ABSTRACT

WALLACE, BENJAMIN CRAIG. Trout Population and Production Dynamics in North Carolina State Park Streams. (Under the direction of Thomas J. Kwak.)

Stream trout (Salmonidae) fisheries provide popular recreational fishing opportunities in North Carolina and nationwide. These fisheries are often managed under historical practices with limited information available to evaluate or plan management alternatives. The use of dynamic rates of population functions can serve as a superior method to quantify trout populations and provide a scientific basis from which to guide management decisions. Three trout species, brook trout *Salvelinus fontinalis*, brown trout *Salmo trutta*, and rainbow trout *Oncorhynchus mykiss*, inhabit streams under a variety of management regulations and stocking regimes in Stone Mountain State Park, North Carolina. To investigate trout population and production dynamics in intensively utilized southern Appalachian Mountain streams, we studied six stream reaches to (1) intensively sample and quantify critical population parameters of stream trout in a State Park, (2) develop empirical estimates of stream trout production rate based on population parameters, (3) sample and quantify nongame fish assemblages associated with trout fisheries, (4) measure and quantify water quality and instream habitat characteristics associated with trout and nongame fish assemblages, and (5) present the results of this study in an applied context toward guiding management strategies for stream trout fisheries in North Carolina State Parks, as well as other coldwater streams across North America.

Of the three unstocked streams sampled, brook trout were present in two and brown trout were present in all three. Wild trout are short-lived with a maximum age of two years among fish sampled in Stone Mountain State Park streams. Mean annual brook trout density in unstocked waters ranged from 195 to 234 fish/ha and that for brown trout was 169 to 2,038 fish/ha. Annual brook trout production ranged from 5.91 to 8.81 kg/ha and annual brown trout production ranged from 14.07 to 64.16 kg/ha in unstocked waters. Age-0 and age-1 fish contributed the most production in the unstocked waters. Distributional sampling revealed brook trout in allopatry in the uppermost headwaters of two unstocked streams.

Brook trout, brown trout, and rainbow trout were present in all three sampled reaches of the East Prong Roaring River. Trout densities in delayed harvest managed waters fluctuated widely over time and could not be explained by the frequency and density of stocking alone. Few trout remained in the sampling reaches for long periods of time after stocking into delayed harvest waters. Trout density in hatchery supported waters declined rapidly after being opened to harvest.

Nongame fish were collected in four of the six sampling reaches, and species richness ranged from 2 to 13. Nongame fish density was highest in a portion of the East Prong Roaring River where instream and riparian habitat rehabilitation previously occurred. Instream habitat, stream gradient, and overhead cover were similar within unstocked waters and within stocked waters but were different between the two stream groups. Stream temperatures in the East Prong Roaring River are marginally suitable for trout. Other water quality measurements were similar among all reaches that were studied.

Salmonid production can be used to monitor success of stream trout populations and, in conjunction with the ecotrophic coefficient, guide management decisions in coldwater streams nationwide. Annual production to mean annual biomass ratios developed from our empirical estimates of production can be used to estimate production in the future with reduced sampling effort. Based on my findings, management options for streams in Stone Mountain State Park are presented. My results, in addition to future research and monitoring, can improve understanding of trout population dynamics, native trout distribution, habitat modifications, and management effects.

Trout Population and Production Dynamics in North Carolina State Park Streams

by
Benjamin Craig Wallace

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Fisheries and Wildlife Sciences

Raleigh, North Carolina

2010

APPROVED BY:

Dr. Kenneth H. Pollock

Dr. James A. Rice

Dr. Thomas J. Kwak, Chair of
Advisory Committee

BIOGRAPHY

Ben Wallace was born in Payson, Utah, on October 25, 1984. Having moved all over the country at an early age, he finally settled in Lake View, Iowa, at age 13. Growing up with his brother, Jim, in an environment rich with opportunities for outdoor recreation, Ben spent every available moment hunting and fishing. Through his parents, Craig and Jackie Wallace, hunting and fishing, and growing up in a small community, Ben learned valuable principles that taught him to respect and understand the value of the natural resources. Ben graduated from Wall Lake View Auburn High School in 2003 and started his undergraduate studies that same year.

Ben's grandfather, Jim W. Wallace, who was a conservation officer, greatly influenced his decision to study natural resources as an undergraduate student at Iowa State University. A summer spent working for the Iowa Department of Natural Resources Fisheries Management Branch with the likes of Lannie Miller and Don Herrig persuaded Ben to focus his studies on fisheries. He continued to gain valuable experience in fisheries management the following two summers while working in Atlantic, Iowa, with Chris Larson and Mark Boucher, and in Clear Lake, Iowa, with Jim Wahl and Scott Grummer.

Ben graduated in May 2007 from Iowa State University with a bachelor's degree in Animal Ecology with an option in Fisheries. The following summer, he was offered an opportunity to study trout population dynamics in the mountains of North Carolina with Dr. Tom Kwak. Ben started his graduate work at North Carolina State University in the fall of

2007. The following pages document the past two and a half years of Ben's life in North Carolina.

ACKNOWLEDGMENTS

Unfathomable thanks to Dr. Tom Kwak for providing me with this opportunity and his knowledge, experience, and guidance. Dr. Kwak's support and friendship are matched only by his willingness to share his secret hunting locations around Raleigh, North Carolina. Drs. Jim Rice and Ken Pollock provided a great deal of ecological insight as well as advice in sampling and statistical design. For their assistance, I am truly grateful. I cannot thank Wendy Moore enough for making my life and student experience easier than it should have been.

Funding for this research was provided by the North Carolina Department of Environment and Natural Resources, Division of Parks and Recreation. Ed Corey, Marshall Ellis, and Brian Strong provided a great deal of advice and assistance in the field. Edward Farr was essential in the logistics of our sampling and providing housing for project personnel and background information about Stone Mountain State Park. Many thanks to the office staff, Denise Marquez and Annette Hall, at Stone Mountain State Park and to Matt Amadon, Greg Church, Mike Edwards, and Kelly Hoke for their help in the field. Darrell Richardson was always available to help make repairs to equipment. I would also like to extend my thanks to all of the park rangers and maintenance staff at Stone Mountain State Park for helping in more ways than I can count.

Numerous members of the North Carolina Wildlife Resources Commission played a vital role in conducting this research. Doug Besler, Kyle Briggs, Kevin Hining, Kin Hodges, and Mallory Martin provided a great deal of advice and background information. The

Armstrong State Fish Hatchery crew in Marion, North Carolina, made tagging thousands of trout for this project possible.

Field work and data collection would not have been possible without the assistance of many individuals. Dan Weaver was present from day one for every sampling trip we took to the mountains. Patrick Cooney spent a great deal of time in the field and offered a profusion of advice throughout my graduate career. Christin Brown, Elissa Buttermore, Justin Dycus, Joe Smith, Christon Wiles, James Wilson, and Jamie Wyatt were of great help in the field. This work would simply not be possible if not for all of these individuals.

I would like to thank Mark Boucher, Lewis Bruce, Tom Gengerke, Scott Grummer, Don Herrig, Chris Larson, Lannie Miller, and Jim Wahl for their influence in my decision to make a career of studying fish. David Waggie had an early influence in my interest in science. Dr. Mike Quist played a pivotal role in my studies at Iowa State University and gave me the confidence to pursue graduate school.

Lastly, I would be nothing without the support of friends and family. Friends Michael Fisk, Julie Harris, Steve Midway, Michael Miller, Rich Noble, Josh Raabe, and Mike Waine were always present to provide support and comic relief. Laura Wagner often took a backseat to this work, and for her unconditional understanding and positive reinforcement I am forever indebted. My grandmothers, Alice Elrick and Norma Wallace, constantly supplied encouragement and valuable advice. To my grandfather, Jim W. Wallace, who is perhaps the single greatest influence in my path in life, words cannot express my gratitude. My parents, Craig and Jackie Wallace, and my brother, Jim A. Wallace, have provided me with the foundation from which I draw support, confidence, understanding, and a drive to succeed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

Coldwater stream trout (Salmonidae) fisheries are among the most important natural resources in the United States in terms of angling and economics. Although trout inhabit a variety of aquatic systems (e.g., lakes and reservoirs), the majority of trout anglers prefer stream fishing (Griffith 1999). In North America, trout fishing continues to be a growing recreational activity, and streams are commonly stocked with native and nonnative hatchery reared fish to maintain high catch rates (Griffith 1999; Kulp and Moore 2005).

The southern Appalachian Mountains mark the southern edge of the distribution of three trout species in eastern North America (Flebbe 1994). Brook trout *Salvelinus fontinalis* are the only trout native to the eastern United States. Rainbow trout *Oncorhynchus mykiss*, native to the Western United States, and brown trout *Salmo trutta*, native to Europe, have been widely introduced throughout the eastern United States and other parts of the world (Crowl et al. 1992). While stocking nonnative salmonids can enhance the angling experience, it generally has an adverse effect on the native brook trout in the southern Appalachians by restricting them to the extreme headwaters of montane streams (Flebbe 1994). However, in the western United States, the situation is the opposite, where introduced brook trout contribute to the decline of native salmonids, such as the Colorado River cutthroat trout *Oncorhynchus clarkii pleuriticus* (Thompson and Rahel 1996).

In the early 20th century, native trout populations in the southern Appalachian Mountains were adversely affected by anthropogenic activities such as railroad and dam construction and extensive logging (Strange and Habera 1998). A study by Swift and Messer

(1971) reported that maximum stream temperatures increased at least 3.5 °C from previous conditions in watersheds that were completely removed of vegetation in the southern Appalachian Mountains. After extensive logging was reduced in the 1930s, brook trout ranges continued to decrease while introduced salmonids began to expand their range (Lohr and West 1992). Furthermore, brook trout are more susceptible to angling than rainbow trout and brown trout (Nuhfer and Alexander 1994), which can decrease their numbers in an already competitive or degraded environment. Intensive stocking of brown trout, rainbow trout, and northern strains of brook trout in response to declining numbers of native trout was common practice to keep up with angler demand in the southern Appalachians (e.g., Habera and Strange 1993; Kulp and Moore 2005). However, at the time, little thought was given to the consequences of stocking nonnative trout into streams inhabited by the southern Appalachian brook trout, a species now known to be genetically distinct (McCracken et al. 1993).

Recently, there has been a growing concern toward protecting the southern Appalachian brook trout (Habera and Moore 2005). The state of North Carolina has officially designated the southern Appalachian brook trout as a state heritage species (Epifanio 2000). The U.S. National Park Service's policy is to protect native species, while enhancement of recreational fisheries ranks second (Kulp and Moore 2005). The American Fisheries Society's Southern Division Trout Committee has offered guidelines to facilitate enhancement and preservation of the southern Appalachian brook trout (Habera and Moore 2005). Many agencies in the southern Appalachian region have followed suit and have begun to shift their research and management toward the protection and enhancement of native brook trout populations (e.g., Lohr and West 1992; Flebbe 1994; Strange and Habera 1998).

Fishing regulations typically play an important role in coldwater fisheries management where harvest can easily exceed annual surplus production due to low water fertility and slow growth of fishes (Noble and Jones 1999). The popularity of stream trout fishing has prompted a number of conservation organizations (e.g., Trout Unlimited, Fly Fishing Federation), local and non-local anglers, and other stakeholders (e.g., local governments) to become more involved in the management process (Gigliotti and Peyton 1993), driving fishery managers to attempt to strike a balance between management based on science and the desires of the fishery's constituents (Habera and Strange 1993). Often managers will partition the resources among users through different regulations, such as catch-and-release or delayed harvest (i.e., catch-and-release of stocked fish followed by a period of harvest), in an attempt to satisfy various angler groups and meet multiple management objectives (Noble and Jones 1999); thus, regulations are not always developed on a strict scientific basis.

