictive models for the discrimination of three groups designated for percentages of brook and brown

Figure 9. Plots of observed brook trout standing stocks (g/m^2) in 1981 and 1982 versus brook trout standing stocks predicted with 1982 and 1981 multiple regression models, respectively.

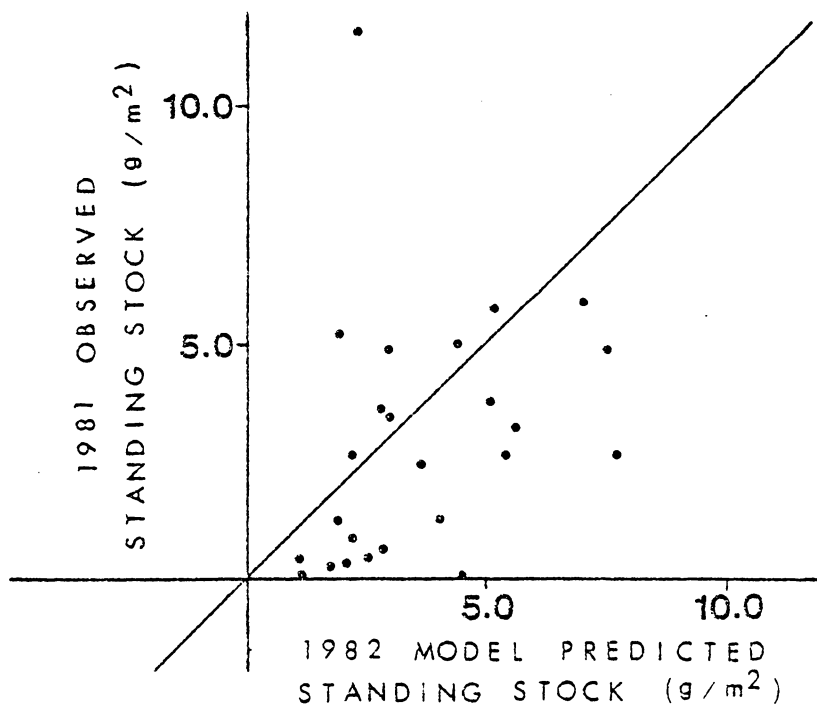
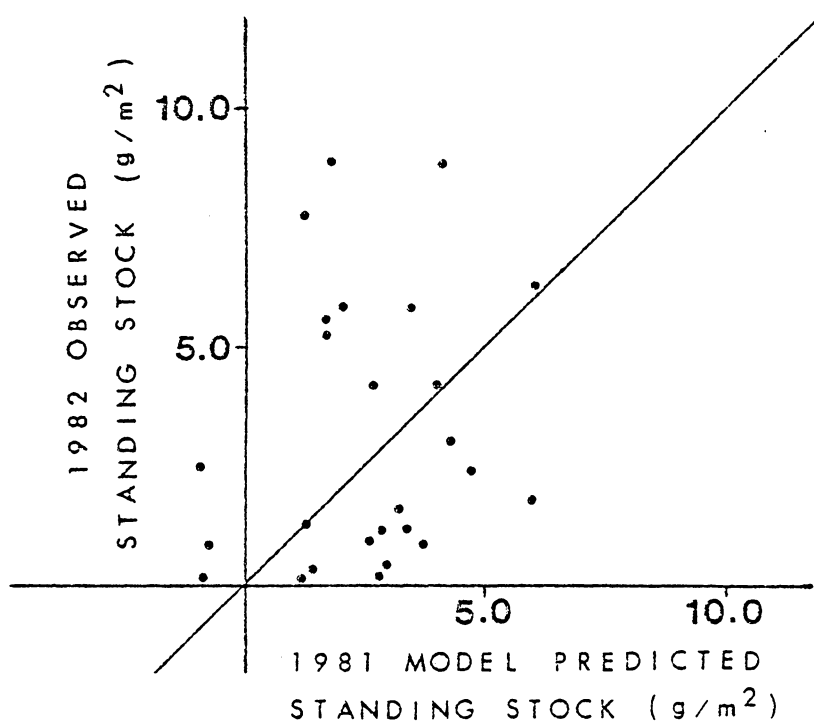


Figure 10. Plots of observed brown trout standing stocks (g/m^2) in 1981 and 1982 versus brown trout standing stocks predicted with 1982 and 1981 multiple regression models, respectively.

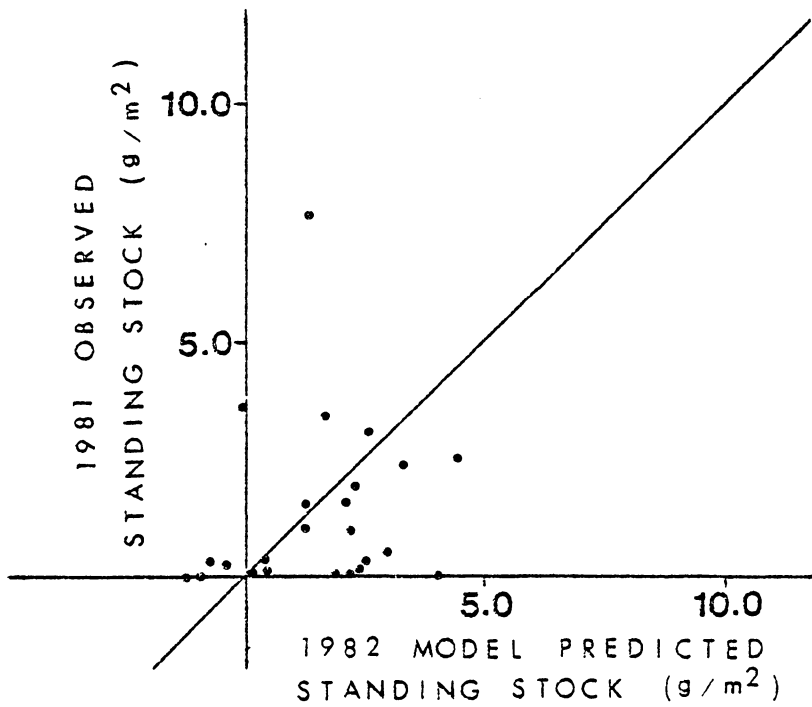
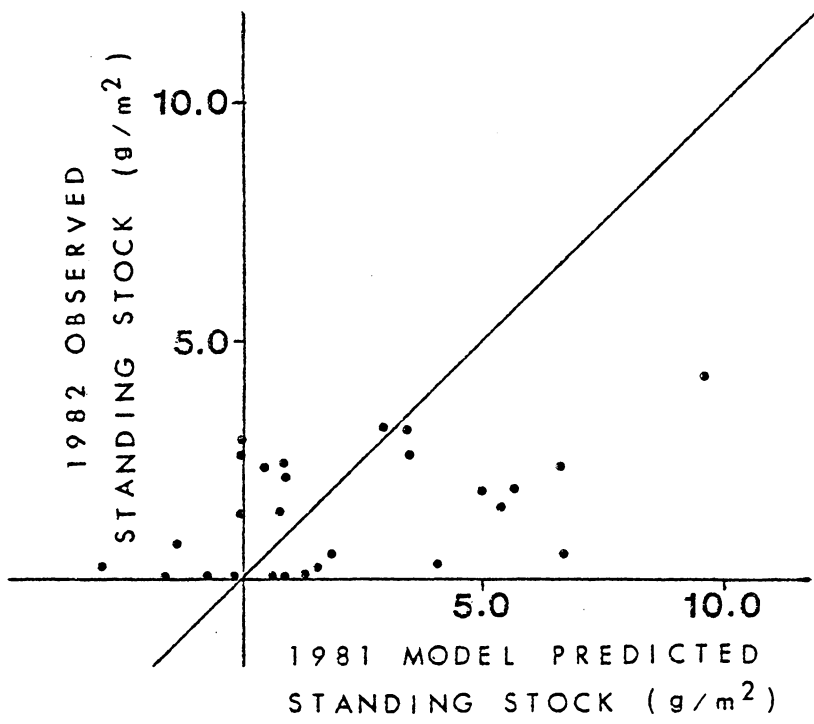
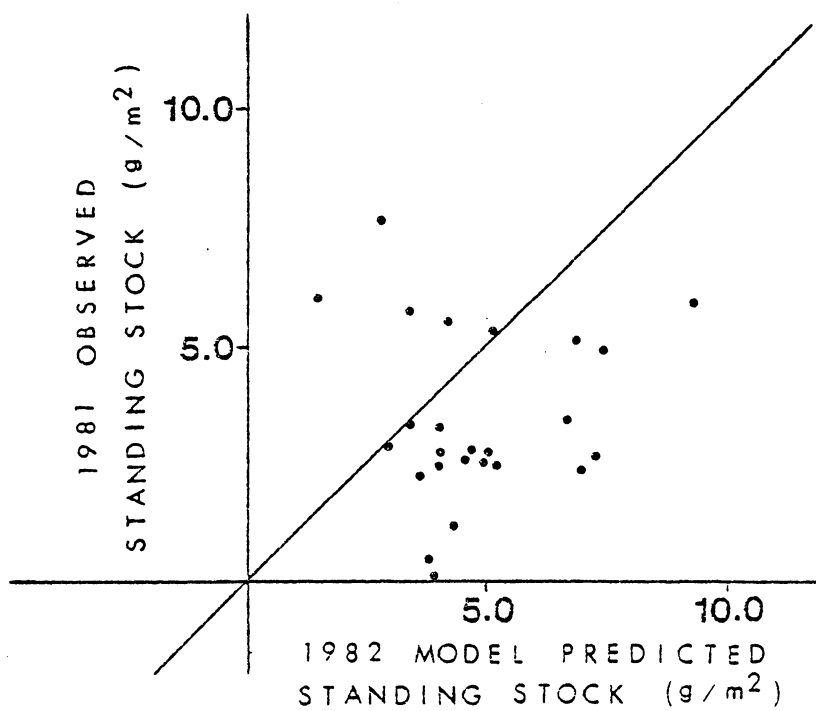
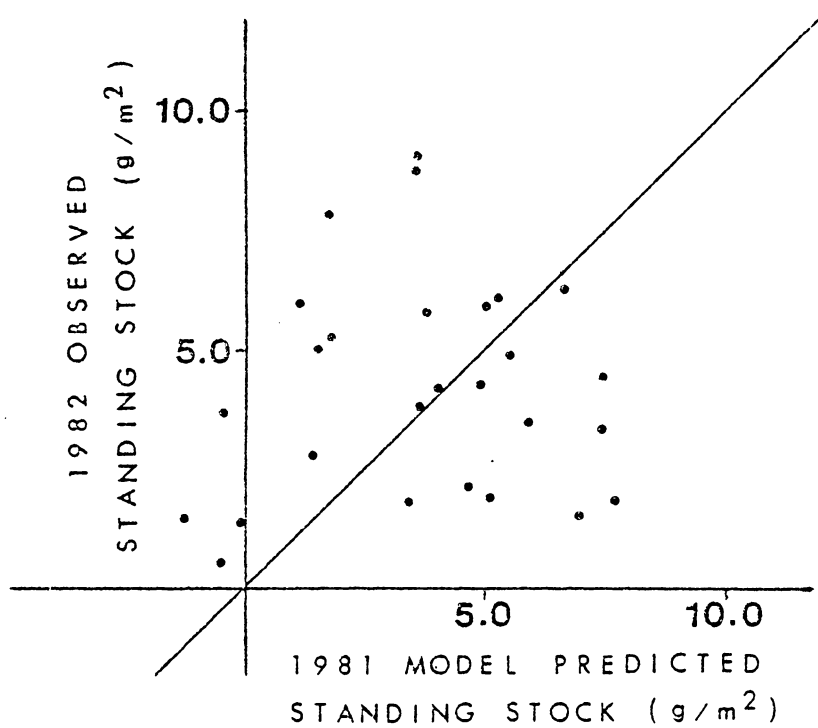


Figure 11. Plots of observed total trout standing stocks (g/m^2) in 1981 and 1982 versus brown trout standing stocks predicted with 1982 and 1981 multiple regression models, respectively.



trout standing stocks. The best discriminant function models included the following variables:

(1) X3 X5 X11 X16 X18

(2) X2 X3 X6 X7 X8 X11 X15 X17 X18

for 1981 and 1982, respectively (Table 18). The independent variables common to both models were average width (X3), percent boulder (X11) and maximum temperature (X18). Other variables in the models were average depth (X2), discharge (X5), percent pool (X6), percent instream cover (X7), percent canopy cover (X8), pH (X15), conductivity (X16) and alkalinity (X17).

The 1981 model was developed and then validated with the same data set. The percent correct prediction based on this method of validation was 93.3% for group 1, 66.7% for group 2 and 100.0% for group 3. The same validation procedure for the 1982 model resulted in 100.0% correct prediction for all three groups.