In the past, management strategies for salmonids have evolved with nationally changing trends and varying management objectives, but there are no clear criteria to determine which of those strategies is most appropriate (Kulp and Moore 2005). Today, some populations continue to be managed based on historical practices or following a standardized protocol without specific knowledge or a scientific basis. Since the 1960s, data acquisition has improved due to advances in assessment techniques, such as electrofishing and tagging (Noble and Jones 1999). This has allowed agencies to reduce the use of generic regulations and develop management strategies for specific systems. Nonetheless, budgetary and time constraints play an important role in the number of empirical estimates that can be produced by state agencies (Waters 1992); accordingly, it is not practical to collect and quantify data from every fishery. It is common practice for agencies to develop a standard, simplified approach by sampling representative populations and to apply those results over a broad scale (e.g., Scarnecchia and Bergersen 1987; Thorn et al. 1997). Scarnecchia and Bergersen (1987) and Kwak and Waters (1997) demonstrated that it is possible to use easily measurable parameters, such as conductivity and alkalinity, to estimate more complex parameters, such as biomass and production. Waters (1992) suggested that it is possible to estimate production of a specific species based on existing data from other samples.

Data resolution for fish population management ranges from occurrence data (presence-absence of a species), catch rates (usually catch per unit effort), estimates of abundance (fish number or biomass per area), to dynamic rates of population functions (such as growth, mortality, and production over time). Because coldwater stream trout fisheries are subject to a highly dynamic environment (Griffith 1999), using a dynamic rate of population function is the best method to quantify and characterize stream trout populations. Production is a synthesis of population biomass, recruitment, growth, and mortality and is especially responsive to the welfare of a population and environmental change (Mann and Penczak 1986; Kwak and Waters 1997). Fish production is the best quantitative indicator of the performance of a population in any habitat (Jones et al. 1996; Minns et al. 1996; Randall and Minns 2000), and the range of methods used to estimate it are numerous (Chapman 1978; Hayes et al. 2007). With the advent of several landmark publications (e.g., Waters 1977; Mann and Penczak 1986), computer software applications (Railsback et al. 1989; Kwak 1992) and more recent studies (e.g., Kwak and Waters 1997; Randall and Minns 2000; Almodóvar et al. 2006), estimates of production are gaining wide acceptance and grow increasingly abundant in the literature. The annual production rate of salmonids is effective in the assessment of populations in lotic environments (e.g., O'Connor and Power 1976; Scarnecchia and Bergersen 1987; Randall and Minns 2000), as well as the determination of the effects of fishing regulations and habitat alterations (Waters 1992).

Although production rate can provide valuable insight into how a fishery may be managed, it is not routinely estimated by fishery managers because it requires substantial time and effort (Waters 1992). In lieu of empirical estimates for specific fisheries, estimates of production rates based on existing data are potentially useful in fisheries management. Production estimates of salmonid populations are abundant in the literature. However, the wide range of such estimates (15-300 kg/ha) and varying influential variables (e.g., age-structure, water quality) make it difficult to form accurate estimates solely from the literature to apply to a specific fishery (Waters 1992). The annual $P/\overline{B}$ ratio (annual production/annual mean biomass), has been shown to remain fairly constant among individual trout species and is an accepted tool used in estimating annual production (e.g., Waters 1977; Chapman 1978; Hayes et al. 2007). By multiplying a standard $P/\overline{B}$ ratio by a measure of the standing stock biomass, an approximate estimate of annual production can be calculated (Waters 1977). However, more recent literature has shown that the $P/\overline{B}$ ratio varies with the age-structure of a population, suggesting that estimates of production based exclusively on a standard $P/\overline{B}$ ratio in populations that have not been quantified would be met with reduced accuracy (Waters 1992; Kwak and Waters 1997).

While the literature suggests that production rates should be incorporated into the management process (e.g., Kwak and Waters 1997; Hayes et al. 2007), there should be some means by which to quantify the effects of such strategies. The ecotrophic coefficient (annual harvest/annual production) discussed by Waters (1992) can serve as an index to measure the effects of regulations, fishing pressure, and habitat alterations. For example, special regulations (e.g., catch-and-release, minimum size restrictions) will result in a low ecotrophic coefficient. In areas where there are more relaxed regulations, a higher coefficient may be found due to higher exploitation rates. Other variables, such as habitat and fish vulnerability, may influence the ecotrophic coefficient as well. Waters (1992) suggested that improved habitat may lower the coefficient by increasing the amount of production in a given stream reach.

The assessment of trout populations in coldwater streams is essential to effective fishery management; however, the presence and interactions of other fish species must also be considered. In a study of a small Appalachian stream containing brook trout, nongame fish species contributed as much as 86% of the overall production within that stream (Neves and Pardue 1983). Garman and Nielsen (1982) experimentally stocked brown trout into a stream and found that nongame species abundance declined due to predation by brown trout. In a similar study, Zimmerman and Vondracek (2006) suggested that native brook trout can coexist with slimy sculpins *Cottus cognatus* without competing, whereas nonnative brown trout may compete for food resources with slimy sculpins. Ross (1991) suggested that the introduction of non-native salmonids to stream fish assemblages generally has an adverse effect on native fish populations. However, there are some instances in which introduced trout and native nongame species coexist with little interaction (through competition or predation). Robinson et al. (2003) showed that non-native rainbow trout and native Little Colorado spinedace *Lepidomeda vittata* can coexist with no negative effects.

Aquatic scientists and fishery managers view water quality and habitat protection in Appalachian streams as a vital component in conserving wild fish populations (Habera and Strange 1993). Coldwater streams are so sensitive to disturbance that regulations are commonly put in place to regulate habitat degradation and watershed use (Noble and Jones 1999). In North Carolina, it is required that a 7.6 m buffer of undisturbed riparian vegetation be maintained on all private lands adjacent to trout streams (NCWRC 2005a). Water quality parameters (Scarnecchia and Bergersen 1987; Kwak and Waters 1997), instream habitat (Flebbe and Dolloff 1995; Flebbe 1999), and watershed practices (Habera and Strange 1993; Binns 1994) influence trout density, biomass, and production. However, streams are dynamic, and the relative influence of various physical and biotic factors may differ among streams or change from year to year in a given stream. For example, Scarnecchia and Bergersen (1987) showed a positive relationship between trout production and water quality in small streams in northern Colorado, whereas Kwak and Waters (1997) found no significant relationship between trout populations and production and water quality in southeastern Minnesota streams. Abundance of pools, cascades, and vegetation in streams are important factors affecting the occurrence of trout (Jutila et al. 2001). Habitat rehabilitation can successfully increase salmonid production as well as the carrying capacity of a system (Binns 1994; Thorn et al. 1997; Quinn and Kwak 2000). In recent years, the hemlock woolly adelgid *Adelges tsugae*, an exotic insect pest, has become a growing concern in areas that have dense populations of hemlocks *Tsuga* spp. (Jenkins et al. 1999; McClure and Cheah 1999; Webb et al. 2003). In some areas of the eastern United States, observed mortality of hemlocks caused by the woolly adelgid have been has high as 99% (Jenkins et al. 1999). However, some studies have shown that certain biological controls can help prevent hemlock mortality and promote new growth of hemlocks affected by the woolly adelgid (McClure and Cheah 1999; Webb et al. 2003). Several studies have concluded that streams with watersheds dominated by hemlocks experience more stable thermal and flow regimes and are more likely to sustain brook trout populations (Snyder et al. 2002, 2005). The loss of hemlocks, especially in a headwater stream ecosystem, could carry negative consequences not only for the fishery, but for the forest community as a whole. Evaluation of existing habitat and water quality in streams should aid in understanding stream trout population dynamics.

In 2008, approximately 92,000 anglers targeting mountain trout spent an estimated $146 million in North Carolina (NCWRC 2009). Many of the coldwater streams that contain trout species are located within State Parks; they are intensively fished and are managed and stocked by the North Carolina Wildlife Resources Commission (NCWRC). Angler interviews conducted by the NCWRC from November 2006 to June 2007 showed that 80% of anglers mostly or at least half of the time fished for stocked trout (as opposed to wild trout; NCWRC 2007). In the same interviews, most anglers were satisfied with their trout fishing experiences in North Carolina; however, some common frustrations included lack of time to fish, dissatisfaction with regulations or limits, and lack of trout.

Historically, rainbow trout and brown trout were introduced into North Carolina waters as early as the 1880s and early 1900s, respectively (Ahn et al. 2000). Although these introduced salmonids provide a valuable resource for anglers, they also may compete with native brook trout that currently have a significantly reduced range in the region. In interviews conducted by the NCWRC, anglers ranked native brook trout protection and restoration highly as an area of importance in the NCWRC trout management program (NCWRC 2007). Given the intense fishing pressure and accessibility, State Parks in North Carolina offer a unique opportunity to study highly exploited stream trout fisheries. Stone Mountain State Park (SMSP) alone receives approximately 60,000 angler visits targeting trout on an annual basis (Edward Farr, NC Division of Parks and Recreation, unpublished data). Understanding trout production, as well as dynamics of nongame fish populations, water quality, and habitat in North Carolina State Parks, applied in a management context, will provide crucial information useful in the management of coldwater trout streams and the preservation of native trout species that may be applied more widely to intensely fished coldwater systems.

While information on production rates provides the most complete description of a fish population's success, and thus is best suited to guide management decisions, it is not routinely estimated by fishery managers (Waters 1992). Therefore, empirical estimates of production will provide valuable information on parameters such as growth, recruitment, and mortality necessary for management planning, as well as an indication of biomass available for harvest.

My research focuses on the population and production dynamics of stream-dwelling trout occurring in a North Carolina State Park. Our specific objectives were to (1) conduct intensive sampling to quantify critical population parameters of stream trout in coldwater stream fisheries and ecosystems in a State Park, (2) employ accepted methods to develop empirical estimates of production of stream trout based on population parameters, (3) sample and quantify assemblages of nongame fishes associated with trout fisheries in coldwater streams, (4) measure and quantify water quality and instream habitat characteristics associated with trout and nongame fish assemblages, and (5) present results of this study in an applied context toward guiding management strategies for trout fisheries and stream ecosystems in North Carolina State Parks, as well as other coldwater streams. Results of this research may help to better understand the ecological and biological processes associated with trout populations from which an objective information base can be developed to guide fisheries and ecosystem management strategies, planning, and implementation.

Study Area

Sampling sites for this research were located in the northern edge of the Yadkin/Pee-Dee River basin of North Carolina in an area that receives intense fishing pressure throughout the year. The streams sampled flow into the Roaring River, a tributary of the Yadkin River, which ultimately flows to the Atlantic Ocean in South Carolina. Six different stream reaches were sampled in four streams. All but one of the sampling reaches are located within SMSP (Figure 1), on the eastern edge of the Blue Ridge escarpment in the Mountain Province of Wilkes and Alleghany counties (NCDEHNR 1994). The park consists of 5,440 ha of land characterized by extremely rugged, wooded terrain with 27 km of cascading trout streams flowing over granite bedrock. The park includes some of the most remote wilderness conditions found in the North Carolina State Parks system.

Sampling was conducted in four different streams in SMSP (Table 1), under different fishery management regulations (Table 2). Garden Creek is a second order stream and flows into the East Prong Roaring River (EPRR); it is designated a wild trout water and harvest fishing is allowed with single hook, artificial lures only and a daily creel of limit of four trout, combined species with a minimum harvestable length of 178 mm. Historically, Garden Creek was stocked with brook trout throughout 1941-42 and 1955-69 and stocked with rainbow trout in 1947 and 1970-72 (NCWRC 2005a). However, at present, naturally reproducing populations of both brook trout and brown trout are established there. There are historic samples on Garden Creek and the sampling site for this study was chosen as such to be located on a historic sampling site, located at the sixth trail crossing from the mouth of the stream (Site 1, Figure 1). In this particular reach of the stream, brook trout and brown trout occur in sympatry.

Bullhead Creek is designated a wild trout water, with catch-and-release fishing only; it flows into the EPRR. This stream is managed under limited fishing access with special regulations in which anglers must register and pay a $15 fee to fish a specific portion of the stream (among 8 total) with fly rods and artificial flies with barbless hooks only. Bullhead Creek was formerly owned and managed by a private fishing club (Edward Farr, personal communication) and was historically stocked with brook trout, brown trout, and rainbow trout in the 1940s-60s (NCWRC 2005a). When Bullhead Creek was annexed as part of SMSP, trout stocking ceased, and the only known trout species currently inhabiting the stream is a naturally reproducing allopatric population of brown trout. The fish in Bullhead Creek are hand fed pelleted rations by park personnel one to two times per week, and have produced trophy-size brown trout. The sampling site on Bullhead Creek is located at the downstream edge of the fourth angling section, which is designated in the park's fishing regulations (Site 2, Figure 1). Bullhead Creek is a third order stream where it flows into the EPRR, but our sampling site was located in a reach where it is a second order stream.

Rich Mountain Creek is a catch-and-release only stream and is managed under the same regulations and gear restrictions as Bullhead Creek. Rich Mountain Creek is a tributary to, and is designated as section three of the Bullhead Creek angling circuit. It is a second order stream. Historically, this stream was stocked with brook trout throughout the 1940s-60s and also stocked with rainbow trout in the 1940s (NCWRC 2005a). Currently, only naturally reproducing populations of brook trout and brown trout inhabit the stream. Rich Mountain Creek was chosen as a stream that would provide information on what trout populations in Garden Creek might resemble without harvest and what trout populations in Bullhead Creek could be without supplemental feeding. The sampling site on Rich Mountain Creek is located approximately 1 km upstream from its confluence with Bullhead Creek and contains sympatric populations of brook trout and brown trout (Site 3, Figure 1).

All three of the aforementioned sites are spring-fed streams characterized by high-gradients and sequences of cascades and pools. The average width of the streams ranges between 4 and 6 m. The landscape of the watersheds of these streams is that of extremely steep terrain and forested vegetation dominated by oak *Quercus spp*., hickory *Carya* spp., and pines *Pinus* spp. Rhododendron *Rhododendron* spp. and hemlocks border the streams providing overhead cover and shade.

Three sites were located on the EPRR and are located in reaches where it is a third order stream. Two are located within SMSP and are designated by the NCWRC as delayed harvest streams. One of these sites is in a portion of the stream that has remained relatively unaltered since it has become part of SMSP. This site is located at the confluence of Widows Creek and the EPRR and is referred to as "Delayed Harvest Upstream" in this study (Site 4, Figure 1). The second site on the EPRR is located downstream of the Delayed Harvest Upstream site in a reach that has undergone substantial instream and riparian habitat rehabilitation, and is referred to as "Delayed Harvest Downstream". Riffle and pool sequences have been created by construction of rock weirs in the stream channel providing increased habitat complexity. Delayed Harvest Downstream is located approximately 0.4 km downstream of the confluence of Garden Creek and the EPRR (Site 5, Figure 1). Delayed harvest streams are open to fishing year round, but closed to harvest from October through April of the following year and are open to harvest from June through September. Streams that are designated delayed harvest receive stockings of brook trout, brown trout, and rainbow trout at relative densities of approximately 40%, 20%, and 40%, respectively, on a regular basis throughout the period of no harvest, and then receive supplemental stockings sporadically during the period when harvest is allowed. During the period of no harvest, angling gear is restricted to single hook artificial lures only; when harvest is allowed there are no gear restrictions and a daily creel of 7 trout, combined species of any length is allowed.

The third site on the EPRR is downstream of the delayed harvest sections and is the only site outside of SMSP. This site is located in the reach where Longbottom Road crosses over the EPRR (Site 6, Figure 1). This portion of the stream is designated as a hatchery supported water and receives stockings of brook trout, brown trout, and rainbow trout. The hatchery supported section is open to harvest from the first weekend in April to the last weekend in February. There are no gear restrictions when the season is open and a daily creel of 7 trout, combined species of any length is allowed.

Estimating production of trout in the sampling sites on the EPRR was not an objective of my research, as these stream reaches received an influx of trout throughout the year making it difficult to distinguish fish by date of stocking. However, trout density and biomass in relation to season openings and closings and stocking events were of interest and were estimated. The stream reaches at all three sites on the EPRR are approximately 8 to 10 m wide and have a lower gradient than those in the tributary sites (Sites 1-3, Figure 1). The vegetation in the immediate watershed is a mix of grasses and timber, and the landscape is less steep than the wild trout designated waters.

Field Procedures

Trout Sampling

All trout species were collected using electrofishing powered by non-lethal, pulsed direct current (DC). Two backpack electrofishing units (Smith Root, Inc. models 12-B and LR-24) were used in collecting fish at all sites throughout the study. Due to low water conductivity, the standard trailing cable cathode was replaced, and two hand-held probes were used with each backpack electrofishing unit (one anode, one cathode). One netter collected fish in wild trout designated reaches, and two netters collected fish in hatchery designated reaches due to greater stream widths and fish numbers. Stunned fishes were immediately collected and held in buckets for the duration of the sampling event. Fresh water was continually exchanged and portable aerators were employed to reduce fish stress. Many studies have documented injury rates, mortality, and effects on growth of salmonids using pulsed DC (e.g., Gatz et al. 1986; Mesa and Schreck 1989; Hollender and Carline 1994; Thompson et al. 1997; Carline 2001). Gatz et al. (1986) found that growth rates for brown trout and rainbow trout were less than average when shocked repeatedly at 1.5-2.5 month intervals. However, pulsed DC electrofishing showed little effect on long term growth and body condition of brown trout and rainbow trout when repeatedly shocked at intervals greater than 3 months (Thompson et al. 1997). Although spinal injuries and hemorrhaging in trout can occur when electrofishing, using pulsed DC, rather than alternating current, reduces injury rates (Reynolds 1996). Furthermore, Reynolds (1996) suggests that these types of injuries occur more commonly in trout over 300 mm in length. Trout of this size were not expected to be found in any of the wild trout designated waters. We adjusted electrofishing power output at a threshold rate that would stun fish and allow capture, but not result in excessive electric power exposure (i.e., 0.10-.020 A).

Trout were collected at each site in the wild trout designated waters during four separate mark-recapture sampling events, throughout one year, so that seasonal and annual population parameters could be estimated. Each stream reach was sampled in April, June, and October, 2008, and in April, 2009. At least 3 months were allowed to pass between samples at each site, with the exception of a 2-month interval between April and June 2008 samples, to estimate the biomass accumulated throughout one year. The peak of brown trout spawning activity has been found to occur during a small window of time in November in a southern Appalachian river (Burrell et al. 2000). In another Appalachian river, brook trout spawning activity was observed in October and November, and likely ends in December (Petty et al. 2005). Sampling in wild trout waters during the fall was timed so that developed gonad mass would be included in the biomass estimates.

A closed Petersen mark-recapture method (Ricker 1975; Pine et al. 2003) was used to estimate absolute density during each seasonal sample. A mark-recapture method was the most practical means to obtain the desired data. All trout collected during the marking event (i.e., initial capture event) were identified to species, measured (mm TL), weighed to the nearest gram, and marked with a partial upper caudal fin clip. Once all pertinent data were collected, fish were returned to the stream in good condition within the boundaries of the sample site. Any mortality observed during the capture event was recorded so as not to violate the assumptions of the Petersen mark-recapture method. Mesa and Schreck (1989) found that wild trout return to normal behavior 24 hours after being shocked and handled. Therefore, the recapture event for each seasonal sample did not occur less than 24 hours or more than one week after the capture event for the corresponding sample. All trout collected during the recapture event were measured, weighed, and inspected for an upper caudal fin clip. Scale samples were taken from all trout collected in the capture event and all unmarked fish collected in the recapture event for age determination. Scales were removed from the portion of the fish directly below the dorsal fin and above the lateral line (DeVries and Frie 1996). Scale samples from each individual fish were placed in small envelopes and assigned a unique number for lab processing.

The length of the stream reaches sampled in the wild trout designated waters was between 200 and 300 m. Brown trout in a southern Appalachian river exhibited high site fidelity, with instream movements averaging less than 30 meters (Burrell et al. 2000). Brown trout in small streams captured via electrofishing have exhibited some upstream movements upon release (Nordwall 1999). However, Dunham et al. (2002) found no sufficient evidence that electrofishing increases brook trout movement, even after the fish were handled, measured, weighed, marked with fin clips, and had scales removed for aging. Furthermore, vertical steps and falls in the stream channel act as short-term barriers and inhibit brook trout movement upstream (Adams et al. 2000). Steep cascades and waterfalls are commonplace in the designated wild trout streams; thus, all sample locations included a natural barrier to fish movement at the upstream end. At each sampling site, during each seasonal sample, stream width was measured at ten equally spaced intervals within the sampling reach so that population parameters could be expressed per area, seasonally and annually.

Trout sampling in delayed harvest and hatchery supported designated waters was conducted in the same manner as in the wild trout designated waters. However, the focus of sampling these sites was to quantify trout density and abundance of hatchery fish in the stream. Thus, sampling was scheduled so that the effects of stocking and angler harvest could be observed. Four mark-recapture sample events were conducted in April, June, and October, 2008 and in April, 2009 on the two sites in the delayed harvest designated waters of the EPRR. All trout stocked into the delayed harvest waters of the EPRR in October were given an adipose fin clip at the Armstrong State Fish Hatchery in Marion, North Carolina, so that they could be distinguished among trout from other stockings. During the October, 2008 and April, 2009 samples, trout with adipose fin clips were recorded to estimate the percentage of trout held over in the stream during the period of catch-and-release only fishing.

Five mark-recapture events were conducted on one site in the hatchery supported section of the EPRR in April, June, and October, 2008 and in April, 2009. Two mark-recapture samples were conducted in the hatchery supported section in April, 2008, to examine trout density immediately before and approximately two weeks after harvest fishing was allowed. Estimating growth rates of these particular fishes was not an objective as the hatchery supported section of the stream is a put-and-take fishery.

Distributional Sampling

The distribution of trout species in headwater streams was examined during this research project. Numerous studies have cited a shift in the within stream distribution of native brook trout in response to the presence of introduced salmonids (e.g., Lohr and West 1992; Flebbe 1994). Garden Creek and Rich Mountain Creek were sampled in July of 2009 to determine if areas of these rivers contained allopatric populations of brook trout and brown trout. These two rivers were chosen because our seasonal sampling sites contained sympatric populations of brook trout and brown trout. Sampling started near the source of the two rivers and subsequent samples were taken as workers hiked downstream. In Garden Creek there were eight sampling locations spaced 1 km apart and in Rich Mountain Creek there were nine sampling locations. The first six sampling sites on Rich Mountain Creek were spaced 0.5 km apart, however, the distance between the last three sites varied as working daylight became as issue. Two backpack electrofishing units (Smith Root, Inc. models 12-B and LR-24) were used to sample fish for 50 river meters in an upstream direction at each interval throughout the entire length of Garden Creek and Rich Mountain Creek. Fish that were collected at each sampling site during the distributional sampling were identified by species, measured (mm TL), and weighed (g). Presence-absence was recorded and catch per unit effort was calculated for each species.

Nongame Fish Sampling

Nongame fish sampling was conducted once in each study site during August 2008 to determine abundance and standing stock biomass during base flow. Due to logistical constraints and potentially high marking mortality of small nongame fish species (Simonson and Lyons 1995), a removal method was employed (Seber 1982). In this study, a three-pass removal method was used to estimate nongame fish abundance using two backpack electrofishing units (Smith Root, Inc. models 12-B and LR-24) and two netters. Effort was held constant throughout by ensuring that all instream habitat was thoroughly electrofished in each pass and every effort was made to collect all stunned fish. We waited at least 15 minutes between passes. Fish from each pass were held in a perforated holding pen in the stream outside of the sampling transect and sequestered until sampling was completed. Each fish was identified to species, measured (mm TL), and weighed to the nearest 0.01 g. In instances where high numbers of a particular species were collected, a subsample of lengths and weights of 50 fish were measured.

Sampling reaches for nongame fish species were approximately 50-70 m in length and were located within trout sampling reaches. Each sampling reach for nongame fish included macrohabitats (e.g., riffles, runs, pools, cascades) of the entire trout sampling reach. In reaches lacking natural barriers, block nets (3.2 mm ace mesh) were set at the downstream and upstream ends of the sampling transect to ensure a closed population. At each site, stream width was measured at ten equally spaced intervals within the reach so that fish abundance and biomass could be expressed per area.

Habitat Surveys

Habitat availability assessments were conducted at each of the six sampling sites during July 2009. Sampling was conducted during a period when discharge was approximately equal to the U.S. Geological Survey 40-year mean discharge at the Roaring River gauging station (i.e., base flow).