The predictive capabilities of the discriminant function models were examined for (1) the percent correct prediction of the 1982 groups with the 1981 model and (2) the correct percent prediction of the 1981 groups with the 1982 model. The 1981 model correctly predicted the actual 1982 groups as follows: 41.6% group 1, 55.6% group 2 and 83.3% group 3. The 1982 model correctly predicted the

Table 18. Independent variables and coefficients of the "best" predictive discriminant function models for groups 1, 2 and 3 in August 1981 and 1982. Groups defined by percentage standing stocks as follows: group 1 (>75% brook trout), group 2 (25-75% brook and brown trout) and group 3 (>75% brown trout).

YEAR	INDEPENDENT VARIABLE	GROUP		
		1	2	3
1981	Constant	-380.274	-420.072	-501.178
	Average Width (X3)	5.685	7.032	5.784
	Discharge (X5)	260.632	276.239	360.527
	Boulder (%) (X11)	2.761	2.850	3.313
	Conductivity (X16)	2.359	2.509	2.990
	Maximum Temperature (X18)	30.067	31.337	33.657
1982	Constant	-23602.280	-24588.327	-25519.921
	Average Depth (X2)	26919.995	27602.154	28276.475
	Average Width (X3)	89.152	92.199	93.538
	Pool (%) (X6)	-1.051	-1.253	-1.077
	Instream Cover (%) (X7)	-439.539	-488.299	-461.175
	Canopy Cover (%) (X8)	-13.700	-14.161	-15.104
	Boulder (%) (X11)	53.080	54.333	56.069
	pH (X15)	6766.839	6894.393	7017.972
	Alkalinity (X17)	33.163	34.057	35.807
	Maximum Temperature (X18)	-108.540	-107.438	-108.986

actual 1981 groups as follows: 21.4% group 1, 50.0% group 2 and 100.0% group 3. The overall correct classification percentages of the 1981 and 1982 models were 55.6% and 42.9%, respectively (Table 19).

Average stream width and maximum stream temperature have been identified as the two environmental factors consistently related to the abundance and distribution of brook and brown trout in the streams investigated. The relationship between brook trout standing stocks and average stream width was negative while that between brown trout standing stocks and maximum stream temperature was positive. In addition, the distribution of both species was consistently related in both years to average stream width and maximum stream temperature. Graphic representation of the relationships between these two factors and average standing stocks of brook and brown trout, in August 1981 and 1982 combined, strongly support the results of the multiple regression and discriminant function analysis multivariate screening techniques (Figures 12,13).

Objective (2) : Brown Trout Movements

The populations of brook and brown trout in the Conway River and North Fork Thornton River where brown trout movements were assessed were very dissimilar. The June 1981 mark-recapture population estimates for (1) the Conway River were 203 brown trout and 33 brook trout and (2) the North

Table 19. Prediction of study section groups in August 1982 and 1981 using discriminant function models developed for August 1981 and 1982, respectively. Groups defined by percentage standing stocks as follows: group 1 (>75% brook trout), group 2 (25-75% brook and brown trout) and group 3 (>75% brown trout).

YEAR	ACTUAL GROUP	(PREDICTED GROUP)			TOTAL CORRECT PREDICTION
		(1)	(2)	(3)	
1982	1	12(5)	0(4)	0(3)	12(5)
	2	0(0)	9(5)	0(4)	9(5)
	3	0(0)	0(1)	6(5)	6(5)
	TOTAL				27(15)
1981	1	14(3)	0(7)	0(4)	14(3)
	2	0(0)	6(3)	0(3)	6(3)
	3	0(0)	0(0)	6(6)	6(6)
	TOTAL				28(12)

Figure 12. Average standing stocks of brook and brown trout in all streams, in August 1981 and 1982 combined, versus average stream width.

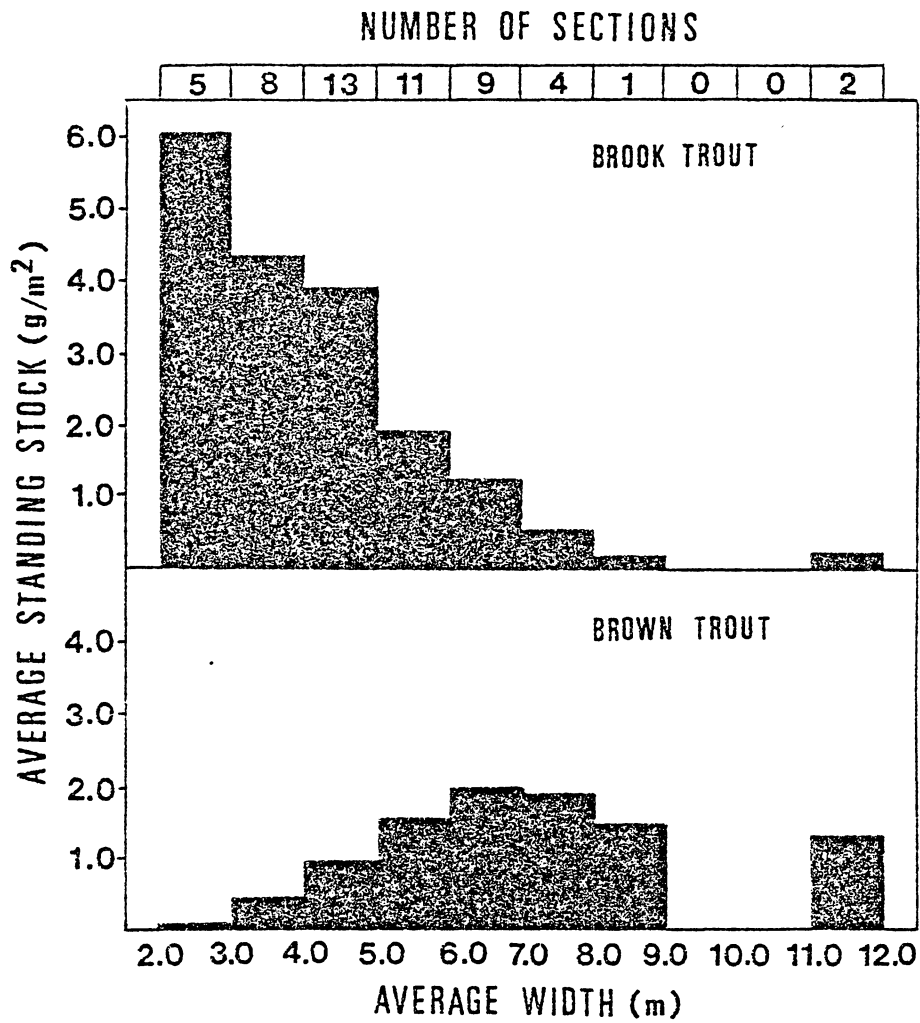
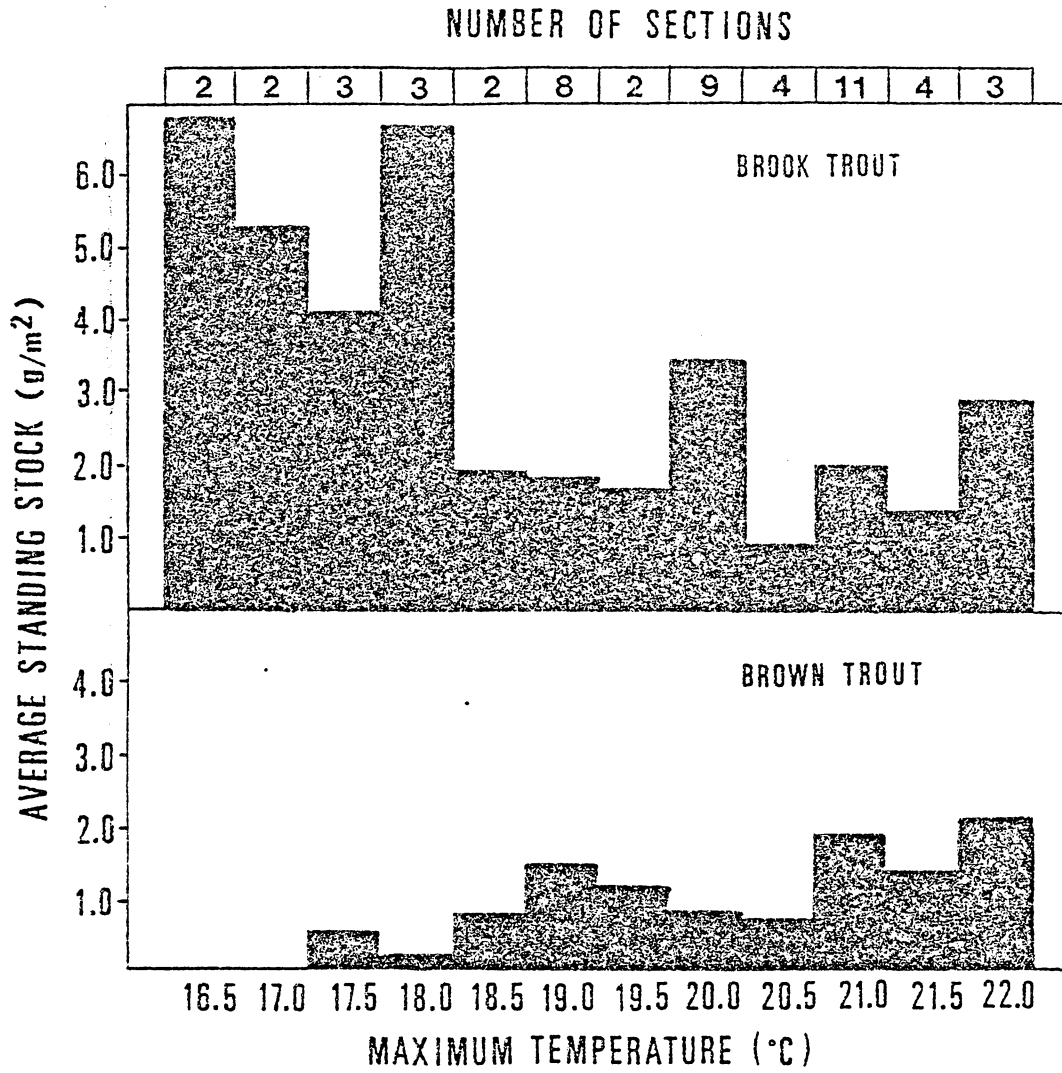


Figure 13. Average standing stocks of brook and brown trout in all streams, in August 1981 and 1982 combined, versus maximum stream temperature.



Fork Thornton River were 18 brown trout and 1509 brook trout in the lower 1600 m. These relative abundances of brook and brown trout were consistent for each stream throughout the duration of the study.

Originally, the objective was to monitor brown trout movements in the uppermost 2400 m of their range in each stream. The upstream limit of brown trout was adequately approximated in the North Fork Thornton River in the June 1981 survey but was not adequately approximated in the Conway River. Therefore, brown trout movements in the North Fork Thornton River were assessed in the uppermost area of their range while those in the Conway River were assessed in an area approximately 3.0 km downstream from their upstream limit.

Net Movements

Brown trout movements were monitored in the Conway and North Fork Thornton Rivers from June 1981 through July 1982. Movements of brown trout are summarized in Tables 20 and 21 for the Conway and North Fork Thornton Rivers, respectively.

The 1980 year class (i.e. age 1+ in 1981 and age 2+ in 1982) was the only group to display substantial movement during any time period in both streams. Movements of the 1980 year class in the Conway River resulted in small net (i.e. mean) upstream advances of less than 80 m for each time period. The 1979, 1973 and 1977 year classes did not

Table 20. Net movements (m) of brown trout in the Conway River from 15 June 1981 to 12 July 1982.

TIME INTERVAL	YEAR CLASS			
	1980	1979	1978	1977
15 June 1981 - 25 October 1981	+42 ¹ (38) ³	0 (4)	0 (1)	0 (1)
15 June 1981 - 10 April 1982	+67 (9)	0 (1)	- (0)	0 (1)
15 June 1981 - 12 July 1982	+75 (4)	- (0)	- (0)	- (0)
25 October 1981 - 10 April 1982	+5 (21)	-50 ² (2)	- (0)	0 (1)
25 October 1981 - 12 July 1982	+38 (16)	0 (2)	0 (1)	- (0)
10 April 1982 - 12 July 1982	+50 (6)	0 (1)	- (0)	- (0)

¹ + denotes net upstream movement (m)

² - denotes net downstream movement (m)

³ () sample size

Table 21. Net movements (m) of brown trout in the North Fork Thornton River from 13 June 1981 to 13 July 1982.

TIME INTERVAL	YEAR CLASS	
	1980	1977
13 June 1981 -	0	-100
30 October 1981	(2) ³	(1)
13 June 1981 -	+600 ¹	-
24 April 1982	(2)	(0)
13 June 1981 -	0	-
13 July 1982	(1)	(0)
30 October 1981 -	-33 ²	-
24 April 1982	(3)	(0)
30 October 1981 -	0	-
13 July 1982	(2)	(0)
24 April 1982 -	-100	-
13 July 1982	(3)	(0)

¹ + denotes net upstream movement (m)

² - denotes net downstream movement (m)

³ () sample size

move from original marking sections in the Conway River except for one individual which moved 100 m downstream between 25 October 1981 and 10 April 1982 (Table 20). Older age brown trout were invariably recaptured at the original capture location (i.e. generally a pool) in each sample. One 1980 year class fish tagged on 25 October 1981 was captured by an angler in February 1982 in the Rapidan River approximately 17 km downstream from the original marking section. This was the only tagged fish captured outside of the 2400-meter study area. Quantitative electrofishing in August, 1981 and 1982, provided no evidence of other brown trout movements out of the study area, either upstream or downstream.

The 1980 year class displayed both net upstream and downstream movements in the North Fork Thornton River during the study period. One individual of the 1980 year class moved upstream 1200 m between 13 June 1981 and 24 April 1982. The 1977 year class fish moved downstream 100 m between 13 June 1981 and 30 October 1981 (Table 21). As in the Conway River, quantitative electrofishing in August, 1981 and 1982, provided no evidence that other tagged brown trout had moved out of the 2400-meter study area.

The net movements of the different year classes represent average movements for those groups. However, the movements of individual fish may be more meaningful than net

movements when considering potential upstream expansion of brown trout range. With the exception of those fish displaying extensive downstream (Conway River) and upstream (North Fork Thornton River) movements, individual fish of all year classes showed relatively little movement from original marking sections. In the Conway River, the greatest movements by individual fish were 200 m upstream or downstream. In the North Fork Thornton River, the greatest movements by individual fish were 300 m downstream and no upstream movement from original marking sections. Thus, the majority of recaptured brown trout remained within 200 m of the original marking sections; 98.7% in the Conway River (78 out of 79) and 71.4% in the North Fork Thornton River (7 out of 9).

Tag Retention

Percent tag retention was determined for the lowermost 1600 m and uppermost 800 m in the Conway River but only for the total 2400 m in the North Fork Thornton River. A substantial number of brown trout were tagged in the upper 800 m of the Conway River in the October 1981 sample, making it necessary to consider the study area as two distinct sections when calculating tag retention. Only one brown trout was tagged in this area (i.e. upper 800 m) of the North Fork Thornton River in October 1981, so this fish was pooled into the estimates of tag retention for the whole

2400-meter study area.

Tag retention in the Conway River was greater than 70.0% for all time periods except from 10 April 1982 through 12 July 1982. Tag retention during this period was only 45.8% in the lowermost 1600 m of the study area (Table 22). Many tagged fish in the lowermost 1600 m had been released 13 months previously on 15 June 1981. Tag retention was 75.0% or greater for all time periods in the North Fork Thornton River (Table 23). Thus, tag retention by brown trout was generally greater than 70.0% for most time periods in both streams. Tags could have been lost by (1) the wire wearing through the dorsal musculature and/or (2) unwinding of the wire which secured the tags.

Tag Recovery

A total of 240 tagged fish were released in the Conway River: 120 on 15 June 1981 and 120 on 25 October 1981. Fifteen tagged fish were released in the North Fork Thornton River: 10 on 13 June 1981, 3 on 30 October 1981 and 2 on 24 April 1982.

Percent tag recovery was determined for each time period and ranged from 0.0-50.0% in the Conway River (Table 24) and 0.0-100.0% in the North Fork Thornton River (Table 25). Tag recoveries of the 1980 year class fish ranged from 15.4-46.9% in the Conway River and 28.6-50.0% in the North Fork Thornton River. Tag recoveries of the 1979, 1978 and

Table 22. Percent tag retention by brown trout in the Conway River from 15 June 1981 to 12 July 1982.

TIME INTERVAL	TAGS RECAPTURED	ADIPOSE CLIPS RECAPTURED	TOTAL MARKS RECAPTURED	PERCENT TAG RETENTION
15 June 1981 - 25 October 1981 (Lower 1600 m)	44	12	57	77.2
25 October 1981 - 10 April 1982 (Lower 1600 m)	22	6	28	78.6
10 April 1982 - 12 July 1982 (Lower 1600 m)	11	13	24	45.8
25 October 1981 - 10 April 1982 (Upper 800 m)	7	0	7	100.0
10 April 1982 - 12 July 1982 (Upper 800 m)	10	2	12	83.3

Table 23. Percent tag retention by brown trout in the North Fork Thornton River from 13 June 1981 to 13 July 1982.

TIME INTERVAL	TAGS RECAPTURED	ADIPOSE CLIPS RECAPTURED	TOTAL MARKS RECAPTURED	PERCENT TAG RETENTION
13 June 1981 - 30 October 1981	3	1	4	75.0
30 October 1981 - 24 April 1982	4	1	5	80.0
24 April 1982 - 13 July 1982	3	0	3	100.0

Table 24. Percent tag recovery based on corrected tag availability in the Conway River from 15 June 1981 to 12 July 1982.

YEAR CLASS	SAMPLE	CORRECTED TAGS AVAILABLE		TAGS RECOVERED		PERCENT TAGS RECOVERED	
		1	2	1	2	1	2
1980	October 1981	81	-	38	-	46.9	-
	April 1982	117	39	18	8	15.4	20.5
	July 1982	54	32	12	6	22.2	18.8
1979	October 1981	8	-	4	-	50.0	-
	April 1982	10	2	1	0	10.0	0.0
	July 1982	5	2	0	1	0.0	50.0
1978	October 1981	4	-	1	-	25.0	-
	April 1982	6	2	0	0	0.0	0.0
	July 1982	3	2	1	0	33.3	0.0
1977	October 1981	2	-	1	-	50.0	-
	April 1982	2	1	1	0	50.0	0.0
	July 1982	1	1	0	0	0.0	0.0

1 refers to the lowermost 1600 meters of the study area
 2 refers to the uppermost 800 meters of the study area

Table 25. Percent tag recovery based on corrected tag availability in the North Fork Thornton River from 13 June 1981 to 13 July 1982.

YEAR CLASS	SAMPLE	CORRECTED TAGS AVAILABLE	TAGS RECOVERED	PERCENT TAGS RECOVERED
1980	October 1981	7	2	28.6
	April 1982	8	4	50.0
	July 1982	10	3	30.0
1977	October 1981	1	1	100.0
	April 1982	1	0	0.0
	July 1982	1	0	0.0

1977 year classes tended to be lower and ranged from 0.0-50.0% in the Conway River and 0.0-100.0% in the the North Fork Thornton River. Fewer older age tagged fish were available in either study area.

Tag recovery decreased as time periods increased, probably because of fewer tagged fish at large as a result of tag loss and mortality. Percent tag recovery was underestimated for each period because natural and angling mortality were not considered when calculating corrected tag availability. Thus, tag recovery was actually higher for each period than the computed values.

Tag Effects

Condition factors of tagged and untagged 1980 year class fish in the Conway River were different in the October 1981 and July 1982 samples. Results of one-sided unpaired t-tests at a decision level of 0.05 provide strong evidence that a significant tagging effect occurred during the period from 15 June 1981 through 25 October 1981 and that no tagging effect occurred during the period from 25 October 1981 through 12 July 1982 (Table 26).

It was assumed that the condition factor (C.F.) of the fish reflected their "well-being" and that reduction of condition in tagged fish would indicate a negative tagging effect. There was a 4.6% reduction in condition factor of tagged fish (C.F. = 0.940) compared to untagged fish (C.F. =

Table 26. Results of one-sided, unpaired t-tests on the condition factors of tagged and untagged 1980 year class brown trout in the Conway River on 25 October 1981 and 12 July 1982.

PARAMETER	25 October 1981 ¹	12 July 1982 ²
CONDITION FACTOR (UNTAGGED)	0.985	1.000
CONDITION FACTOR (TAGGED)	0.940	1.018
TEST STATISTIC	3.337	-12.967
P-VALUE	<0.001	>0.995
D.F.	140	21

¹ Fish tagged 15 June 1981

² Fish tagged 25 October 1982

0.985) in the October 1981 sample. The tags apparently had a negative effect; however, the biological significance of this reduction is questionable. Conversely, the condition factor of tagged fish (C.F. = 1.018) was slightly greater than that of untagged fish (C.F. = 1.000) in the July 1982 sample. A small number of tags resulted in minor necrosis of the muscle tissue surrounding the inserted wire but no other visible signs of reduced condition or health due to tags were evident from recaptured fish in the field.

DISCUSSION

Results of this investigation allow an evaluation of several aspects of the ecology of coexisting brook and brown trout populations in streams. The relationships of observed brook and brown trout abundance and distribution patterns to selected environmental factors and seasonal brown trout movements are discussed with respect to the frequently perceived phenomenon of brown trout displacement of brook trout.

Abundance and Distribution Patterns of Fish Populations

The observed abundance and distribution patterns of brook trout, brown trout and non-game fish populations were characteristic of numerous streams across North America (Nelson 1965, Vincent and Miller 1969, Nyman 1970, Brynildson et al. 1973, Gard and Flittner 1974, Kaeding 1980) and typical of the longitudinal zonation of fishes on a global scale (Hynes 1970). The consistent recurrence of these abundance and distribution patterns over such a wide range of coldwater lotic systems, particularly by brook and brown trout, is suggestive of a generalized response by these populations to some key environmental factors.

This study identified maximum stream temperature and average stream width (i.e. stream size) as the main environmental factors related to the observed salmonid abundance and distribution patterns. At this point, it is

necessary to distinguish the difference between limiting and regulating factors. Limiting factors determine the boundaries within which a species is distributed while regulating factors influence the abundance of that species within its distributional boundaries (Krebs 1978). The possible limiting and regulating influences of the environmental factors identified by this investigation, as being related to the observed salmonid abundance and distribution patterns, are discussed below.

Distribution : Limiting Factors

Temperature is a primary determinant of salmonid distribution in both lentic and lotic systems. The observed distribution patterns closely corroborate previous studies which have documented brook and brown trout distribution relative to stream temperatures. Although brook trout were present in sections with maximum stream temperatures up to 22 °C, abundance generally declined in downstream sections exceeding 20 °C (Figure 13). Previous investigations have documented the infrequent occurrence of brook trout in areas of streams exceeding 20 °C in Virginia (Burton and Odum 1945) and Ontario (Dymond 1953). Brown trout were absent from upstream study sections which did not exceed 17.5 °C (Figure 13). Vincent and Miller (1969) reported that the upstream limit of brown trout occurred at maximum stream temperatures not exceeding 13-15 °C in several Colorado

streams while Davis (1965) and Calhoun (1966) found 28 °C a downstream limiting temperature in California streams. Evidence provided by these studies indicates the importance of temperature as a limiting factor to brook and brown trout distribution in streams.

Fish species have thermal preferences and attempt to occupy temperatures within that preferendum (Ferguson 1958). Brook trout have a lower temperature preferendum (9-11 °C) than brown trout (13-15 °C) under laboratory conditions which may correspond to optima for physiological function (Peterson et al. 1979). In stream environments, brown trout are typically found in areas with higher maximum temperatures than brook trout (Burton and Odum 1945, Dymond 1953, Davis 1965, Calhoun 1966) again reflecting a tolerance to higher temperatures by brown trout. The observed distribution patterns of brook and brown trout may, in part, reflect choice by these two species for stream areas with specific thermal conditions. Further, a differential, physiological response by these species to temperature could result in brook trout being better adapted to the colder headwaters than brown trout with respect to survival, growth and/or competitive capabilities, thus favoring brook trout in these areas. The same scenario could apply to brown trout being better adapted to warmer downstream areas.

Further support for the importance of temperature as a

limiting factor is provided through a closer examination of the observed non-game fish species assemblages relative to brown trout distribution. The observed fish species assemblages were found to occur in six streams over a period of several years including: (1) two streams (Rose and St. Mary's Rivers) in June 1976, (2) two streams (North Fork Moormans and Hughes Rivers) in August 1981 and (3) two streams (Conway and North Fork Thornton Rivers) in August, 1981 and 1982. The consistent recurrence of fish species assemblages in a geographic region reflects a general response by those species to watershed conditions (Karr 1981). The repetitive nature of the observed fish species assemblages suggests that some environmental requirements of brown trout and associated species are similar. Specifically, the preferred temperatures of some non-game fish species occurring below the upstream limit of brown trout (i.e. category 1) and those positively associated with brown trout (i.e. category 2) (Table 6) are equal to or greater than the preferred temperature of brown trout (Stauffer et al. 1976). Thus, temperature preferenda may influence the distribution patterns of these fish species in the summer resulting in the observed fish species assemblages.

Although there is general agreement with previous studies documenting brook and brown trout distribution

relative to temperature, the relationship is not clear for the North Fork Thornton and North Fork Moormans Rivers. These streams were characterized by stenothermal conditions (19-21 °C) during August and September and yet distribution patterns were similar to those in the Conway and Hughes Rivers which had stronger thermal gradients (16.5-22 °C) in August and September. Possibly the small differences in temperatures observed were sufficient to elicit (1) choice by the species for stream areas with specific thermal conditions and/or (2) a differential physiological response by these two species, in the North Fork Thornton and North Fork Moormans Rivers. Other possible explanations could be that (1) maximum temperature was not the only measurement of this factor which was "biologically meaningful" to the fish, (2) the other environmental factor (i.e. stream size) identified was a more important influence on the observed distribution patterns and/or (3) other environmental factors not identified influenced the observed distribution patterns.