Microhabitat was characterized at ten transects within each of the six sampling sites. The location of the first transect was randomly chosen between the start of the trout sampling transect and a point two mean stream widths upstream. Each successive transect was then spaced two mean stream widths apart. At each transect, left and right bank angles were measured using a Suunto clinometer (model PM5/360PC). A spherical densiometer (model-A) was used to estimate overstory density and stream shading at the left and right banks and in the middle of the stream at each transect. Visual observations were made to record the presence of hemlocks in the riparian zone at each transect.

At each transect, a fiberglass measuring tape was suspended across the stream perpendicular to the flow. Microhabitat variables were measured at points located one-tenth of the mean stream width along the measuring tape. For example, if a reach had a mean stream width of 6 m, then microhabitat measurements were taken every 0.6 m along the transects. At each point on each transect, depth and current velocities were measured and substrate and instream cover were categorized. Depth was measured to the nearest centimeter using a top setting wading rod. Bottom current velocities were measured 1 cm off the stream bottom with a Marsh-McBirney, Inc. (model 2000) portable flowmeter attached to the top setting wading rod. Mean water velocity was measured at 60% of the water column for depths less than 1 m. Where depths exceeded 1 m, mean water velocity was measured as the mean of water velocities measured at 20% and 80% of the water column. The two most dominant substrate types, classified by a modified Wentworth scale (Bovee and Milhous 1978), were visually estimated at each point in an area equal to one square cell of the spacing of each point. The presence of instream cover was visually estimated within the same area as the substrate at each point. Instream cover categories included coarse woody debris, undercut bedrock, or any rock larger than large cobble, and providing potential velocity refuge or protection from potential predators (i.e., embedded boulders that did not provide refuge were not considered as cover).

Water temperature was recorded throughout the period of one year at each sampling site using Onset HOBO temperature data loggers. Temperature was recorded every hour so that daily and weekly minimum and maximum, and daily, weekly, and seasonal averages could be calculated.

Water Quality Sampling

Water quality parameters were measured once in July 2009 during the habitat availability assessments at each of the six sampling sites. A Hydrolab (model MS-5) was used to measure pH, dissolved oxygen (mg/L), and specific conductivity (µS/cm) in all six sampling sites. Water samples were collected from each site, held in Nalgene bottles on ice, and analyzed at our field station within 12 hours of the time they were collected. A Hach environmental kit was used to measure total alkalinity (mg/L as $CaCO_3$), nitrates (mg/L as NO_3^--N), and orthophosphorus (mg/L as PO_4^{3-}). Total alkalinity was measured using a phenolphthalein and total method with a digital titrator (Hach model 16900). Nitrates and orthophosphorus were measured with a digital colorimeter (Hach model DR/850) using a cadmium reduction method and an orthophosphate ascorbic acid method, respectively.

Estimating Population Parameters

Wild Trout

To estimate annual production, estimates of population size must first be calculated. A closed Petersen mark-recapture method was used to estimate fish density four times within a year. Pop/Pro Modular Statistical Software, developed by Kwak (1992), was run using a Chapman modified Petersen formula to estimate abundance $(\hat{N})$ as

$$\hat{N} = \frac{(M+1)(C+1)}{(R+1)}, \tag{1}$$

for each seasonal sample, where M is the number of marked fish in the population, C is the total number of fish captured in the second sample run, and R is the number of recaptured fish in the second sample run. Biomass $(\hat{B})$ for fishes was estimated as

$$\hat{B} = \hat{N}(\overline{w}), \tag{2}$$

where $\overline{w}$ is the mean weight for a given age group. There is size selective bias (i.e., electrofishing is generally more effective in sampling larger fish) that is inherent with electrofishing (Anderson 1995). Therefore, fish were stratified by size, and seasonal population and biomass estimates were calculated by 4-cm length groups. In a few instances, consecutive length groups were further combined (e.g., 8-cm length groups) due to small sample sizes. Population size, biomass estimates, and associated variances, were estimated for each length group and age cohort. Mean abundance and biomass estimates by cohort were calculated for each interval between seasonal samples and were weighted by the number of days within each interval for an annual mean. These estimates were also used to estimate growth and mortality rates and $P/\bar{B}$ by cohort. Observed acute mortalities during the mark events were omitted when running Pop/Pro and manually added after abundance and biomass were estimated. The instantaneous rate of growth (G) method, employing Pop/Pro, was used to estimate annual production $(\hat{P})$ for a given trout species as

$$\hat{P} = \hat{\bar{B}}\hat{G}, \tag{3}$$

where $\hat{\bar{B}}$ is the mean interval biomass weighted by days. Production is defined as the rate of tissue elaboration over time (Waters 1977); therefore, estimates were converted into standard area units (ha) over time (e.g., kg/ha/yr). All associated variances were computed using Pop/Pro Modular Statistical Software following the statistical methods of Newman and Martin (1983).

Aging Fish

Estimating production by means of the instantaneous rate of growth method requires age information on fish. Because age structure can vary among populations of the same species, age was determined for each fish in each seasonal sample from each study site in the wild designated trout waters. Although otoliths may provide for more accurate age estimates in trout species, it requires the fish to be sacrificed. Mortality of this magnitude would violate critical assumptions of a closed Petersen mark-recapture method. Hining et al. (2000) concluded that scales from rainbow trout could be used with reliable accuracy and precision for fish up to two years of age. Collecting scales is a non-lethal means of aging fish. In this study scales were taken from trout on the left side dorsal to the lateral line (DeVries and Frie 1996). In the lab, each scale sample was placed between two cellulose acetate plastic slides (76.2 x 25.4 x 0.76 mm) and run through an Ann Arbor roller press to create an impression of the scale. Age was estimated by viewing scale impressions and counting annuli with an Eyecom microfiche projector (model 7000).

Hatchery Trout

In waters that receive trout stocking, standing stock (i.e., abundance and biomass) was estimated at different points throughout one year. Population size, biomass, and associated variances were calculated for hatchery trout in the same manner as for wild trout. Production estimates of trout populations in the three sample sites in the EPRR were not feasible because the sites received an influx of trout from the hatchery throughout the year. Fish could not be distinguished by the date of their stocking, creating uncertainty when attempting to estimate instream production. Furthermore, trout experience considerable growth in the hatchery, with an average stock size of 260 mm-TL (NCWRC 2005b), making it difficult to clearly read annuli and assign ages to fish.

Delayed harvest waters are stocked with trout in October, November, and in March, April, and May of the following year during the period of catch-and-release only. During the period when harvest is allowed, reduced stockings of trout occur June through August. Approximately 2,175 trout stocked into the EPRR in October, 2008, were uniquely marked to estimate the number of trout from fall stockings held over into the following spring. Trout at the Armstrong State Fish Hatchery in Marion, North Carolina, were anesthetized with tricaine methanesulfonate (MS-222) and given an adipose fin clip. Once marked, the trout were sequestered in a raceway at the hatchery and were stocked exclusively into the delayed harvest designated trout waters in SMSP on October 1, 2008. All trout collected in the October, 2008, and April, 2009, electrofishing samples were inspected for adipose fin clips to estimate the number of holdover trout.

Condition Index

Fish condition was estimated as relative weight (W_r) for each trout individual at all six sampling sites for each season using the length and weight data collected. Mean W_r was calculated according to species using only fish that were larger than the recommended minimum size to avoid the variability in weight measurements commonly associated with smaller fish (i.e., brook trout ≥130 mm, brown trout ≥140 mm, rainbow trout ≥120 mm; Anderson and Neumann 1996). Mean W_r was also calculated for fish sampled in a reach on Bullhead Creek 2 km upstream of the seasonal sampling site (Site 2, Figure 1), so that condition could be compared between fish that receive pelleted rations and those that do not. A pairwise *t*-test was computed using JMP 8.0 to detect significant differences between mean W_r of fish that receive feed and those that do not.

Nongame Fishes

A closed population three-pass removal method was used to estimate population parameters of nongame fishes in all six study sites. In all streams where nongame fish were collected, three passes were conducted, and a decline in catch-per-unit-effort of each species was achieved.

Pop/Pro Modular Statistical Software (Kwak 1992) was used to calculate a maximum likelihood estimate of abundance $(\hat{N})$ as

(4)
$$\hat{N} = \frac{6A^2 - 3AT - T^2 + T\sqrt{T^2 + 6AT - 3A^2}}{18(A-T)},$$

where

(5)
$$A = 2c_1 + c_2,$$

(6)
$$T = (c_1 + c_2 ... + c_k),$$

and *c* is the catch on the *k*th pass (Bohlin et al. 1989). Biomass estimates (Equation 2) were also estimated with the software program. Fish were stratified into 2-cm length groups during analyses and then estimates were summed to provide population totals to avoid electrofishing size bias. All associated variances were computed in Pop/Pro following the methods of Bohlin et al. (1989) and Seber (1982).

Results

A total of 17 fish species representing six families were collected throughout the course of this study (Table 3). Three trout species were sampled and brown trout were the most widespread species collected at all study sites. Brook trout were found in five of the six study sites and were absent from the Bullhead Creek sampling site. Rainbow trout were only found in the EPRR study sites.

Population Parameters of Trout in Unstocked Waters

Size and age composition of trout were similar among sampling sites in the unstocked waters. We sampled wild brook trout from 60 to 211 mm TL and wild brown trout from 45 to 291 mm TL. Three age classes (i.e., ages 0-2) of brown trout were present in each of the three sampling sites, and three age classes of brook trout were present in both unstocked streams where they were found. Age-0 brook trout and brown trout recruited to the sampling gear at 60 mm and 45 mm, respectively, and were collected in the June and October sampling events. Age-1 and age-2 brook trout were also collected during each seasonal sample in Garden Creek and Rich Mountain Creek, with the exception of no age-2 brook trout collected during the October sample in Rich Mountain Creek. In all three study sites, age-1 and age-2 brown trout were collected in each seasonal sample.

Mean annual density of brook trout was 195.09 fish/ha in Rich Mountain Creek and 234.13 fish/ha in Garden Creek (Table 4). Brown trout mean annual density ranged from 169.87 fish/ha in Garden Creek to 2,038.69 fish/ha in Rich Mountain Creek (Table 4). Mean annual salmonid density ranged from 404.00 fish/ha in Garden Creek to 2,233.78 fish/ha in Rich Mountain Creek (Table 4). Despite the lack of brook trout in Bullhead Creek, mean annual salmonid density was higher than that of Garden Creek (Table 4). Mean annual salmonid biomass ranged from 12.50 kg/ha in Garden Creek to 31.47 kg/ha Rich Mountain Creek (Table 4). Mean annual brook trout biomass was less than half that of brown trout in all three streams. However, in Garden Creek, mean annual density of brook trout was higher than that of brown trout.

Brook trout and brown trout density was highest in all three streams during June 2008, which coincided with the recruitment of age-0 fish to the sampling gear (Tables 5-7). In cases where age-0 fish were sampled, age-0 fish of both species were at a higher density than any other age, with one exception (June 2008, Rich Mountain Creek; Table 7). When age-0 fish were not sampled, age-1 fish density was higher than that of age-2 of both species, also with one exception (April 2008, Garden Creek; Table 6). Age-1 fish generally contributed the highest amount of biomass in each sample.

Dynamic rates of population functions revealed seasonal trends common to both species sampled in unstocked streams. Instantaneous rates of growth for all cohorts combined for both trout species were highest from October, 2008 to April, 2009 in all streams (Tables 8-12). Conversely, instantaneous mortality rates were highest from June, 2008 to October, 2008 for both species in all streams (Tables 8-12), with one exception (October 2008 to April 2009; Table 10).

Annual salmonid production ranged from 22.88 kg/ha in Garden Creek to 70.08 kg/ha in Rich Mountain Creek (Table 4). Annual brook trout production was 5.91 kg/ha in Rich Mountain Creek and 8.81 kg/ha in Garden Creek (Table 4). Annual brown trout production was always higher than that of brook trout and ranged from 14.07 kg/ha in Garden Creek to 64.16 kg/ha in Rich Mountain Creek (Table 4). Annual salmonid production in Bullhead Creek (all brown trout) was higher than total salmonid production in Garden Creek (Table 4).