Average stream width and correlated variables (i.e. depth and discharge) may be influencing the observed distribution patterns. This is more difficult to assess because few studies have dealt with the influences of stream size parameters (i.e. width, depth, discharge) on salmonid distribution. In general, however, the results of this

study support a substantial number of investigations which have documented a progressive increase in the number of species and larger individuals (both salmonids and non-salmonids) occurring from the shallower, narrower headwaters to the wider, deeper lower reaches (Shelford 1911, Hallam 1959, Kuehne 1962, Sheldon 1968, Hynes 1970, Bustard and Narver 1975, Hocutt and Stauffer 1975, Horowitz 1978, Binns and Eisermann 1979, Foltz 1982). The logical inference is that changes in stream size parameters (i.e. width, depth, discharge) influence the distribution patterns of the fish species in these streams.

This investigation has identified the potential influence of stream size on salmonids. Allopatric brook trout zones occurred in sections with a stream width range of 2.3 - 5.6 m while sympatric brook and brown trout zones ranged from 2.2 - 11.3 m. Binns and Eisermann (1979) reported allopatric brook trout zones with widths of 3.1 - 4.0 m and sympatric brook and brown trout zones of 4.9 - 18.0 m in Wyoming streams. Other studies have simply reported that brook trout predominate in the narrower, shallower headwaters while brown trout predominate in wider, deeper downstream areas (Nyman 1970, Brynildson et al. 1973). Such studies provide some evidence that stream size influences brook and brown trout distribution.

Hypothetically, brook trout are better adapted to

narrower, shallower headwater areas than brown trout because of their smaller body size (R.J. White pers. comm.). Consequently, brook trout would have better survival and/or competitive capabilities than brown trout in such areas. Likewise, larger brown trout may be better adapted to the wider, deeper downstream reaches of these streams.

Scatter plots of average stream width and average stream depth (Appendix Tables 14, 15) versus maximum total length of brook and brown trout (Appendix Tables 3, 4, 5, 6) in the study sections failed to demonstrate any clear relationships between stream size parameters and fish size. Two limitations of this analysis were as follows: (1) most measurements of average stream width and average stream depth were in a narrow range, 2.0 - 8.0 m and 0.06 - 0.28 m, respectively and (2) the measurements did not reflect fish locations in the stream (i.e. not micro-distribution measurements). Other studies have shown a positive relationship between maximum stream depth and maximum fish length for brown trout (Gosse and Helm 1981, Egglishaw and Shackley 1982), rainbow trout (Lewis 1969), cutthroat trout (Griffith 1972) and Gila trout (Rinne 1981). These studies provide some general support for the previously stated hypothesis but details of stream size effects on brook and brown trout distribution will require further study, particularly the measurement of stream size parameters on a

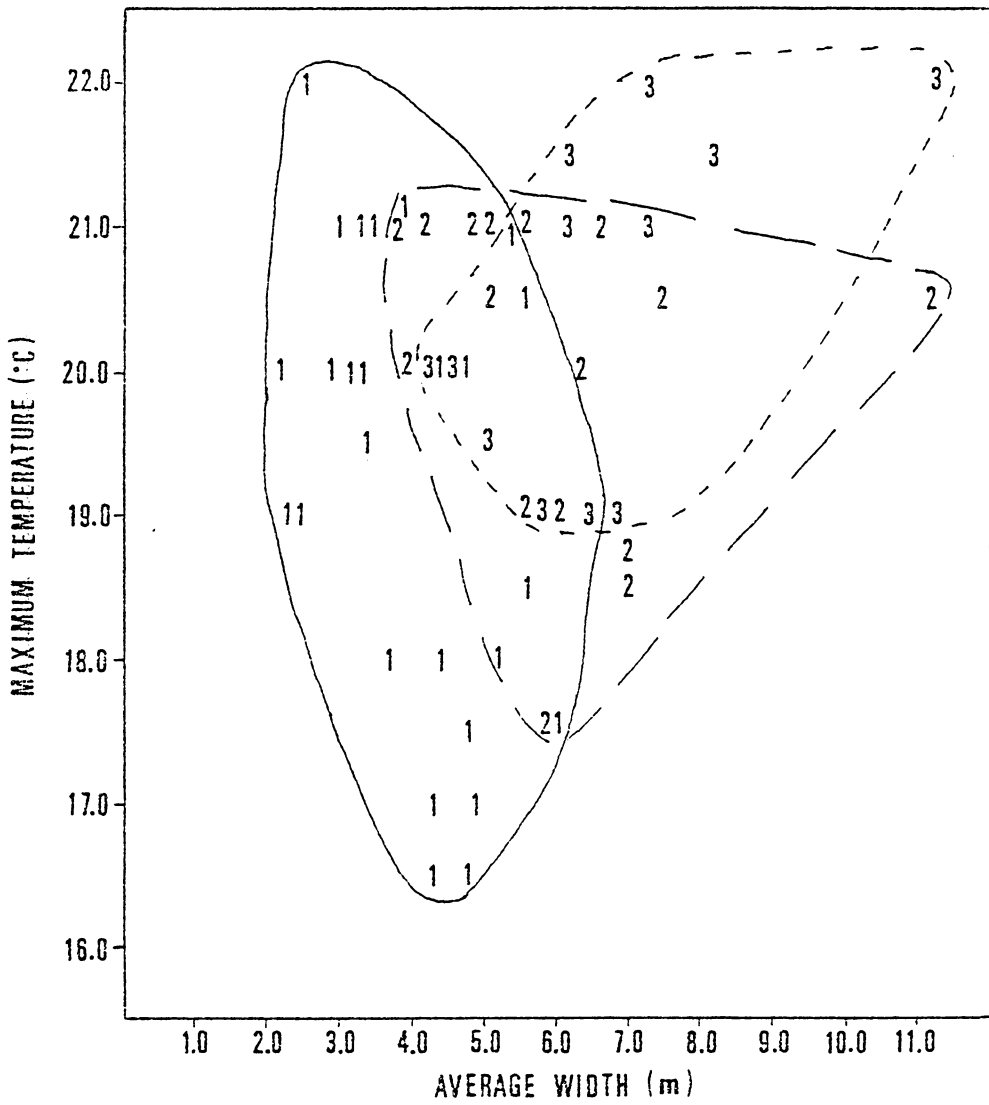
micro-habitat level.

Cluster analysis illustrates the utility of maximum stream temperature and average stream width in discriminating between predominately brook trout zones (group 1) and brown trout zones (group 3) in the study streams (Figure 14). The high degree of overlap with the sympatric zone (group 2) indicates the large area in these streams where the environmental requirements for temperature and stream size by brook and brown trout overlap, thus contributing to the poor predictive capabilities of the 1981 and 1982 discriminant function models.

The nature of this investigation (i.e. a survey of physical, chemical and biological attributes of the streams) makes it impossible to irrefutably ascribe cause and effect from any observed relationship. Based on the importance of temperature to salmonids, however, it would seem reasonable to conclude that a causal relationship exists between maximum stream temperature and the observed salmonid distribution patterns in these streams. There is less evidence to support the contention that stream size caused the observed distribution patterns but it certainly warrants further investigation.

Brown trout distribution was limited in an upstream direction in all the streams investigated. The species did not occur in areas where maximum stream temperatures did not

Figure 14. Occurrence of discriminant function groups for August, 1981 and 1982, relative to maximum stream temperature and average stream width; group 1 (solid line), group 2 (long hatched line) and group 3 (short hatched line). Groups defined by percentage standing stocks as follows: group 1 (>75% brook trout), group 2 (25-75% brook and brown trout) and group 3 (>75% brown trout).



exceed 17.5 °C (Figure 13) and abundance generally declined in areas with average stream width less than 4.0 meters (Figure 12). Possible explanations have been presented for the limiting influences of maximum temperature and stream size. However, no obvious physical or chemical barriers exist which should preclude brown trout from these headwater areas since they occupy the headwaters of many European streams characterized as narrow, shallow and cold water areas (Jones 1948, Nilsson 1957, Huet 1959, Egglshaw 1970, LeCren 1973, Mortensen 1977, Jonsson and Sandlund 1979). One obvious "factor" present in the streams investigated which is not present in European streams is the brook trout, which may be influencing brown trout distribution in upstream areas.

I hypothesize that brook trout act as a "biological barrier" (i.e. limiting factor) to brown trout in an upstream direction in streams they coinhabit. Possible mechanisms of this limitation are (1) better competitive capabilities of brook trout for stream resources due to a more favorable adaptive response to environmental conditions in the headwaters and/or (2) prior residence which favors brook trout in competitive interactions for stream resources with brown trout. Brook trout occupy the headwaters of many North American streams which they coinhabit with brown trout (Vincent and Miller 1969, Nyman 1970, Brynildson et al.

1973, Gard and Flittner 1974, Kaeding 1980) and brook trout apparently are better adapted to the cooler, smaller stream size conditions of these areas than are brown trout. Further, prior residence confers an advantage to salmonids in agonistic encounters for stream resources (Newman 1956, Jenkins 1969) which would favor established brook trout populations in the headwaters in competitive interactions with introduced brown trout.

The observed distribution patterns relative to maximum stream temperature and average stream width may not simply reflect choice by the species for specific areas of the streams but also the influence of behavioral interactions modified by those environmental factors. Thus, the total stream areas which both species could potentially occupy may be less than those which are actually occupied due to behavioral interactions influenced by the physical environment of the streams. The stated hypothesis could be tested by removal of brook trout from the headwaters of a stream, with sympatric brook and brown trout populations, to determine if brown trout respond with an accelerated colonization of the upstream areas devoid of brook trout.

Abundance : Regulating Factors

Brook trout standing stocks were negatively related to average stream width in both August 1981 and August 1982 (Table 17). This relationship does not necessarily imply a

regulating influence by average stream width (i.e. stream size); however, factors related to average width may be influencing brook trout standing stocks. One possible explanation for the observed relationship between brook trout standing stocks and average stream width is that fewer fish species (i.e. brown trout and non-game fishes) occurred in the narrower, headwater areas of the streams investigated while brook trout were the predominate fish species present (Table 4, 5). As a result, brook trout densities may have increased in direct response to fewer numbers of fish species competing for space and food in the headwaters.

Brown trout standing stocks were positively related to maximum stream temperature in both August 1981 and August 1982 (Table 17). The range of observed maximum stream temperatures (17.5-22.0 °C) corresponded to a narrow range of brown trout standing stocks (2.2 - 0.5 g/m²) (Figure 13). These results do not provide strong evidence to conclude that maximum stream temperature acted as a regulator of brown trout abundance. Instead, the range of observed maximum stream temperatures apparently provided suitable conditions for brown trout survival and growth while other factors acted as regulators, such as instream cover, behavioral interactions and food supply.

The relationship between trout standing stocks and

instream cover was consistent with previous investigations of salmonids. Percent instream cover was positively related to trout standing stocks which is in agreement with other studies documenting increased standing stocks of brook trout (Saunders and Smith 1962, Hunt 1974, Hunt 1976) and brown trout (Lewis 1969, Avery 1980) with increased cover. Instream cover provides protective shelter from predators and severe winter stream conditions (Hartman 1963, Avery 1980). Further, instream cover creates visual isolation from other territorial salmonids with subsequent increases in the number of potential territories in the streambed (Chapman 1966). Thus, increases in instream cover result in the increased carrying capacity of streams for salmonids.

Other environmental variables were included in the regression models but they were not characterized by consistent year to year relationships to trout standing stocks such as average depth, discharge, pH, conductivity, alkalinity and the substrate types. For example, average depth was included in the brook trout standing stock models for 1981 and 1982 but had positive and negative relationships in those years, respectively. Lack of a consistent relationship (i.e. change of coefficient sign) between average depth and brook trout standing stocks does not necessarily imply a lesser potential regulating influence by average depth. Average depth was highly

correlated with other environmental variables in both August 1981 and August 1982 (Table 15, 16). Intercorrelation among independent variables can result in (1) a coefficient sign change or (2) exclusion of variables from the models for different years (Green and Vascotto 1978, Johnson 1981). Thus, coefficient sign changes and/or exclusion of variables from the models could have occurred for many variables, such as average depth, due to the high degree of intercorrelation among the independent variables.

Regulation of salmonid populations, or any fish population, does not occur only through the influences of the physical and chemical environment. Food supply, intra- and interspecific behavioral interactions, angling mortality and natural mortality are all known to regulate fish population levels. Without consideration of these factors in conjunction with physical and chemical measurements, it is not surprising that a large percentage of the variation in observed salmonid abundance patterns was not explained by the multiple regression models.