Production was generally highest from April to June when fish experienced relatively moderate growth rates with a relatively large amount of biomass present (Tables 8-12) and was always lowest from June to October. Age-0 fish contributed the highest amount of production in cases where density of age-0 fish was large relative to other age classes in the population (Tables 8, 10, 11). When the density of age-1 fish was at least approximately half of the density of age-0 fish, age-1 fish contributed the most to total production (Tables 9 and 12). Annual salmonid $P/\overline{B}$ ratios ranged from 1.78 in Bullhead Creek to 2.23 Rich Mountain Creek. The $P/\overline{B}$ ratio significantly declined with age in all cases, but there was no trend according to species (Table 4, Figure 2). Total $P/\overline{B}$ ratios were highest from October, 2008 to April, 2009, when the 2006 cohort was not sampled in any stream in April, 2009 (Tables 8-12).

Indices of Condition

Our results suggest that individual fish condition may be enhanced by artificial feeding, but the effect may be confounded with site elevation and stream longitudinal position. In Bullhead Creek during April, 2009, the brown trout mean W_r value (99.41±1.37 SE) of fish in reaches that received pelleted rations were significantly higher ($P<0.0001$) than those of fish from an upstream reach without feeding (90.99±1.18; Table 13). Further, brown trout mean W_r in the portion of Bullhead Creek that receives feed was higher than that of brown trout in Rich Mountain Creek that do not receive feed (95.97±1.37), but not significantly so ($P = 0.0871$). However, the site on Bullhead Creek with no feeding is approximately 2 km upstream from the study site that receives feed with an elevation difference of approximately 35 m, and the Rich Mountain site is approximately 27 m higher in elevation than the Bullhead Creek site that receives feed. Thus, the feeding effect may be confounded with elevation, stream longitude, or trout density-dependent effects.

There were apparent trends in mean W_r of trout in the delayed harvest and hatchery supported sampling sites. Brown trout generally had highest mean W_r, followed by brook trout, and then rainbow trout at all the sampling sites in the EPRR (Tables 14 and 15). Mean W_r for each species decreased from April 2008 to June 2008 at all three of those sampling sites. Mean W_r of trout in the stocked waters was generally lowest during the summer months. Following stockings, trout in the stocked waters generally had a mean W_r similar to that of trout in the unstocked waters. However, mean W_r of trout in stocked waters was generally lower than that of trout in unstocked waters as summer progressed.

Longitudinal Distribution

We sampled trout along the entire reach of the two streams that contain sympatric populations of brook trout and brown trout (i.e., Garden Creek and Rich Mountain Creek) to observe the longitudinal distribution of the two species. Brown trout were found in allopatry in the lower reaches of Garden Creek. As elevation increased, brook trout and brown trout were found to occur in sympatry. In both streams, allopatric brook trout were found in the uppermost headwaters (Figures 3 and 4). Brook trout CPUE was highest when brown trout were not present.

Distributional sampling of trout was not conducted on Bullhead Creek because brown trout were the only trout species present in the study site. Additionally, the sample to determine brown trout *Wr* in the unfed portion of the stream, 2 km upstream of the study site, revealed no brook trout.

Standing Stock of Trout in Stocked Waters

Trout density and biomass were estimated on multiple dates throughout a one-year period in the sample sites that received trout stocking by the NCWRC. Although the NCWRC strives to achieve stockings composed of 40% brook trout, 20% brown trout, and 40% rainbow trout, catch composition in our samples varied widely throughout the year (Figures 5-7).

Sampling and resulting parameter estimates approximately 17 days after the delayed harvest waters were opened to harvest (June 2008) revealed a substantial decline in trout density and biomass relative to that in the spring (April 2008). In both sites in the delayed harvest section, brown trout density and biomass was higher than that of brook trout and rainbow trout approximately 17 days after harvest fishing was allowed (Tables 16 and 17). Trout density did not increase with the number of stockings during the period of no harvest (Figures 5 and 6). Trout stocking occurred along the entire reach of the delayed harvest section in the EPRR during this study, and these parameter estimates reflect the distribution of those fish within our two sampling reaches. That is, a stocking of 2,175 trout is distributed over the entire reach of the delayed harvest section in the EPRR, and we sampled a portion of those fish. Over 85% (n=163) of the trout sampled in the delayed harvest waters in October, 2008, after the stocking, were marked with an adipose fin clip. However, only one rainbow trout with an adipose fin clip from the October, 2008 stocking was sampled in April, 2009, reflecting minimal survival in the delayed harvest sites.

In the hatchery supported site, trout density and biomass fell from 352 fish/ha after stocking, but before harvest was allowed, to 43.12 fish/ha 12 days after the stream was opened to harvest (Table 18). Brown trout, albeit in low densities, were the only trout species sampled in July and October, 2008 in the hatchery supported site (Figure 7).

Nongame Fish Assemblages

A total of 14 nongame fish species were collected in four of the six sampling sites in August, 2008 (Tables 19 and 20); only salmonids occurred in Garden Creek and Rich Mountain Creek. Total nongame fish density was 22,184 fish/ha in the upstream site and 44,746 fish/ha in the downstream site of the delayed harvest waters in the EPRR (Table 19). The hatchery supported section in the EPRR had a total nongame fish density of 15,174 fish/ha (Table 19). Bullhead Creek was the only unstocked stream sampled with nongame fishes present, and total density was 2,546 fish/ha (Table 20). The hatchery supported section of the EPRR had the highest species richness of nongame fishes (13 species), whereas Bullhead Creek had the lowest (2 species). The delayed harvest downstream site had a higher nongame species richness, total density, and total biomass than the delayed harvest upstream site (Table 19). Two non-trout gamefish species were collected in low abundances associated with fish community sampling: redbreast sunfish *Lepomis auritus* and smallmouth bass *Micropterus dolomieu*. Fantail darters *Etheostoma flabellare* and blacknose dace *Rhinichthys atratulus* were the most widely distributed nongame fish species, whereas mountain redbelly dace *Phoxinus oreas* and smallmouth bass were each only found in one sampling site (Table 3).

Habitat

Instream habitat characteristics were similar among the three sites in the unstocked waters and among the three sites on the EPRR, but were distinct between the two stream groups, reflecting differences in stream size (Table 21). Unstocked waters tended to be more shallow and narrow with lower mean column water velocity and discharge than the delayed harvest and hatchery supported sites. Stream gradient in the unstocked waters was at least seven times greater than that of sites in the EPRR. Bedrock and medium gravel were the dominant substrates in the unstocked waters, whereas very coarse gravel, silt, and small cobble were most prominent in the delayed harvest and hatchery supported waters. Undercut bedrock and small boulders provided the most instream cover and velocity refuge. Overhead shading in the delayed harvest downstream site was considerably lower than any other site. Hemlocks were present along the streams at all sample sites and a large number appeared to be infected by the woolly adelgid. Visual observations noted many dead, yet still standing, hemlocks along the entire reach of Rich Mountain Creek.

Water Quality

Critical water quality parameters were examined for each sampling site from water samples collected during base flow conditions (Table 22). All streams were slightly basic with pH ranging from 7.32 to 7.84. Dissolved oxygen ranged from 8.99 to 9.38 mg/L. Specific conductivity was low among all sites and ranged from 15.30 to 22.30 µS/cm.

Nitrates and alkalinity were also low and ranged from 0.04 to 0.12 mg/L as NO_3^--N and 3.10 to 6.70 mg/L as $CaCO_3$, respectively. Orthophosphorus ranged from 0.10 to 0.17 mg/L as PO_4^{3-} in all sites except the hatchery supported section, where it was 2.37 mg/L as PO_4^{3-}, which is directly adjacent to an emu farm.

Daily water temperatures recorded during the sampling year reflected the presence and absence of different trout species. Throughout the course of this study, water temperature in Garden Creek and Rich Mountain Creek never reached the upper thermal tolerance limit (Eaton et al. 1995) of brook trout (22.3 °C) or brown trout (24.1 °C; Figures 8 and 9). In late summer 2008, weekly maximum water temperatures exceeded the upper thermal tolerance limit of brook trout, but not brown trout, in Bullhead Creek (Figure 10). In all three sites in the EPRR, weekly maximum water temperatures exceeded the upper thermal tolerance limits of brook trout, brown trout, and rainbow trout (24.0 °C) during the summer months of 2008 (Figures 11-13). Mean weekly temperature only exceeded the upper thermal tolerance limit of brook trout in the hatchery supported site in the EPRR (Figure 13).

Discussion

Wild trout populations in SMSP are short lived and seldom exceed lengths of 250 mm. The maximum age of both wild trout species (i.e., brook trout and brown trout) sampled in this study was 2 years old. Maximum age of naturally reproducing brook trout in the Appalachian region rarely exceeds 3 years (Habera and Moore 2005). In accord with our findings, Neves and Pardue (1983) observed only three age classes of brook trout in a second order Appalachian stream. In trout populations in Pennsylvania streams with similar age structure and water chemistry, age-1 brook trout contributed to the total egg production, albeit at a low rate relative to age-2 and age-3 fish (Wydoski and Cooper 1966). Mature age-1 brook trout and brown trout were reported in a second order stream in Massachusetts (Carlson and Letcher 2003). The short life span and low numbers of age-2 brook trout and brown trout suggest that age-1 fish contribute significantly to reproduction and annual production in SMSP streams.

Annual salmonid production estimates in SMSP (22.88 to 70.08 kg/ha) fall within the range of other estimates for North American coldwater streams, but are at the lower margins of estimates from Europe (Table 23). Waters (1992) proposed that annual salmonid production rates of 100-300 kg/ha are indicative of highly productive streams. As expected, our estimates of annual production in soft, headwater Appalachian streams were well below 100 kg/ha. However, our estimates in this study range higher than other estimates of annual production in the southern Appalachian region (e.g., Neves and Pardue 1983; Whitworth and Strange 1983; Loar et al. 1985; Table 23). Our lowest production estimate from June to October (3.34 kg/ha, Tables 8-9) was comparable to the July to October estimate by Ensign et al. (1990) of 4-5 kg/ha, but our other two estimates from June to October (9.16 and 15.8 kg/ha; Tables 10-12) were two to three times higher.

$P/\overline{B}$ ratios calculated for salmonids in our study were similar to estimates provided by Kwak and Waters (1997) when three age classes were present. Our calculated $P/\overline{B}$ ratios were higher than Clarke and Scruton's (1999) $P/\overline{B}$ estimates for Newfoundland streams; however, they sampled trout populations with up to five year classes present. Kwak and

Waters (1997) demonstrated that $P/\overline{B}$ ratios decline as the number of year classes in a population increases. $P/\overline{B}$ ratios were always higher for both species in younger age classes. Waters (1992) concluded that $P/\overline{B}$ ratios for brown trout are usually lower than those for brook trout; however, strong year classes of a given species can have dramatic effects on the $P/\overline{B}$ ratio. This holds true in our study. Brown trout exhibited lower $P/\overline{B}$ ratios than brook trout, except in Rich Mountain Creek, where brown trout recruitment was exceptionally high.

Contrary to literature expectations, in unstocked SMSP streams where sympatric populations of brook trout and brown trout are present, age-0 salmonids contributed the highest percentage of annual salmonid production. Whereas, age-1 brook trout and brown trout contributed the largest percentage of annual production in the population of each species in southeastern Minnesota streams (Kwak and Waters 1997). Production is directly influenced by growth and biomass, and biomass is directly influenced by abundance. Age-1 fishes typically make up a large percentage of the population and experience higher growth rates than older fish. High estimates of age-0 fish production relative to other age classes in this study reflect exceptional reproductive success and recruitment of juvenile fishes.

Garden Creek had the lowest annual salmonid production, biomass (Table 4), nitrates, and orthophosphorus (Table 22), but was the highest in elevation (Table 1) and width:depth ratio (Table 21). Scarnecchia and Bergersen (1987) reported that salmonid production and biomass in Rocky Mountain streams was inversely related to elevation and possibly, width:depth ratio. Relationships between salmonid production and stream alkalinity have been frequently reported (e.g., Scarnecchia and Bergersen 1987; Kwak and Waters 1997;

Almodóvar et al. 2006). Annual production in Garden Creek was lower than predicted annual production when fitted to Kwak and Waters' (1997) model relating alkalinity to production. Furthermore, Garden Creek is the only one of the three unstocked streams where harvest is allowed, which may limit standing stock and production. Elevation, instream habitat characteristics, low alkalinity, and harvest may all be factors contributing to the low salmonid productivity of Garden Creek.