The main relationships identified by the two multivariate screening techniques were consistent with current knowledge of salmonid ecology in streams. Inclusion of these factors in the various statistical models yielded good explanatory properties for a specific observed data set (i.e. same year) but had poor predictive capabilities for

another observed data set (i.e. different year). It is necessary to re-emphasize that the multivariate screening techniques were used to identify relationships and not to develop predictive models. Regardless, it is critical to this study and future investigations of this nature to resolve the question; why were these models such poor predictors?

Statistical Models : Assumption Violations

Several statistical factors likely contributed to the poor predictive capabilities of the statistical models developed in this study. One problem was the violation of a basic assumption that simple linear relationships exist between the dependent and each independent variable, unless otherwise specified (Draper and Smith 1966). It is known that species often respond in a modal fashion to an environmental gradient which results in the inability of these procedures to adequately model the "true" functional relationship (Green and Vascotto 1978, Johnson 1981). This response probably occurred for some variables, resulting in a change in sign of the coefficients of some variables between years. Therefore, the inability to correctly model all the observed relationships contributed to the poor predictive capabilities of those models. Better predictive models could have been developed using transformations of variables and/or more complicated models such as polynomials

(Draper and Smith 1966) but interpretation of such models is difficult (Johnson 1981). Without a priori knowledge of the "true" functional relationships between the dependent and independent variables, the only alternative was to develop models assuming the simplest case (i.e. existence of simple linear relationships).

Another assumption violation concerned the relationships among the independent variables. Intercorrelation among independent variables restricts information about the separate roles of those variables, often with resultant exclusion of some independent variables from the models (Draper and Smith 1966). The high degree of inter-correlation among the independent variables (Tables 15, 16) confounded the analysis of the relationships in the streams investigated, possibly excluding some important relationships.

Other factors could have contributed to the poor predictive models developed including: (1) seasonal and diel variations in the independent variables were not evaluated because measurements were only taken in the late summer, low flow period assuming this was the most critical time for salmonids relative to these variables, (2) some variables influencing the salmonids in the streams could not be measured such as floods and droughts, (3) some variables influencing salmonids in the streams were not measured such

as velocity, food supply, angling mortality and intra- and interspecific behavioral interactions and (4) measurements of some variables may not have been the most "biologically meaningful" representation of those variables to the fish. Cumulatively, the factors listed could have contributed to the inadequacy of the models to sufficiently explain the observed variation in salmonid abundance and distribution patterns.

Future Research Needs

Despite the assumption violations and problems associated with the multivariate screening techniques utilized in the analysis, several important relationships were identified. Future investigations of limiting and regulating factors of salmonids should at least include measurement of the following variables: stream size (i.e. width, depth, discharge), temperature and instream cover. Time series studies which evaluate the variables over wider ranges, different seasons and several years will be necessary to (1) develop functional relationships between salmonid distribution and abundance and environmental variables and (2) account for annual shifts in distribution and fluctuations in abundance relative to the variables.

Unfortunately, time series studies of even a small number of important variables will continue to be plagued with the problems previously discussed, especially

intercorrelation among independent variables and the inability to measure some important variables adequately. Determination of functional relationships will require large sample sizes and data collection will be expensive. Such studies would yield valuable information about general mechanisms of salmonid limitation and regulation but would only be applicable in a specific manner (i.e. prediction) to streams with similar watershed conditions.

Brown Trout Movements

The majority of brown trout, in the Conway and North Fork Thornton Rivers, exhibited restricted movements and maintained limited home ranges throughout the movement assessment period. There was little indication of substantial long-range movements except by a small percentage of individuals in each population. The results of this tagging study support a vast body of literature which has repeatedly documented the sedentary nature of most stream resident salmonids, including brown trout (Schuck 1943, Allen 1951, Shetter 1968, Mense 1975, Jackson 1980, Bachman 1982), brook trout (Shetter 1968, Whitworth 1980), rainbow trout (Stefanich 1951, Jenkins 1969, Cargill 1980, Whitworth 1980) and cutthroat trout (Miller 1957). The overwhelming evidence provided by these studies indicates that restricted movements (< 200 m from original tagging sections) are a distinctive trait of most stream resident

brown trout and other salmonids.

Older age brown trout (age 2+ and older) exhibited the most restricted movements throughout the study. The extremely limited home ranges of these older age fish indicate that essential resources such as food, cover, space, spawning substrate and other environmental requirements were available in a limited stream area on an annual basis. These larger, older age fish apparently acquired, occupied and successfully defended optimal sites in the streams. Maintenance of restricted home ranges may be related to an energy optimization strategy (Bachman 1982) and/or development of a better escape strategy and territory defense through prior residence (Jenkins 1969).

My qualitative observations indicated that the sites occupied by older age brown trout provided the "best" depth and cover combinations throughout the length of each study area. These sites were generally large, deep pools with associated cover such as boulders and undercut banks. Jenkins (1969) also observed that larger, older brown trout in the Owens River, California occupied the best available pools in a section of stream. Based on these observations, it appears that depth and cover associated with pools were two important factors determining the suitability of a site for older age brown trout on an annual basis. The analysis of pool quality indicated that higher quality pools (class 1

and 2), although scarce, were present in upstream areas not currently occupied by brown trout. This may indicate the suitability of these areas for older age brown trout if upstream movements by older age fish occur in the future.

The 1980 year class (age 1+) of brown trout was the only age group which displayed substantial movements in either stream. Although most movements tended to be limited in nature (<200 m from original tagging sections), some long-range movements did occur. The small increments of movement exhibited by the majority of age 1+ brown trout suggest that essential environmental resources were available within close proximity to original tagging sections. Movements by these younger age fish may have been related to defeat in agonistic encounters for stream resources (Chapman 1962) and/or (2) the search for habitat proportional to body size because of growth and subsequent changes in spatial requirements (Chapman 1966).

The preceding discussion of brown trout movements assumes that movements were not an artifact of sampling. The possibility exists that the movements documented were influenced by the sampling design. Since no block nets were placed at the boundaries of sections, brown trout may have moved into upstream sections through active avoidance of the electrofishing gear. Although this is a possibility and probably occurred to some degree, it has been my experience

during electrofishing that trout will only move short distances to adequate cover and remain there. Consequently, they are either captured or passed over during the electrofishing run. Therefore, even if the movements reported were to some extent an artifact of sampling, the small increments of movement documented for the majority of the brown trout are still a valid assessment of brown trout movements in these streams.

The long-range movements documented for two 1980 year class fish are characteristic of a small percentage of most stream salmonid populations. Individuals displaying these movements are commonly referred to as transients (Gerking 1953, Jenkins 1969). Reasons for long-range movements are not easily discerned, especially considering the fact that environmental requirements were apparently satisfied within close proximity to original tagging sections for the majority of the other brown trout. Possibly these fish were defeated in agonistic encounters, and once displaced, made extensive long-range movements due to an inability to establish a new territory. Another possibility is that movements were caused by a "tag effect"; however, evidence provided by analysis of the condition factors of tagged and untagged fish suggests this was not the case. Reduction in condition factor of tagged fish was only 4.6% in October 1981, indicating a minimal effect due to tags. Jackson

(1980) used a similar tagging process and reported no appreciable effect on survival or growth. I hypothesize that the long-range movements are related to a "predisposed tendency" by certain individuals (i.e. transients) to make long-range movements atypical of the majority of the population.

Despite the general lack of long-range movements, the small net upstream advances documented in both streams for 1980 year class fish indicates that the potential exists for further expansion of brown trout range into currently allopatric brook trout zones. Evidence provided by my study suggests that this would likely be a slow yet steady process which could be accelerated through infrequent long-range movements by transients. Expansion of brown trout range in this manner could be likened to a "leap frog" process whereby brown trout progressively expand their distribution into upstream areas. The process may take many years but brown trout could ultimately predominate in the headwaters currently occupied by allopatric brook trout populations.

Brown Trout Impacts on Brook Trout Populations

My investigation highlights the difficulties of describing the realized and potential impacts of an introduced fish species on native fish populations. The lack of adequate, comparable data prior to brown trout introductions into these streams approximately twenty years

ago precludes determining whether the observed abundance and distribution patterns of brook trout and non-game fish populations are the result of the influence of brown trout or other environmental factors. Therefore, definitive documentation of brown trout displacing brook trout in these streams is not possible.

Waters (1983) recently documented brown trout replacing brook trout in relative abundance over a 15-year period in Valley Creek, Minnesota and suggested that these changes could have been due to habitat perturbations interacting with the innate behavior of brook and brown trout. However, an adequate data base prior to brown trout introductions into Valley Creek precluded an evaluation of which factors were most important, habitat perturbations or brown trout. It is evident that a before-after manipulative study is necessary to document the impact of brown trout when introduced into a stream with an existing brook trout population. A before-after manipulative study would entail three phases; (1) documenting relationships of a brook trout population to selected environmental factors for several years, followed by, (2) the introduction and establishment of a brown trout population and (3) subsequent documentation of changes in the brook trout population relative to selected environmental factors and brown trout. This study design would allow direct assessment of the "effect" of

brown trout on the brook trout population, alleviating the need to make inferences about mechanisms causing the observed distribution and abundance patterns in sympatric populations of these species which proliferate the literature.

At present, brown trout populations in the streams investigated appear to be in an equilibrium state as evidenced by the recurrence of the observed fish species assemblages relative to brown trout distribution. This apparent equilibrium has developed over a short time span (twenty years), however, and there is not strong evidence to conclude that this condition will remain static. As discussed, the potential exists for upstream range expansion through movements which could alter these apparent equilibrium states of brown trout distribution.

Management Recommendations

Future decisions concerning brown trout introductions in the geographic region of Virginia investigated can be directly aided by the results of my study. A classification scheme incorporating documented fish species assemblages (Table 6), maximum stream temperature (Figure 13) and average stream width (Figure 12) can be utilized to assess the potential for (1) establishment and maintenance of reproducing brown trout populations and (2) impacts of brown trout on existing brook trout populations prior to further

brown trout introductions in the region. Table 27 provides ranges of maximum stream temperature and average stream width which correspond to high, intermediate and low densities of brook and brown trout. Fish population surveys, in conjunction with measurement of these two environmental factors, would allow an a priori evaluation of streams in this geographic region for further brown trout introductions. The presence of fish species in category 1 would identify stream areas with the greatest potential for establishment of brown trout populations, presence and absence of category 2 fish species would be useful in identifying the brown trout transition zone and the presence of only category 3 species would identify stream areas which brown trout would probably not occupy upon establishing a reproducing population.

I emphasize the applicability of this classification scheme only to the geographic region investigated since it was tested on several streams in southwestern Virginia (i.e. Floyd and Carroll counties) and provided poor prediction of the observed brown trout distribution patterns. The streams in southwestern Virginia differed from those investigated in north-central Virginia with respect to: (1) lower stream gradients, (2) fish species presence and absence, (3) intense agricultural activity (grazing and crops) and (4) greater water fertility (conductivity and alkalinity).

Table 27. Ranges of average stream width (m) and maximum stream temperature ($^{\circ}\text{C}$) corresponding to high, intermediate and low densities of brook and brown trout in Shenandoah National Park streams.

SPECIES	DENSITY	AVERAGE WIDTH ¹	MAXIMUM TEMPERATURE ²
BROOK TROUT	HIGH	2.0 - 5.0	16.5 - 18.0
	INTERMEDIATE	5.0 - 7.0	18.0 - 20.0
	LOW	7.0 - 11.0	20.0 - 22.0
BROWN TROUT	HIGH	6.0 - 11.0	20.0 - 22.0
	INTERMEDIATE	4.0 - 6.0	18.0 - 20.0
	LOW	2.0 - 4.0	16.5 - 18.0

¹ Refer to Figure 12

² Refer to Figure 13

These observed differences support the contention that classification schemes incorporating fish species assemblages are rarely useful over wide geographic regions due to specific local differences in the fauna and the physical and chemical environments of streams (Hynes 1970). This suggests, however, that classification schemes similar to the one developed, could be developed for specific geographic regions in Virginia, perhaps utilizing the Virginia trout stream survey data base (Coyle et al. 1982).

Based on this investigation, some general guidelines can be established concerning the management of brook and brown trout in Virginia streams. This study showed that the highest densities of brown trout were found in areas with specific maximum temperature regimes (19-22 °C) and coincident larger average stream width (6.0-11.3 m), such as the Conway River. The same maximum temperature regimes (19-22 °C) and coincident smaller average stream width (2.0-5.0 m) had lower densities of brown trout, such as the North Fork Thornton River. Thus, the greatest potential for establishment and maintenance of a sizeable, reproducing brown trout population will be in those streams characterized by adequate maximum temperature regimes (19-22 °C), larger average stream width (6.0-11.3 m) and the presence of other essential resources such as spawning gravel and cover.

The dilemma is that streams most suitable for brown trout introductions, if occupied by brook trout, will probably contain good brook trout populations in the headwaters. In these cases, it may be a poor decision to introduce brown trout due to the potential for negative impacts by brown trout on those brook trout populations. Although this study provides no direct proof, recent historical evidence strongly implicated brown trout in the displacement of brook trout from a Minnesota stream (Waters 1983). The already restricted nature of brook trout populations in Virginia (i.e. limited to headwater streams on the southern fringe of their continental distribution) warrants special concern about actions which may threaten those populations. Perhaps future brown trout introductions would be most appropriate in (1) mountain streams draining the Blue Ridge Mountains and Appalachian Plateau devoid of brook trout and/or (2) spring creeks in the valley floors of the state, to avoid potential negative impacts of introduced brown trout on native brook trout populations.

Sound management of existing sympatric brook and brown trout populations in Virginia streams is important. Several factors influencing these populations may tend to favor brown trout including (1) excessive fishing pressure due to the greater angling vulnerability of brook trout compared to brown trout (Cooper 1951, Marshall and MacCrimmon 1970) and

(2) human activities which degrade headwater areas. These factors could potentially reduce brook trout populations to levels which allow brown trout to expand their range upstream and consequently impact to a greater degree on brook trout populations. Protecting brook trout from severe impacts by these factors would promote better brook trout fisheries and possibly impede brown trout range expansion.

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APPENDIX

Appendix Table 1. Standing stocks (g/m²) and population estimates (in parentheses) of brook trout age groups in August 1981.

STREAM	STUDY SECTION	AGE				TOTAL
		0+	1+	2+	3+	
CONWAY RIVER	5	1.27 (100)	2.50 (37)	1.00 (3)		4.77 (140)
	7	0.59 (63)	1.29 (18)	0.54 (2)		2.42 (83)
	9	0.08 (9)	0.32 (3)			0.40 (12)
	11	0.07 (7)	0.22 (2)			0.29 (9)
	13	0.05 (3)	0.12 (1)			0.17 (4)
	15	0.01 (1)				0.01 (1)
	17					0.00 (0)
NORTH FORK THORNTON RIVER	1	0.13 (6)	1.66 (14)	0.85 (2)		2.64 (22)
	2	0.08 (2)	3.60 (21)	1.10 (2)		4.78 (25)
	3	0.36 (28)	2.83 (30)			3.19 (58)
	4	0.59 (33)	3.32 (22)	1.74 (3)		5.65 (58)
	6	1.32 (89)	4.80 (49)	5.88 (14)		12.00 (152)
	8	0.38 (37)	0.21 (2)			0.59 (39)
	9	0.29 (24)			3.06 (3)	3.35 (27)
NORTH FORK MOORMANS RIVER	1	1.22 (42)	0.95 (6)	0.28 (1)		2.45 (49)
	2	1.76 (136)	1.63 (15)	0.28 (1)		3.67 (152)
	3	0.51 (41)	3.04 (29)	0.62 (2)	0.91 (2)	5.08 (74)
	4	1.11 (68)	1.58 (10)	0.77 (2)		3.46 (80)
	5	0.02 (1)	1.15 (8)			1.17 (9)
	6	0.01 (1)				0.01 (1)
	7					0.00 (0)
HUGHES RIVER	1	0.29 (33)	5.48 (54)	5.58 (20)		11.35 (107)
	2	0.26 (28)	1.40 (17)	4.15 (23)		5.81 (68)
	3	0.11 (15)	3.44 (33)	1.42 (6)		4.97 (54)
	4	0.07 (10)	0.82 (10)	1.69 (8)		2.58 (28)
	5	0.08 (12)	0.62 (9)	0.23 (1)		0.93 (22)
	6	0.18 (37)	0.49 (10)	0.53 (3)		1.20 (50)
	7	0.02 (2)	0.40 (3)			0.42 (5)

Appendix Table 2. Standing stocks (g/m²) and population estimates (in parentheses) of brook trout age groups in August 1982.

STREAM	STUDY SECTION	AGE					TOTAL
		0+	1+	2+	3+	4+	
CONWAY RIVER	1	1.07 (92)	4.45 (67)	1.71 (10)	0.36 (1)		7.59 (170)
	2	0.43 (37)	3.48 (52)	2.14 (12)			6.05 (101)
	3	0.61 (60)	3.69 (58)	1.36 (8)			5.66 (124)
	4	0.33 (57)	1.57 (36)	1.89 (13)	0.26 (1)		4.05 (107)
	5	0.50 (53)	2.17 (29)	1.07 (6)	0.34 (1)		4.08 (89)
	6	0.08 (10)	1.01 (15)	1.16 (6)			2.25 (31)
	7	0.50 (63)	1.71 (26)	0.67 (5)			2.88 (94)
	8	0.10 (18)	0.98 (17)	0.14 (1)			1.22 (36)
	9	0.13 (20)	0.57 (8)	0.18 (1)			0.88 (29)
	10	0.04 (6)	0.81 (11)				0.85 (17)
	11	0.08 (10)	0.54 (7)	0.17 (1)			0.79 (18)
	12	0.01 (1)	0.10 (2)				0.11 (3)
	13		0.13 (1)				0.13 (1)
	14		0.09 (1)	0.14 (1)			0.23 (2)
	15		0.06 (1)				0.06 (1)
	16		0.11 (1)				0.11 (1)
	17		0.05 (1)				0.05 (1)
NORTH FORK THORNTON RIVER	1	0.22 (18)	1.03 (9)	4.49 (18)			5.74 (45)
	2	0.13 (8)	1.84 (10)	5.77 (17)	0.83 (1)		8.57 (36)
	3	0.20 (15)	2.12 (27)	2.79 (12)			5.11 (54)
	4	0.48 (27)	4.66 (39)	3.52 (10)			8.66 (76)
	5	0.30 (20)	1.72 (22)	1.34 (5)			3.36 (47)
	7	0.31 (38)	2.36 (38)	1.94 (11)	0.74 (2)		5.35 (89)
	8	0.19 (23)	0.71 (10)	0.20 (1)			1.10 (34)
	9	0.11 (12)	0.60 (9)	0.19 (1)	0.83 (2)		1.73 (32)
	10	0.05 (4)	1.19 (11)	0.21 (1)			1.45 (16)
	11	0.03 (2)	0.36 (3)			0.63 (1)	1.02 (6)

Appendix Table 3. Standing stocks (g/m^2) and population estimates (in parentheses) of brown trout in August 1981.

STREAM	STUDY SECTION	0+	1+	2+	AGE 3+	4+	TOTAL
CONWAY RIVER	5		0.46 (2)				0.46 (2)
	7	0.09 (6)		0.90 (1)			0.99 (7)
	9	0.07 (6)	0.87 (5)		2.08 (1)		3.02 (12)
	11	0.03 (3)	0.08 (1)				0.11 (4)
	13	0.14 (9)	0.54 (3)	1.73 (3)			2.41 (15)
	15	0.21 (15)	0.74 (5)	0.85 (2)		5.66 (2)	7.46 (24)
	17	0.09 (5)	0.49 (2)			2.73 (1)	3.31 (8)
NORTH FORK THORNTON RIVER	1						0.00 (0)
	2						0.00 (0)
	3						0.00 (0)
	4		0.22 (1)				0.22 (1)
	6		0.87 (4)	0.97 (1)			1.84 (5)
	8	0.02 (1)				1.83 (1)	1.85 (2)
	9	0.02 (1)			3.51 (2)		3.53 (3)
NORTH FORK MOORMANS RIVER	1						0.00 (0)
	2						0.00 (0)
	3		0.34 (1)				0.34 (1)
	4		0.98 (3)	1.11 (1)			2.09 (4)
	5		1.41 (4)				1.41 (4)
	6						0.00 (0)
	7						0.00 (0)
HUGHES RIVER	1						0.00 (0)
	2						0.00 (0)
	3						0.00 (0)
	4	0.07 (4)	0.20 (1)				0.27 (5)
	5	0.02 (1)	0.15 (1)				0.17 (2)
	6	0.02 (1)	0.30 (2)	0.62 (2)			0.94 (5)
	7		0.23 (1)	0.43 (1)	1.56 (1)		2.22 (3)

Appendix Table 4. Standing stocks (g/m²) and population estimates (in parentheses) of brown trout age groups in August 1982.

STREAM	STUDY SECTION	0+	1+	2+	AGE 3+	4+	TOTAL
CONWAY RIVER	1						0.00 (0)
	2						0.00 (0)
	3						0.00 (0)
	4	0.21 (18)		0.53 (1)			0.74 (19)
	5	0.02 (1)					0.02 (1)
	6	0.02 (1)				2.44 (1)	2.46 (5)
	7	0.03 (1)	0.35 (2)		2.66 (2)		3.04 (5)
	8	0.02 (2)	0.49 (4)		0.89 (1)		1.40 (7)
	9	0.03 (4)	1.15 (8)			1.90 (1)	3.08 (13)
	10	0.03 (3)	0.28 (2)	0.23 (1)			0.54 (6)
	11	0.14 (13)	0.34 (3)				0.48 (16)
	12	0.10 (13)	0.18 (1)				0.28 (14)
	13	0.14 (8)	0.40 (3)	1.38 (3)			1.92 (14)
	14	0.03 (3)	0.89 (8)	0.58 (2)			1.50 (13)
	15	0.21 (15)	0.43 (4)		1.13 (1)		1.77 (20)
	16	0.01 (1)	0.68 (5)	0.50 (1)	1.13 (1)	1.84 (1)	4.16 (9)
	17	0.10 (10)	0.44 (5)	1.12 (4)	0.67 (1)		2.33 (20)
NORTH FORK THORNTON RIVER	1						0.00 (0)
	2						0.00 (0)
	3						0.00 (0)
	4						0.00 (0)
	5		0.22 (1)				0.22 (1)
	7	0.06 (5)	0.14 (1)				0.20 (6)
	8	0.04 (3)	0.19 (2)			2.12 (1)	2.35 (6)
	9						0.00 (0)
	10	0.02 (2)	0.47 (2)	0.60 (1)	1.20 (1)		2.29 (6)
	11	0.02 (1)			2.17 (2)		2.19 (3)

Appendix Table 5. Average total length (mm) and weight (g) of brook trout in the Conway, North Fork Thornton, North Fork Moormans and Hughes Rivers in August 1981 and 1982.

STREAM	PARAMETER	AGE				
		0+	1+	2+	3+	4+
CONWAY RIVER (1981)	LENGTH (mm)	50	135	219		
	WEIGHT (g)	4.0	26.0	105.6		
	SAMPLE SIZE	169	59	5		
CONWAY RIVER (1982)	LENGTH (mm)	66	133	181	223	
	WEIGHT (g)	3.3	23.6	61.7	113.9	
	SAMPLE SIZE	412	318	64	3	
NORTH FORK THORNTON RIVER (1981)	LENGTH (mm)	66	133	209	268	
	WEIGHT (g)	3.2	23.2	91.0	270.9	
	SAMPLE SIZE	205	136	21	3	
NORTH FORK THORNTON RIVER (1982)	LENGTH (mm)	68	134	183	240	289
	WEIGHT (g)	3.2	23.9	63.0	154.5	225.5
	SAMPLE SIZE	164	178	75	5	1
NORTH FORK MOORMANS RIVER (1981)	LENGTH (mm)	73	151	205	253	
	WEIGHT (g)	4.5	36.3	94.3	146.2	
	SAMPLE SIZE	263	68	6	2	
HUGHES RIVER (1981)	LENGTH (mm)	64	139	193		
	WEIGHT (g)	2.6	28.8	72.0		
	SAMPLE SIZE	127	135	61		

Appendix Table 6. Average total length (mm) and weight (g) of brown trout in the Conway, North Fork Thornton, North Fork Moormans and Hughes Rivers in August 1981 and 1982.

STREAM	PARAMETER	AGE				
		0+	1+	2+	3+	4+
CONWAY RIVER (1981)	LENGTH (mm)	79	166	295		461
	WEIGHT (g)	5.8	68.4	287.7		780.6
	SAMPLE SIZE	42	18	6		4
CONWAY RIVER (1982)	LENGTH (mm)	79	184	265	371	446
	WEIGHT (g)	6.2	64.6	195.3	538.6	933.8
	SAMPLE SIZE	84	44	13	6	3
NORTH FORK THORNTON RIVER (1981)	LENGTH (mm)	77	166	296	354	380
	WEIGHT (g)	5.6	45.8	218.2	467.1	538.4
	SAMPLE SIZE	2	5	1	2	1
NORTH FORK THORNTON RIVER (1982)	LENGTH (mm)	76	176	272	335	416
	WEIGHT (g)	4.6	54.7	200.0	391.3	755.9
	SAMPLE SIZE	11	6	1	3	1
NORTH FORK MOORMANS RIVER (1981)	LENGTH (mm)		208	292		
	WEIGHT (g)		99.9	310.1		
	SAMPLE SIZE		8	1		
HUGHES RIVER (1981)	LENGTH (mm)	85	189	228	343	
	WEIGHT (g)	7.4	69.4	135.5	481.0	
	SAMPLE SIZE	6	5	3	1	

Appendix Table 7. Standing stocks (g/m²) and population estimates (in parentheses) of non-game fish species in the Conway River in August 1981. The - indicates no standing stock estimate.