Gradient may also influence stream trout production. Kozel et al. (1989) found trout standing stock to be higher in streams with low gradients (0.1-1.4%) than streams with moderate gradients (1.5-4.0%). However, Rich Mountain Creek has a gradient of nearly 10% and had the highest standing stock of trout as well as the highest amount of production. Although Rich Mountain Creek has a high gradient relative to the streams studied by Kozel et al. (1989), the underlying geology, undercut bedrock, and numerous cascades create a considerable amount of pools with cover providing habitat for trout. Rich Mountain Creek produced an exceptionally strong 2008 year class of brown trout. Over 70% of the estimated annual production of brown trout was contributed by the 2008 year class. The strong year class coupled with the abundance of pool habitat could help explain the relatively high estimates of salmonid production in Rich Mountain Creek.

Annual salmonid production in Bullhead Creek was higher than that in Garden Creek, but lower than that in Rich Mountain Creek. A study of North Carolina mountain trout streams evaluated the effectiveness of supplemental feeding of wild brown trout and rainbow trout populations and concluded that the use of automatic feeders over a period of three years did little to increase the number of brown trout >250 mm (NCWRC 1995). In Bullhead Creek, the largest fish we sampled was 265 mm TL (180 g), and no brown trout were sampled that were in the size range that is considered a preferred (300-379 mm TL), memorable (380-459 mm TL), or trophy (>459 mm TL) size fish for the species (Anderson and Neumann 1996). Condition of brown trout in the portion of Bullhead Creek that receives supplemental feed was significantly higher than that in the upstream portion that does not receive feed, but it was not significantly higher than that in Rich Mountain Creek, where fish feed exclusively on natural prey items. W_r of brown trout may also be negatively correlated with elevation and stream longitude, which may be confounding factors. Therefore, we are unable to clearly demonstrate any enhancement of trout condition from feeding effects due to elevational and longitudinal differences. Nevertheless, mean W_r of brown trout in both locations of Bullhead Creek and in Rich Mountain Creek are near 100, which is considered to be ecologically and physiologically optimal for fish populations (Anderson and Neumann 1996; Table 13). Our results also do not indicate if feeding affects overall production in Bullhead Creek relative to our other study sites.

Although our estimates of annual salmonid production in SMSP are comparable to other studies in the southern Appalachian region, the proportion of production contributed by native brook trout is much lower relative to the production contributed by brown trout. In reaches where brook trout and brown trout occur in sympatry, the contribution to annual salmonid production by brook trout was 8-40%. Carlson et al. (2007) suggested that nonnative brown trout experience faster growth rates than native brook trout by maintaining a size advantage. Brown trout are more aggressive and can exclude brook trout from preferred instream habitat (Fausch and White 1981), which can have negative effects on brook trout growth (Carlson et al. 2007). Mean annual brown trout biomass was always higher than mean annual brook trout biomass due to relatively high densities and larger sizes of brown trout. Low annual production estimates of brook trout relative to brown trout in our study streams provides evidence that brown trout may be competitively dominant. However, many factors affect the growth, production, and presence among trout species. For example, habitat may favor brown trout in our sampling sites, whereas habitat upstream from the sampling sites, where water temperatures are cooler, may favor brook trout.

The distribution of trout species in these headwater streams suggests a gradual displacement of brook trout by brown trout. Brook trout only exist in allopatry in uppermost headwaters in SMSP. A study by Schmitt et al. (1993), using data collected by the NCWRC (1983), reported positive correlations of brook trout density to elevation and instream cover, and negative correlations to pH, stream length and width, and flow. Numerous studies have cited declines in brook trout abundance due to the introduction of rainbow trout in the southern Appalachian Mountain region (e.g., Whitworth and Strange 1983; Larson and Moore 1985; Lohr and West 1992; Flebbe 1994; Hayes et al. 1996; Galbreath et al. 2001). Although rainbow trout were historically stocked in our study streams, none were sampled during the course of this study. Wild brook trout populations in the presence of brown trout are at risk of hybridization, which can be detrimental to reproductive success (Cucherousset et al. 2008). Waters (1999) reported a severe decline in brook trout abundance and replacement by brown trout over a 21 year period in a Minnesota stream. Brook trout in SMSP are at the southern edge of their distribution in North America (Flebbe 1994). Fausch (2008) hypothesized that native fish on the southern margin of their range are predisposed to displacement by nonnative species as natural disturbances can have more of an effect in these regions. Given the fact that brown trout have a slightly higher thermal tolerance than brook trout, rising stream temperatures in the future, either due to climate change or loss of stream shading, may lead to further displacement of brook trout in streams where they still occur.

Longitudinal changes in nutrients, energy flow, production pathways, and biota occur within a lotic system as stream order increases (Vannote et al. 1980). Thus, the location of sampling sites within a drainage basin may influence annual production, and those estimates that are based on a single location may not be representative of the entire stream network. Newman and Waters (1989) sampled eight contiguous stream reaches over a three-year period and found that, in some instances, production was significantly different between sections. Conversely, they found that growth rates did not significantly differ between sections. Production is the product of mean annual biomass (influenced by density) and growth. Therefore, trout density affects the amount of production in a given stream reach if growth remains constant. Newman and Waters (1989) suggested that trout density and production were regulated by differences in reach-scale habitat. In my research, visual observations during the distributional sampling of trout suggest that habitat and physical characteristics remain fairly constant among reaches within Garden Creek and Rich Mountain Creek, with the exception of extreme headwaters, where a higher stream gradient was observed. Variation in trout production throughout these streams could be investigated further by simply estimating density and biomass at different locations. These density and biomass estimates could then be used in conjunction with the growth rates that were previously obtained to observe any differences in production relative to stream longitude.

In the delayed harvest waters of the EPRR, trout densities appear to fluctuate widely and cannot be explained by the frequency and density of stockings alone (Figures 5 and 6). No obvious trends were apparent in the relation of frequency of stockings to trout density in the EPRR delayed harvest upstream site. However, in the EPRR delayed harvest downstream site, trout density was estimated at 849 fish/ha after three stockings during a no harvest period, 219 fish/ha after reduced stockings (i.e., fewer fish stocked) during harvest, and 452 fish/ha after one stocking after the close of harvest. The downstream site is in a portion of the stream that has undergone extensive instream and bank rehabilitation. The canopy is less dense over the downstream site than that in the upstream site, and coupled with the numerous riffle pool sequences constructed in the stream channel, provides an enticing section of river for anglers to target. During periods of allowable harvest in the hatchery supported section of the EPRR, trout density was considerably lower than during the period of no harvest after a stocking, suggesting a strong harvest impact. At all three sites in the EPRR, brown trout made up the majority of fish species sampled during periods of harvest, even though they comprised only 20% of the stocked fish. This result further supports the vulnerability of brook trout and the resistance of brown trout to capture by angling found in other studies (e.g., Cooper 1952; Nuhfer and Alexander 1994; NCWRC 2005b; Baird et al. 2006).

In delayed harvest waters during the fall, trout are stocked with the intention that they will grow and be available for harvest the following summer. However, only one rainbow trout marked with an adipose fin clip (i.e., fish from October, 2008 stocking) was sampled in April, 2009 in the EPRR delayed harvest sites. This indicates that few stocked trout survive and remain in the stream throughout the winter where they were initially stocked. Trout are often considered a relatively sedentary species maintaining small home ranges (e.g., Cargill 1980; Clapp et al. 1990; Bunnell et al. 1998); however, the opposite findings in some studies refuted this conclusion (e.g., Gowan and Fausch 1996; Baird et al. 2006). Approximately three weeks after stocking in October 2008, over 85% of the trout sampled in the delayed harvest sections of the EPRR had adipose fin clips suggesting short-term sedentary behavior of stocked trout. It is possible that trout dispersed out of the study areas over the winter, but high densities of trout upstream and downstream of the sites from stocking, as well as natural barriers upstream (i.e., waterfalls in tributaries) and downstream (i.e., beaver dams), leave migrating fish few options to seek a more suitable environment. Mean W_r of trout in the delayed harvest and hatchery supported sites decreased from April 2008 to the summer of 2008 suggesting weight loss as summer progressed. Additionally, mean W_r was generally highest for trout in our April 2008 and 2009 sampling, which occurred approximately two weeks after stocking. Thus, trout are stocked in relatively good condition, but experience a decrease in body condition the longer they remain in the stream.

Stocked trout in the EPRR that are accustomed to eating pelleted feed may find it difficult to capture enough prey in a wild environment to meet metabolic demands and survive over long periods, especially in months when energy is in high demand. Trout can experience a summer food limitation in the southern Appalachian Mountains (Cada et al. 1987; Ensign et al. 1990) and can experience inadequate energy intake during the winter months as well (Cunjak et al. 1987). Furthermore, Baird et al. (2006) concluded that stocked fish experience low growth rates and reduction in weight over extended periods of time after stocking.

Illegal harvest, catch-and-release hooking mortality, and predation are additional factors that likely contribute to the lack of long-term retention of stocked trout. Trout caught multiple times within a short time period may be exposed to a higher risk of catch-and-release hooking mortality. A creel survey of the delayed harvest waters in the EPRR revealed that each trout was caught an average of 2.8 times during the catch-and-release portion of the season (NCWRC 1993). That same study suggested that catch rates of trout during the period of legal harvest would have been higher had there not been catch-and-release hooking mortality and illegal harvest. River otters *Lontra canadensis* and great blue herons *Ardea herodias* are frequently observed in SMSP (Edward Farr, personal communication). Numerous studies have demonstrated that otters frequently feed on fish (e.g., Melquist and Hornocker 1983; Carss et al. 1990). Another study revealed that great blue herons can consume up to 39% of trout in concrete raceways (Glahn et al. 1999).

Species richness of nongame fish among sites in the EPRR (11-13 species) was higher than that among sites in the wild trout waters (0-2 species). Nongame fish assemblages in the EPRR were similar in species richness to other southern Appalachian streams (4-10 species; Freeman et al. 1988; 3-14 species; Weaver, unpublished data). Similar to our results, Neves and Pardue (1983) found that bluehead chub were among the most dominant nongame fish species in a small Appalachian stream. Presence and abundance of nongame fish in the EPRR, or lack thereof in its tributaries, may be related to stream channel geomorphology. Blacknose dace and fantail darters, which are well suited to swift waters and higher stream gradients, were the only nongame species sampled in the tributaries of the EPRR. Catostomids, centrarchids, and ictalurids were sampled in the EPRR where the gradient is lower and areas of deep water are more abundant. The highest density and biomass of all nongame fishes were found in the delayed harvest downstream site. The high densities of nongame fishes in this area may reflect the intended success of improved fish habitat via instream and bank rehabilitation carried out by the North Carolina State Parks (NCSRI and SMSRSC 2000). However, it seems as though habitat rehabilitation did little to rectify high water temperatures as the delayed harvest upstream and delayed harvest downstream sites both exceeded the upper thermal tolerance limits of trout. Similar to our own results, Quinn (1994) reported that nongame fish populations were at least 20% higher in rehabilitated stream reaches when compared to reference reaches in low gradient streams in Minnesota.

Stream temperature is among the most basic factors limiting trout distribution (Flebbe 1994). Throughout the course of this study, stream temperatures never reached the upper thermal tolerance of brook trout or brown trout in Garden Creek and Rich Mountain Creek (Figures 8 and 9). However, maximum weekly stream temperatures in Bullhead Creek exceeded the upper thermal tolerance limit of brook trout in late summer of 2008 (Figure 10). Bullhead Creek is slightly wider, with less overhead shading, than Garden Creek and Rich Mountain Creek, which may play a role in limiting brook trout presence. Hemlocks infected by the woolly adelgid were observed along all streams and may result in rising stream temperatures if overhead shading is reduced. Maximum weekly stream temperatures in all three sites on the EPRR exceeded the upper thermal tolerance limit for all trout species found in SMSP during the summer of 2008 (Figures 11-13). However, these peaks in temperature were periodic and fish may be able to find suitable thermal refuge in deep pools, shaded areas, sites of upwelling, or small coldwater tributaries until water temperatures dropped. Baird and Krueger (2003) observed congregations of brook trout utilizing tributary confluences and areas of upwelling as thermal refuge. The hatchery supported site was the only site where mean weekly stream temperatures exceeded the upper thermal tolerance for brook trout, and no brook trout were sampled during the summer months when this occurred (Figure 13).