SPECIES	STUDY SECTION						
	1	2	3	4	5	6	7
BLACKNOSE DACE	0.75 (19)	0.55 (28)	0.41 (24)	0.30 (21)	0.39 (24)	0.42 (31)	0.33 (20)
LONGNOSE DACE	0.32 (2)	0.22 (4)	0.10 (2)	0.58 (14)	0.40 (5)	0.69 (13)	1.60 (28)
ROSYSIDE DACE			0.06 (2)		0.23 (15)	1.00 (64)	0.28 (14)
MOTTLED SCULPIN		1.23 (52)	0.61 (39)	0.44 (33)	0.44 (28)	1.03 (66)	1.03 (68)
TORRENT SUCKER		0.30 (2)	1.81 (12)	0.81 (9)	1.04 (11)	2.09 (19)	3.04 (31)
AMERICAN EEL	- (1)						- (1)
RIVER CHUB		1.72 (19)	0.80 (6)				1.49 (8)
WHITE SUCKER			3.13 (1)				
FALLFISH				0.58 (5)	0.70 (7)	0.38 (14)	0.24 (4)
FANTAIL AND JOHNNY DARTER						0.01 (1)	
BLUEHEAD CHUB						0.38 (1)	
MARGINED MADTOM							0.13 (1)

Appendix Table 8. Standing stocks (g/m^2) and population estimates (in parentheses) of non-game fish species in the North Fork Thornton River in August 1981.

SPECIES	STUDY SECTION						
	1	2	3	4	5	6	7
BLACKNOSE DACE	1.99 (44)	0.53 (13)	0.95 (27)	1.58 (26)	3.40 (96)	1.10 (73)	1.31 (103)
LONGNOSE DACE			0.56 (3)	0.45 (5)	0.23 (2)	0.60 (11)	0.57 (8)
ROSYSIDE DACE					1.42 (31)	0.06 (3)	0.76 (21)
MOTTLED SCULPIN	0.54 (7)	0.47 (9)	0.71 (24)	1.85 (36)	1.76 (47)	1.17 (40)	1.64 (78)
RIVER CHUB					5.60 (12)	0.32 (1)	1.68 (3)
WHITE SUCKER					7.52 (13)	0.11 (2)	0.49 (5)
FALLFISH						0.86 (1)	0.61 (8)
FANTAIL AND JOHNNY DARTER					0.08 (7)	0.05 (2)	0.07 (6)

Appendix Table 9. Standing stocks (g/m²) and population estimates (in parentheses) of non-game fish species in the North Fork Moormans River in August 1981.

SPECIES	STUDY SECTION						
	1	2	3	4	5	6	7
BLACKNOSE DACE	0.59 (20)	1.44 (62)	0.86 (29)	0.91 (34)	0.52 (26)	0.86 (53)	1.01 (64)
LONGNOSE DACE				0.23 (4)	0.25 (3)		0.09 (4)
ROSYSIDE DACE	0.06 (1)			1.66 (28)	1.97 (62)	3.71 (100)	1.47 (73)
TORRENT SUCKER	1.89 (13)	1.11 (10)	1.62 (14)	6.05 (53)	2.53 (21)	3.69 (30)	4.94 (54)
WHITE SUCKER				8.36 (4)	0.07 (1)		
FALLFISH					0.07 (1)	0.37 (2)	1.16 (10)
FANTAIL AND JOHNNY DARTER	0.07 (2)	0.18 (9)	0.30 (13)	0.04 (2)	0.04 (3)	0.10 (4)	0.27 (25)
MARGINED MADTOM					0.21 (1)	0.27 (4)	0.62 (5)
CREEK CHUB				0.63 (2)			
COMMON SHINER					0.48 (3)	1.17 (8)	0.17 (2)
MOUNTAIN REDBELLY DACE				0.04 (1)	0.16 (7)	0.44 (17)	0.23 (18)
STONEROLLER					0.09 (1)	0.08 (1)	0.12 (2)

Appendix Table 10. Standing stocks (g/m²) and population estimates (in parentheses) of non-game fish species in the Hughes River in August 1981. The - indicates no standing stock estimate.

SPECIES	STUDY SECTION						
	1	2	3	4	5	6	7
BLACKNOSE DACE				0.98 (78)	0.25 (29)	0.97 (76)	1.16 (59)
LONGNOSE DACE				0.15 (3)	0.48 (13)	1.85 (32)	1.81 (21)
ROSYSIDE DACE						0.10 (4)	1.21 (84)
MOTTLED SCULPIN					0.27 (14)	1.64 (72)	1.15 (63)
AMERICAN EEL	- (1)	- (1)		- (1)			
RIVER CHUB							2.28 (14)
WHITE SUCKER							1.06 (3)
FALLEFISH						0.11 (2)	0.50 (9)
FANTAIL AND JOHNNY DARTER							0.08 (8)
CREEK CHUB							0.11 (1)

Appendix Table 11. Standing stocks (g/m²) and population estimates (in parentheses) of non-game fish in the Conway River in August 1982. The - indicates no standing stock estimate.

SPECIES	STUDY SECTION																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
BLACKNOSE DACE	0.02 (1)	0.62 (17)	0.15 (6)	0.43 (12)	0.52 (25)	0.27 (15)	0.14 (8)	0.15 (8)	0.18 (11)	0.19 (11)	0.29 (27)	0.27 (13)	0.35 (28)	0.34 (23)	0.07 (6)	0.10 (10)	
LONGNOSE DACE			0.13 (1)		0.22 (3)		0.30 (5)	0.33 (4)	0.19 (2)	0.62 (11)	0.42 (8)	0.34 (5)	0.41 (9)	0.27 (6)	0.50 (11)	0.92 (32)	
ROSSIDE DACE				0.05 (1)				0.03 (1)	0.30 (11)	0.07 (3)	0.09 (7)	0.29 (13)	0.54 (31)	0.58 (29)	0.40 (23)	0.12 (8)	
MOTTLED SCULPIN						0.50 (19)	0.32 (22)	0.45 (27)	0.62 (34)	0.40 (32)	0.11 (15)	0.12 (8)	0.26 (19)	0.24 (14)	0.20 (11)	0.35 (24)	
TORRENT SUCKER						0.38 (4)	1.39 (11)	1.67 (10)	0.82 (6)	1.14 (12)	0.38 (7)	1.41 (8)	1.79 (16)	1.87 (22)	1.45 (13)	0.97 (17)	
AMERICAN EEL															- (1)		
RIVER CHUB					0.35 (1)	0.25 (2)	0.48 (2)	0.02 (1)	0.66 (5)	0.87 (8)		0.16 (3)	0.31 (4)	0.02 (1)	0.06 (1)		
WHITE SUCKER								2.63 (1)					1.22 (1)				
FALLFISH										0.08 (1)	0.49 (7)	0.92 (5)	0.05 (1)	1.47 (7)	1.00 (7)	0.38 (4)	
FANTAIL AND JOHNNY DARTER													0.01 (1)		0.01 (1)		
BLUEHEAD CHUB																0.09 (2)	
MARGINED MADTOM															0.04 (1)	0.24 (3)	
CREEK CHUB													0.12 (1)				
COMMON SHINER																0.05 (1)	

Appendix Table 12. Standing stocks (g/m²) and population estimates (in parentheses) of non-game fish species in the North Fork Thornton River in August 1982.

[illegible]

Appendix Table 13. The frequency of occurrence of brown trout (species X) and longnose dace (LD), rosieside dace (RS) and torrent sucker (TS) (species Y) in study sections on Shenandoah National Park waters.

STREAM	SPECIES (Y)	X PRESENT Y PRESENT	X ABSENT Y PRESENT	X PRESENT Y ABSENT	X ABSENT Y ABSENT	N
CONWAY RIVER 3-4 AUGUST 1981	LD	7	0	0	0	7
	RD	4	0	3	0	7
	TS	6	0	1	0	7
CONWAY RIVER 2-5 AUGUST 1982	LD	12	0	2	3	17
	RD	10	0	4	3	17
	TS	11	0	3	3	17
NORTH FORK THORNTON RIVER 12-13 AUGUST 1981	LD	4	1	0	2	7
	RD	3	0	1	3	7
	TS	-	-	-	-	-
NORTH FORK THORNTON RIVER 9-10 AUGUST 1982	LD	5	3	0	2	10
	RD	4	1	1	4	10
	TS	-	-	-	-	-
NORTH FORK MOORMANS RIVER 5-6 AUGUST 1981	LD	2	1	1	3	7
	RD	2	3	1	1	7
	TS	3	4	0	0	7
HUGHES RIVER 10-11 AUGUST 1981	LD	3	0	1	3	7
	RS	2	0	2	3	7
	TS	-	-	-	-	-
ROSE RIVER 15-17 JUNE 1976	LD	1	1	0	3	5
	RS	1	0	0	4	5
	TS	-	-	-	-	-
ST. MARY'S RIVER 22-24 JUNE 1976	LD	2	0	1	3	6
	RS	2	0	1	3	6
	TS	2	0	1	3	6

Appendix Table 14. Measurements of selected physical parameters in the Conway, North Fork Thornton, North Fork Moormans and Hughes Rivers in August 1981.

STREAM	STUDY SECTION	AVERAGE DEPTH(m)	AVERAGE WIDTH(m)	GRADIENT (ft/mile)	DISCHARGE (m ³ /sec)	PERCENT POOL(%)
CONWAY RIVER	5	0.19	4.4	257.6	0.145	37.0
	7	0.18	5.9	390.4	0.099	63.3
	9	0.18	5.8	157.0	0.252	50.8
	11	0.14	6.5	170.9	0.161	35.5
	13	0.20	5.1	191.6	0.092	53.2
	15	0.17	6.2	146.2	0.183	74.1
	17	0.18	5.5	124.2	0.251	40.8
NORTH FORK THORNTON RIVER	1	0.06	2.5	357.4	0.007	41.6
	2	0.11	2.3	429.3	0.009	52.1
	3	0.12	3.4	313.1	0.005	50.0
	4	0.09	2.2	157.0	0.003	44.4
	6	0.13	3.2	134.1	0.008	59.0
	8	0.17	4.2	201.1	0.006	56.1
	9	0.13	3.8	117.0	0.005	81.1
NORTH FORK MOORMANS RIVER	1	0.08	3.3	214.6	0.023	41.6
	2	0.10	4.3	279.7	0.017	61.7
	3	0.21	4.6	219.8	0.007	78.1
	4	0.17	4.0	184.0	0.057	60.6
	5	0.12	4.2	214.6	0.005	73.5
	6	0.11	3.5	201.1	0.027	57.5
	7	0.12	4.3	189.2	0.020	58.1
HUGHES RIVER	1	0.28	3.7	357.4	0.023	64.6
	2	0.17	4.8	643.9	0.099	51.4
	3	0.20	4.3	429.3	0.022	46.7
	4	0.15	5.6	161.0	0.055	69.1
	5	0.17	6.5	268.3	0.074	56.1
	6	0.16	6.3	195.0	0.093	42.1
	7	0.16	4.4	165.8	0.149	39.3

Appendix Table 15. Measurements of selected physical parameters in the Conway and North Fork Thornton Rivers in August 1982.

STREAM	STUDY SECTION	AVERAGE DEPTH(m)	AVERAGE WIDTH(m)	GRADIENT (ft/mile)	DISCHARGE (m ³ /sec)	PERCENT POOL(%)
CONWAY RIVER	1	0.13	4.3	357.4	0.069	22.7
	2	0.20	4.8	460.1	0.171	47.7
	3	0.18	4.9	429.3	0.253	36.3
	4	0.17	6.0	292.5	0.087	27.3
	5	0.19	5.2	257.6	0.170	40.7
	6	0.22	5.6	322.0	0.206	45.0
	7	0.19	6.0	390.4	0.145	63.3
	8	0.18	7.0	229.8	0.121	41.0
	9	0.22	6.8	157.0	0.158	56.7
	10	0.21	6.6	207.7	0.259	72.4
	11	0.15	7.5	170.9	0.242	20.1
	12	0.17	11.2	222.1	0.159	58.9
	13	0.19	6.2	191.6	0.204	61.9
	14	0.20	8.2	161.0	0.162	76.0
	15	0.21	7.3	146.2	0.126	80.4
	16	0.23	7.3	131.3	0.367	70.9
	17	0.14	11.3	124.2	0.285	57.4
NORTH FORK THORNTON RIVER	1	0.08	3.3	357.4	0.004	35.6
	2	0.12	2.9	429.3	0.011	41.9
	3	0.09	3.8	313.1	0.007	42.9
	4	0.10	2.5	157.0	0.002	37.9
	5	0.06	3.0	89.4	0.016	5.1
	7	0.11	5.4	178.8	0.039	54.9
	8	0.17	5.1	201.1	0.056	46.9
	9	0.15	5.6	113.1	0.045	83.1
	10	0.15	4.8	117.0	0.059	37.9
	11	0.20	5.1	117.0	0.066	53.7

Appendix Table 16. Cover measurements on the Conway, North Fork Thornton, North Fork Moormans and Hughes Rivers in August 1981.