Management Implications

Fish ecologists agree that production is the best measure of ecological success of a population (e.g., O’Connor and Power 1976; Mann and Penczak 1986; Kwak and Waters

1997; Lobón-Cerviá 2003; Almodóvar et al. 2006), and therefore, should be incorporated into the management process when feasible. We believe the $P/\overline{B}$ ratios derived from our empirical estimates of production in North Carolina headwater streams provide a foundation from which to estimate production in streams throughout the southern Appalachian region. The $P/\overline{B}$ ratios (i.e., brook trout and brown trout combined) estimated in our study concur with trends found in other studies on salmonids compiled by Waters (1992); thus reflecting the accuracy of our estimates (Figure 14).

The ecotrophic coefficient, relative to recreational fishing, represents the ratio of angler harvest to production (Ricker 1946; Waters 1992). Waters (1992) suggested that streams with low salmonid productivity (i.e., <100 kg/ha), with limited access (e.g., wilderness streams), could be safe from overfishing with an ecotrophic coefficient of 0.25. In Garden Creek, the least productive stream we sampled, an annual harvest of 5.72 kg/ha would coincide with an ecotrophic coefficient of 0.25. The mean weight of a trout (brook trout and brown trout) vulnerable to angling (i.e., age-1 and age-2) in Garden Creek is approximately 85 g. Thus, an annual harvest of 67 fish/ha, at 85 grams each, would result in an ecotrophic coefficient of 0.25 in Garden Creek with an estimated annual production of 22.88 kg/ha. Anglers typically carry some type of measuring device, as opposed to a weighing device, while fishing. The predicted length of a wild trout in SMSP (using linear regression) weighing 85 grams is 200 mm. Therefore, 67 fish/ha at 200 mm in length, could be harvested from Garden Creek without overfishing. Garden Creek's length of fishable waters is about 7.2 km with a mean width of about 5.2 m, suggesting that 250 catchable trout could be harvested from Garden Creek each year. Thus, a similar stream with comparable trout production rates and size composition could support the annual harvest of 67 fish/ha at 200 mm each.

For the practical purposes of anglers' understanding of regulations, a standard creel limit for all streams may be the most effective approach. In such a case, the most conservative estimate of allowable annual harvest should be used. For example, annual production in Rich Mountain Creek is higher than in Garden Creek. Therefore, an annual harvest of 67 fish/ha in Rich Mountain Creek would result in an ecotrophic coefficient lower than 0.25, indicating the stream is safe from overharvest. Currently, creel limits in streams in SMSP that permit harvest allow for any combination of trout species. If species specific management is desired, the same principle of using annual production estimates and the ecotrophic coefficient to manage all salmonids could be used to manage trout according to species. This may be an appropriate approach for brook trout, which are more vulnerable to angling and their densities tend to be lower than brown trout densities in areas of sympatry. Creel surveys, in conjunction with annual monitoring, would improve understanding of angler impacts on wild trout resources.

Delayed harvest waters are important to anglers and local economies (NCWRC 2009), but our anecdotal finding suggests there is low long-term retention of stocked fish in the streams. Although our study did not elucidate underlying mechanisms, natural mortality, catch-and-release hooking mortality, illegal harvest, and emigration are possible factors contributing to the low retention of stocked fish. For example, tagged trout stocked into an

Adirondack stream typically experienced weight loss and some of those fish were recovered 5 km downstream from where they were stocked (Baird et al. 2006). Furthermore, trout stocked into a California stream in the fall exhibited a decline in body condition, which contributed to mortality as winter progressed (Reimers 1963). Research to understand the mechanisms behind the low retention rates could be applied to improve the utility of stockings in delayed harvest waters. Additionally, angler satisfaction is an important consideration when evaluating any type of fishery that is supported by hatchery reared fish. If angler satisfaction is largely determined by catch rates, then delayed harvest waters aid in achieving that objective. In streams managed as delayed harvest waters, anglers experienced catch rates approximately 1.5-2.5 times higher than in hatchery supported designated waters (NCWRC 1993), and this ratio could be increased further with longer fish retention rates.

The EPRR supports an assemblage of coldwater fishes, and our temperature data indicate that the EPRR is marginally suitable to support trout year round. If the desire is to provide a trout fishery for the public, then stocking appears to be the only viable management option. Yet, there may be concern for establishing naturalized populations from stocked fish and the possibility of hybridization of stocked nonnative and native trout. However, one study has shown that sterile triploid hatchery trout offer a recreational fishery equal to that of diploid hatchery trout, but without the genetic risks (Dillon et al. 2000). Currently, the vast majority of trout stocked in North Carolina streams are sterile, triploid fish which would prevent such occurrences (Kyle Briggs, North Carolina Wildlife Resources Commission, personal communication). Given the annual temperature regime, the use of stocked sterile trout, and our observations during this study, delayed harvest and hatchery supported waters provide a popular recreational fishery which otherwise would not exist.

There are many factors to be considered when managing sport fisheries. Although science may indicate the most appropriate options for a stream biologically, social, political, and economic aspects must be taken into account and sometimes supersede scientific logic. Annual salmonid productivity can be employed to estimate the amount of biomass available for harvest, and thus, the number of fish that can be sustainably removed from a stream. Water's (1992) stated that 25% of the annual production (i.e., ecotrophic coefficient of 0.25) can be removed from low-productivity streams without overfishing, and our results are presented following that guideline as a sustainable harvest. However, mortality from catch-and-release fishing is a critical component in the amount of fish biomass removed from a system and should be considered when allocating harvest, especially in waters that may be intensively fished. A review of catch-and-release mortality studies conducted by Bartholomew and Bohnsack (2005) found an average acute mortality rate of 18% when fish (wide stratum of species) were released after capture with hook and line. It was also found that numerous factors significantly influenced mortality, such as hook location, hook style, bait usage, and handling time of fish. Dubois and Dubielzig (2004) observed a hooking mortality rate of less than 4% in three wild trout species when using spinners with either single or treble, barbed or barbless hooks. Additionally, they reported severe eye damage and jaw injuries in 10% and 6% of fish landed, respectively. Consequently, mortality from certain angling techniques and gear can reduce the amount of biomass available for harvest, especially in low-productivity streams. Stream location and angler access can affect the level of harvest in a given stream (Waters 1992). Streams that are secluded or that require usage fees might result in lower ecotrophic coefficients as some anglers may be unwilling to hike or drive long distances or pay a fee to fish. Thus, limiting stream access through regulations, such as allocating a limited number of permits with or without a daily fee may reduce the level of harvest or catch-and-release hooking mortality.

Habitat information, especially water temperature, provides insight into the ability of a stream to support certain fish species. Although water temperatures may not be optimal for year-round residence of trout, angler demand and other social or political factors may persuade managers to create a seasonal fishery through stocking programs. In such instances, liberal creel limits would allow anglers to exploit a seasonal fishery that may not persist once water temperatures exceed critical thresholds. These types of fisheries are typically associated with streams where angler access requires minimal effort, thus fully utilizing a put-and-take or put-grow-and-take fishery. In SMSP there are a number of streams that vary in thermal regime, access type, stocking regime, and level of wild trout production; hence, there are numerous management options to be considered within the biological, ecological, social, political, and economic environments of Stone Mountain State Park (Table 24).

Future Research and Monitoring

The empirical estimates of fish production rate calculated in this study provide a baseline from which to conduct annual monitoring of populations in SMSP and other streams in the southern Appalachian region. If changes in regulations are implemented, estimates of production using the $P/\overline{B}$ ratio in conjunction with the ecotrophic coefficient could aid in assessing the impacts of those changes. Multiple years of empirical estimates of trout production rates would strengthen understanding of the dynamics of trout populations in southern Appalachian streams and help to further guide management decisions.

Monitoring habitat condition may add insight to environmental influences on interspecific dynamics. Nongame fish densities in the delayed harvest downstream site were significantly higher than in the delayed harvest upstream site, which could be due to habitat rehabilitation, but a planned BACI (before-after, control-impact design) evaluation would be required to attribute the differences to the habitat rehabilitation. This would provide a unique opportunity to study the before and after effects of stream rehabilitation in southern Appalachian rivers. Given the marginally suitable temperatures in the EPRR, if more rehabilitation were to be carried out, careful steps to preserve large trees along stream banks would be beneficial in maintaining a dense overstory.

Streams in SMSP have upstream watersheds that are protected from anthropogenic disturbances. However, the woolly adelgid has the potential to dramatically alter the landscape and stream thermal regimes in SMSP. The abundance of hemlocks and other riparian vegetation in SMSP is critical information for understanding the effects of such a loss. Simple monitoring of changes in overstory density associated with SMSP trout streams could be continued using the same methods we applied in this study to document trends over time.

Distribution of wild brook trout populations relative to wild nonnative brown trout populations can provide insight toward ecology and management of trout fisheries. Ranges of allopatric trout populations can change on an annual basis (Strange and Habera 1998); therefore, multiple years of distributional data could elucidate dynamics and influences on long-term trends or changes. Direct population manipulations, such as removal of brown trout, may be considered if a gradual loss of allopatric brook trout populations seems evident and suitable brook trout habitat is available. There have been efforts to reestablish wild brook trout populations where numbers are low, due to poor habitat or introduced species, and in streams from which they have been extirpated. Clark and Rose (1997) carried out simulations to determine the most effective method of restoring brook trout populations to historical numbers prior to the invasion of rainbow trout. That modeling exercise suggested that electrofishing removal of rainbow trout and stocking of juvenile brook trout could significantly increase brook trout numbers in southern Appalachian streams.

Brook trout are the only salmonid native to North Carolina, and the genetically distinct southern Appalachian brook trout, as described by Habera and Moore (2005), is listed as a state heritage species (Epifanio 2000). Although no genetic testing was conducted in this study, brook trout of the southern Appalachian lineage have been found in some streams in SMSP (Kevin Hining, NCWRC, unpublished data). Conservation of naturally reproducing brook trout populations should be considered in management planning for stream fishes in SMSP. However, the economic impact and recreational value that trout angling has on SMSP and local communities and stakeholders is a valid concern that may guide management. Conservation of wild trout populations, long-term monitoring of fish populations, instream habitat restoration, and watershed preservation and management in Stone Mountain State Park are all critical facets in the effort to maintain a sustainable fishery for the public to enjoy, learn from, and pass on to future generations.

Literature Cited

Adams, S.B., C.A. Frissell, and B.E. Rieman. 2000. Movements of nonnative brook trout in relation to stream channel slope. Transactions of the American Fisheries Society 129:623-638.

Ahn, S., J.E. de Steiguer, R.B. Palmquist, and T.P. Holmes. 2000. Economic analysis of the potential impact of climate change on recreational trout fishing in the southern Appalachian Mountains: an application of a nested multinomial logit model. Climate Change 45:493-509.

Almodóvar, A., G.G. Nicola, and B. Elvira. 2006. Spatial variation in brown trout production: the role of environmental factors. Transactions of the American Fisheries Society 135:1348-1360.

Anderson, C.S. 1995. Measuring and correcting for size selection in electrofishing mark-recapture experiments. Transactions of the American Fisheries Society 124:663-676.

Anderson, R.O. and R.M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-482 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Baird, O.E. and C.C. Krueger. 2003. Behavioral thermoregulation of brook and rainbow trout: comparison of summer habitat use in an Adirondack river, New York. Transactions of the American Fisheries Society 132:1194–1206.

Baird, O.E., C.C. Krueger, and D.C. Josephson. 2006. Growth, movement, and catch of brook, rainbow, and brown trout after stocking into a large, marginally suitable Adirondack river. North American Journal of Fisheries Management 26:180-189.