STREAM	STUDY SECTION	PERCENT INSTREAM COVER	PERCENT CANOPY COVER
CONWAY RIVER	5	9.1	45
	7	4.3	60
	9	3.9	80
	11	1.6	85
	13	4.8	30
	15	2.3	50
	17	2.6	35
NORTH FORK THORNTON RIVER	1	2.0	90
	2	4.9	85
	3	2.9	85
	4	8.3	90
	6	3.0	40
	8	2.5	80
	9	3.2	75
NORTH FORK MOORMANS RIVERS	1	1.3	75
	2	2.4	85
	3	5.5	80
	4	4.7	85
	5	3.1	50
	6	1.1	60
	7	1.5	70
HUGHES RIVER	1	9.4	85
	2	7.3	85
	3	6.7	85
	4	2.0	80
	5	3.4	85
	6	2.5	80
	7	4.2	80

Appendix Table 17. Cover measurements in the Conway and North Fork Thornton Rivers in August 1982.

STREAM	STUDY SECTION	PERCENT INSTREAM COVER	PERCENT CANOPY COVER
CONWAY RIVER	1	4.6	70
	2	6.5	80
	3	4.9	70
	4	5.2	80
	5	5.2	70
	6	7.7	80
	7	6.8	70
	8	5.1	70
	9	6.6	70
	10	3.3	70
	11	2.9	80
	12	4.2	80
	13	5.5	40
	14	4.1	70
	15	3.9	60
	16	5.9	60
	17	2.3	40
NORTH FORK THORNTON RIVER	1	3.4	90
	2	6.3	90
	3	4.9	80
	4	3.4	70
	5	1.6	60
	7	5.9	70
	8	8.8	60
	9	10.3	70
	10	7.1	70
	11	8.3	60

Appendix Table 18. Bottom substrate composition (%) in the Conway, North Fork Thornton, North Fork Moormans and Hughes Rivers in August 1981.

STREAM	STUDY SECTION	SPAWNING SUBSTRATE	BEDROCK	BOULDER	RUBBLE	GRAVEL	SILT
CONWAY RIVER	5	2.0	0.0	36.9	32.1	28.6	2.4
	7	3.1	0.0	34.9	30.8	33.8	0.5
	9	1.1	0.0	50.9	30.9	17.6	0.6
	11	1.3	0.0	28.9	51.3	18.7	1.1
	13	0.4	0.0	64.3	22.4	10.5	2.8
	15	2.7	0.0	32.4	30.2	31.8	5.6
	17	0.0	0.0	40.6	40.6	9.0	5.2
NORTH FORK THORNTON RIVER	1	3.0	4.6	20.0	20.0	47.7	7.7
	2	1.5	0.0	16.1	12.9	59.7	11.3
	3	1.6	10.2	15.9	13.6	39.8	20.5
	4	1.5	0.0	16.7	14.8	40.7	27.8
	6	1.2	0.0	17.9	28.5	38.1	15.5
	8	0.3	0.0	31.0	32.8	22.4	13.8
	9	0.9	0.0	22.1	32.7	26.0	19.2
NORTH FORK MOORMANS RIVER	1	1.7	0.0	28.9	24.4	40.0	6.7
	2	2.5	0.0	17.1	35.9	36.8	10.2
	3	1.9	0.0	34.7	19.4	37.0	8.9
	4	1.6	7.1	30.4	20.5	30.4	11.6
	5	1.4	4.3	30.8	23.9	35.9	5.1
	6	0.2	0.0	23.7	37.1	29.9	9.3
	7	0.0	0.0	28.9	24.4	40.0	6.7
HUGHES RIVER	1	0.8	0.0	36.4	33.3	27.3	3.0
	2	1.3	0.0	51.1	26.3	21.9	0.7
	3	1.0	0.0	49.6	21.8	25.2	3.4
	4	0.8	0.0	26.9	34.4	30.0	8.7
	5	2.0	0.0	44.9	30.3	20.0	4.8
	6	0.5	0.0	39.0	28.2	27.7	5.1
	7	0.7	0.0	47.9	28.1	19.0	5.0

Appendix Table 19. Bottom substrate composition (%) in the Conway and North Fork Thornton Rivers in August 1982.

STREAM	STUDY SECTION	SPAWNING SUBSTRATE	BEDROCK	BOULDER	RUBBLE	GRAVEL	SILT
CONWAY RIVER	1	1.7	32.2	30.6	19.0	17.4	0.8
	2	2.2	2.9	32.4	34.6	27.9	2.2
	3	1.1	2.9	39.3	32.9	22.9	2.1
	4	2.5	0.0	37.4	36.3	22.8	3.5
	5	1.8	5.4	36.2	37.6	16.8	4.0
	6	1.1	4.4	57.5	42.4	12.5	1.3
	7	2.6	1.7	47.7	31.6	18.4	0.6
	8	0.5	3.5	49.5	34.7	11.4	1.0
	9	0.7	1.1	60.5	23.2	14.2	1.1
	10	0.8	0.0	30.2	35.4	24.5	9.9
	11	1.5	0.0	38.4	42.6	17.1	1.9
	12	1.0	0.0	42.4	25.7	22.8	9.0
	13	1.4	0.0	56.2	28.1	12.9	2.8
	14	1.2	0.0	47.1	31.4	16.5	5.0
	15	2.6	0.0	39.6	31.6	25.0	3.8
	16	0.8	0.0	52.8	26.6	13.6	7.0
	17	0.2	0.0	48.5	34.4	14.1	3.0
NORTH FORK THORNTON RIVER	1	1.6	7.5	31.2	28.0	28.0	5.4
	2	2.2	2.5	40.7	22.2	28.4	6.2
	3	2.4	5.7	37.1	29.5	23.8	3.8
	4	1.9	4.3	12.9	55.7	24.3	2.9
	5	1.0	0.0	7.3	52.4	31.7	8.5
	7	1.5	0.0	25.3	37.7	29.9	7.1
	8	0.7	4.1	26.5	42.9	17.0	9.5
	9	1.4	0.0	34.4	44.4	13.8	7.5
	10	2.8	1.5	34.3	35.8	17.9	10.4
	11	1.4	0.0	20.0	49.0	24.8	6.2

Appendix Table 20. Maximum temperature and chemical measurements in the Conway, North Fork Thornton, North Fork Moormans and Hughes Rivers in August 1981.

STREAM	STUDY SECTION	MAXIMUM TEMPERATURE (°C)	pH	CONDUCTIVITY (μmhos)	ALKALINITY (mg/L CaCO ₃)
CONWAY RIVER	5	18.0	6.9	20	25
	7	17.5	6.9	25	25
	9	19.0	6.9	20	30
	11	19.0	6.9	22	25
	13	19.5	6.7	25	25
	15	21.0	6.8	22	25
	17	21.0	6.4	28	25
NORTH FORK THORNTON RIVER	1	19.0	7.2	40	30
	2	19.0	7.3	41	30
	3	19.5	7.3	42	20
	4	20.0	7.2	45	30
	6	20.0	7.3	50	30
	8	20.0	7.2	60	30
	9	21.0	7.1	45	25
NORTH FORK MOORMANS RIVER	1	20.0	7.1	30	30
	2	20.0	7.1	31	25
	3	20.0	7.1	30	25
	4	20.0	7.1	30	25
	5	21.0	7.1	31	25
	6	21.0	7.0	25	30
	7	21.0	7.1	20	30
HUGHES RIVER	1	18.0	7.1	20	15
	2	17.5	7.0	21	10
	3	17.0	6.8	22	15
	4	18.5	6.9	25	20
	5	19.0	7.1	25	10
	6	20.0	7.0	25	20
	7	20.0	7.1	25	20

Appendix Table 21. Maximum temperature and chemical measurements in the Conway and North Fork Thornton Rivers in August 1982.

STREAM	STUDY SECTION	MAXIMUM TEMPERATURE (°C)	pH	CONDUCTIVITY (μ mhos)	ALKALINITY (mg/L CaCO ₃)
CONWAY RIVER	1	16.5	6.8	28	20
	2	16.5	6.6	21	25
	3	17.0	6.5	21	20
	4	17.5	6.6	21	25
	5	18.0	6.6	22	15
	6	19.0	6.6	22	20
	7	19.0	6.7	21	20
	8	18.5	6.6	21	20
	9	19.0	6.6	21	20
	10	21.0	6.6	21	15
	11	20.5	6.7	21	20
	12	20.5	6.6	22	20
	13	21.5	6.6	25	20
	14	21.5	6.6	22	30
	15	21.5	6.6	22	20
	16	22.0	6.6	22	25
	17	22.0	6.7	25	20
NORTH FORK THORNTON RIVER	1	21.0	6.9	41	35
	2	20.0	6.9	46	40
	3	21.0	7.0	50	35
	4	22.0	7.0	50	30
	5	21.0	7.0	51	40
	7	21.5	7.0	42	30
	8	21.0	7.0	41	40
	9	20.5	7.0	39	35
	10	21.0	7.0	39	35
	11	20.5	7.0	40	30

Appendix Table 22. Trout standing stock regression models and selection criteria parameters (MSE, R-SQUARE, PRESS) for August 1981.

MODEL VARIABLES	MSE	R-SQUARE	PRESS
(1) BROOK TROUT			
(a) X1,X2,X3,X6,X7,X8,X11,X16	0.8251	0.9134	38.7946
(b) X2,X4,X5,X7,X11	1.1516	0.8590	41.9553
(c) Int,X1,X2,X3,X6,X7,X8,X11,X16	0.8668	0.9091	41.9823
(d) X2,X5,X7,X8,X11,X14	1.0221	0.8808	45.3568
(e) X2,X4,X7,X11	1.3302	0.8294	47.4819
(f) Int,X5,X7,X8,X11,X14	1.2290	0.8567	54.5499
(g) X2,X3,X7,X8,X12,X13,X15	1.2200	0.8648	55.4815
(2) BROWN TROUT			
(a) X5,X6,X12,X15,X16,X18	0.8317	0.7769	35.8797
(b) Int,X5,X6,X16,X18	0.9539	0.7314	35.6946
(c) X5,X6,X15,X16,X18	0.9461	0.7336	37.4076
(d) Int,X5,X6,X18	1.0640	0.6861	37.8784
(e) X4,X5,X6,X12	1.1029	0.6746	40.1610
(f) X4,X5,X6	1.3969	0.5691	45.1767
(g) X1,X5	1.8781	0.3955	58.1983
(3) TOTAL TROUT			
(a) X2,X3,X5,X6,X7,X11	1.7245	0.7622	66.5922
(b) X3,X5,X6,X7	2.0601	0.6875	70.7978
(c) Int,X3,X5,X6,X7	2.0118	0.7087	71.8295
(d) X6,X7,X15	2.2468	0.6437	71.4038
(e) Int,X3,X5,X6,X7,X8	1.9070	0.7370	75.7319
(f) X3,X6,X7	2.3332	0.6300	73.7586
(g) X6,X7	2.6624	0.5595	82.2255

Appendix Table 23. Trout standing stock regression models and selection criteria parameters (MSE, R-SQUARE, PRESS) for August 1982.

MODEL VARIABLES	MSE	R-SQUARE	PRESS
(1) BROOK TROUT			
(a) Int, X2, X3, X4	1.6844	0.8058	56.6480
(b) X3, X4, X16, X17	1.7687	0.7961	60.5065
(c) Int, X1, X4, X16, X17, X18	1.6397	0.8274	71.7559
(d) Int, X4, X7, X16, X18	1.7757	0.8042	68.6632
(e) X1, X7, X10, X11, X12, X13, X15, X16	1.4062	0.8660	123.5351
(f) Int, X1, X5, X9, X10, X11, X12, X13, X14, X16, X18	1.0362	0.9169	127.9497
(2) BROWN TROUT			
(a) Int, X2, X6, X8, X11, X15, X18	0.4576	0.7701	17.0073
(b) Int, X2, X6, X7, X8, X11, X15	0.4592	0.7693	16.5724
(c) Int, X2, X6, X8, X11, X17, X18	0.5400	0.7288	18.7090
(d) X2, X8, X11, X17	0.6257	0.6385	19.9182
(e) X2, X8, X10, X11, X12, X13, X14, X15	0.6638	0.6838	24.6013
(3) TOTAL TROUT			
(a) Int, X3, X4, X14, X16	1.6078	0.7185	57.4095
(b) X4, X14, X16	1.7924	0.6576	57.9225
(c) Int, X5, X9, X10, X11, X12, X13, X14, X16, X18	1.5374	0.7920	78.2927
(d) X1, X2, X4, X11, X12, X14, X16	1.5012	0.7610	142.9184

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