Bartholomew, A. and J.A. Bohnsack. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Reviews in Fish Biology and Fisheries 15:129-154.

Binns, N.A. 1994. Long-term responses of trout and macrohabitats to habitat management in a Wyoming headwater stream. North American Journal of Fisheries Management 14:87-98.

Bohlin, T., S. Hamrin, T.G. Heggberget, G. Rasmussen, and S.J. Saltveit. 1989. Electrofishing — theory and practice with special emphasis on salmonids. Hydrobiolgia 173:9-43.

Bovee, K.D. and R.T. Milhous. 1978. Hydraulic simulation in instream flow studies: theory and techniques. Instream Flow Information Paper 5. U.S. Fish and Wildlife Service Biological Service Program FWS/OBS-78/33.

Brynildson, O.M. and C.L. Brynildson. 1984. Impacts of a floodwater-retarding structure on year class strength and production by wild brown trout in a Wisconsin coulee stream. Wisconsin Department of Natural Resources Technical Bulletin 146.

Brynildson, O.M. and J.W. Mason. 1975. Influence of organic pollution on the density and production of trout in a Wisconsin stream. Wisconsin Department of Natural Resources Technical Bulletin 81.

Bunnell, D.B.Jr., J.J. Isely, K.H. Burrell, and D.H. Van Lear. 1998. Diel movement of brown trout in a southern Appalachian river. Transactions of the American Fisheries Society 127:630-636.

Burrell, K.H., J.J. Isely, D.B. Bunnell, Jr., D.H. Van Lear, and C.A. Dolloff. 2000. Seasonal movement of brown trout in a southern Appalachian river. Transactions of the American Fisheries Society 129:1373-1379.

Cada, G.F., J.M. Loar, and M.J. Sale. 1987. Evidence of food limitation of rainbow and brown trout in southern Appalachian soft-water streams. Transactions of the American Fisheries Society 116:692-702.

Cargill, II, A.S. 1980. Lack of rainbow trout movement in a small stream. Transactions of the American Fisheries Society 109:484-490.

Carline, R.F. 2001. Effects of high-frequency pulsed-DC electrofishing on a wild brown trout population. North American Journal of Fisheries Management 21:571-579.

Carlson, S.M., A.P. Hendry, and B.H. Letcher. 2007. Growth rate differences between resident native brook trout and non-native brown trout. Journal of Fish Biology 71:1430-1447.

Carlson, S.M. and B.H. Letcher. 2003. Variation in brook and brown trout survival within and among seasons, species, and age classes. Journal of Fish Biology 63:780-794.

Carss, D.N., H. Kruuk, and J.W.H. Conroy. 1990. Predation on adult Atlantic salmon, *Salmo salar* L., by otters, *Lutra lutra* (L.), within the River Dee system, Aberdeenshire, Scotland. Journal of Fish Biology 37:935-944.

Chapman, D.W. 1978. Production in fish populations. Pages 5-25 *in* S.D. Gerking, editor. Ecology of freshwater fish production. Blackwell Scientific Publications, Oxford, Great Britain.

Clapp, D.F., R.D. Clark, Jr., and J.S. Diana. 1990. Range, activity, and habitat of large, free-ranging brown trout in a Michigan stream. Transactions of the American Fisheries Society 119:1022-1034.

Clark, M.E. and K.A. Rose. 1997. An individual-based modeling analysis of management strategies for enhancing brook trout populations in southern Appalachian streams. North American Journal of Fisheries Management 17:54-76.

Clarke, K.D. and D.A. Scruton. 1999. Brook trout production dynamics in the streams of a low fertility Newfoundland watershed. Transactions of the American Fisheries Society 128:1222-1229.

Cooper, E.L. 1952. Rate of exploitation of wild eastern brook trout and brown trout populations in the Pigeon River, Ostego County, Michigan. Transactions of the American Fisheries Society 81:224-234.

Cooper, E.L. and R.C. Scherer. 1967. Annual production of brook trout (*Salvelinus fontinalis*) in fertile and infertile streams of Pennsylvania. Proceedings of the Pennsylvania Academy of Science 41:65-70.

Cote, D. 2007. Measurements of salmonid population performance in relation to habitat in eastern Newfoundland streams. Journal of Fish Biology 70:1134-1147.

Crowl, T.A., C.R. Townsend, and A.R. McIntosh. 1992. The impact of introduced brown and rainbow trout on native fish: the case of Australasia. Reviews in Fish Biology and Fisheries 2:217-241.

Cucherousset, J., J.C. Aymes, N. Poulet, F. Santoul, and R. Céréghino. 2008. Do native brown trout and non-native brook trout interact reproductively? Naturwissenschaften 95:647-654.

Cunjak, R.A., R.A. Curry, and G. Power. 1987. Seasonal energy budget of brook trout in streams: implications of a possible deficit in early winter. Transactions of the American Fisheries Society 116:817-828.

Debowski, P. 1991. Production of brown trout (*Salmo trutta* m. *fario* L.) in two tributaries of the Pasleka River. Polskie Archiwum Hydrobiologii 38:283-294.

DeVries, D.R. and R.V. Frie. 1996. Determination of age and growth. Pages 483-512 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Dillon, J.C., D.J. Schill, and D.M. Teuscher. 2000. Relative return to creel of triploid and diploid rainbow trout stocked in eighteen Idaho streams. North American Journal of Fisheries Management 20:1-9.

DuBois, R.B. and R.R. Dubielzig. 2004. Effect of hook type on mortality, trauma, and capture efficiency of wild stream trout caught by angling with spinners. North American Journal of Fisheries Management 24:609-616.

Dunham, K.A., J. Stone, and J.R. Moring. 2002. Does electric fishing influence movements of fishes in streams? experiments with brook trout, *Salvelinus fontinalis*. Fisheries Management and Ecology 9:249-251.

Eaton, J.G., J.H. McCormick, B.E. Goodno, D.G. O'Brien, H.G. Stefany, M. Hondzo, and R.M. Scheller. 1995. A field information-based system for estimating fish temperature tolerances. Fisheries 20(4):10-18.

Elliott, J.M. 1993. A 25-year study of production of juvenile sea-trout, *Salmo trutta*, in an English Lake District stream. Canadian Special Publication of Fisheries and Aquatic Sciences 118:109-122.

Ensign, W.E., R.J. Strange, and S.E. Moore. 1990. Summer food limitation reduces brook and rainbow trout biomass in a southern Appalachian stream. Transactions of the American Fisheries Society 119:894-901.

Epifanio, J. 2000. The status of coldwater fishery management in the United States: an overview of state programs. Fisheries 25(7):13-27.

Fausch, K.D. 2008. A paradox of trout invasions in North America. Biological Invasions 10:685-701.

Fausch, K.D. and R.J. White. 1981. Competition between brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) for positions in a Michigan stream. Canadian Journal of Fisheries and Aquatic Sciences 38:1220-1227.

Flebbe, P.A. 1994. A regional view of the margin: salmonid abundance and distribution in the southern Appalachian Mountains of North Carolina and Virginia. Transactions of the American Fisheries Society 123:657-667.

Flebbe, P.A. 1999. Trout use of woody debris and habitat in Wine Spring Creek, North Carolina. Forest Ecology and Management 114:367-376.

Flebbe, P.A. and C.A. Dolloff. 1995. Trout use of woody debris and habitat in Appalachian wilderness streams of North Carolina. North American Journal of Fisheries Management 15:579-590.

Freeman, M.C., M.K. Crawford, J.C. Barrett, D.E. Facey, M.G. Flood, J. Hill, D.J. Stouder, and G.D. Grossman. 1988. Fish assemblage stability in a southern Appalachian stream. Canadian Journal of Fisheries and Aquatic Sciences 45:1949-1958.

Galbreath, P.F., N.D. Adams, S.Z. Guffey, C.J. Moore, and J.L. West. 2001. Persistence of native southern Appalachian brook trout populations in the Pigeon River system, North Carolina. North American Journal of Fisheries Management 21:927-934.

Garman, G.C. and L.A. Nielsen. 1982. Piscivority by stocked brown trout (*Salmo trutta*) and its impact on the nongame fish community of Bottom Creek, Virginia. Canadian Journal of Fisheries and Aquatic Sciences 39:862-869.

Gatz, A.J.Jr., J.M. Loar, and G.F. Cada. 1986. Effects of repeated electroshocking on instantaneous growth of trout. North American Journal of Fisheries Management 6:176-182.

Gigliotti, L.M. and R.B. Peyton. 1993. Values and behaviors of trout anglers, and their attitudes toward fishery management, relative to membership in fishing organizations: a Michigan case study. North American Journal of Fisheries Management 13:492-501.

Glahn, J.F., T. Tomsa, and K.J. Preusser. 1999. Impact of great blue heron predation at trout-rearing facilities in the northeastern United States. North American Journal of Aquaculture 61:349-354.

Goodnight, W.H. and T.C. Bjornn. 1971. Fish production in two Idaho streams. Transactions of the American Fisheries Society 100:769-780.

Gowan, C. and K.D. Fausch. 1996. Mobile brook trout in two high-elevation Colorado streams: re-evaluating the concept of restricted movement. Canadian Journal of Fisheries and Aquatic Sciences 53:1370-1381.

Griffith, J.S. 1999. Coldwater streams. Pages 481-504 *in* C.C. Kohler and W.A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Habera, J.W. and R.J. Strange. 1993. Wild trout resources and management in the southern Appalachian Mountains. Fisheries 18(1):6-13.

Habera, J. and S. Moore. 2005. Managing southern Appalachian brook trout: a position statement. Fisheries 30(7): 10-20.

Hayes, D.B., J.R. Bence, T.J. Kwak, and B.E. Thompson. 2007. Abundance, biomass, and production. Pages 327-374 *in* C.S. Guy and M.L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Hayes, J.P., S.Z. Guffey, F.J. Kriegler, G.F. McCracken, and C.R. Parker. 1996. The genetic diversity of native, stocked, and hybrid populations of brook trout in the southern Appalachians. Conservation Biology 10:1403-1412.

Hining, K.J., J.L. West, M.A. Kulp, and A.D. Neubauer. 2000. Validation of scales and otoliths for estimating age of rainbow trout from southern Appalachian streams. North American Journal of Fisheries Management 20:978-985.

Hollender, B.A. and R.F. Carline. 1994. Injury to wild brook trout by backpack electrofishing. North American Journal of Fisheries Management 14:643-649.

Hunt, R.L. 1974. Annual production by brook trout in Lawrence Creek during eleven successive years. Wisconsin Department of Natural Resources Technical Bulletin 82.

Jenkins, J.C., J.D. Aber, and C.D. Canham. 1999. Hemlock woolly adelgid impacts on community structure and N cycling rates in eastern hemlock forests. Canadian Journal of Forestry Research 29:630-645.

Jones, M.L., R.G. Randall, D. Hayes, W. Dunlop, J. Imhof, G. Lacroix, and N.J.R. Ward. 1996. Assessing the ecological effects of habitat change: moving beyond productive capacity. Canadian Journal of Fisheries and Aquatic Sciences 53(Supplement 1):446-457.

Jutila, E., A. Ahvonen, and M. Julkunen. 2001. Instream and catchment characteristics affecting the occurrence and population density of brown trout, *Salmo trutta* L., in forest brooks of a boreal river basin. Fisheries Management and Ecology 8:501-511.

Kozel, S.J., W.A. Hubert, and M.G. Parsons. 1989. Habitat features and trout abundance relative to gradient in some Wyoming streams. Northwest Science 63:175-182.

Kulp, M.A. and S.E. Moore. 2005. A case history in fishing regulations in Great Smoky Mountains National Park: 1934-2004. North American Journal of Fisheries Management 25:510-524.

Kwak, T.J. 1992. Modular microcomputer software to estimate fish population parameters, production rates and associated variance. Ecology of Freshwater Fish 1:73-75.

Kwak, T.J. and T.F. Waters. 1997. Trout production dynamics and water quality in Minnesota streams. Transactions of the American Fisheries Society 126:35-48.

Larson, G.L. and S.E. Moore. 1985. Encroachment of exotic rainbow trout into stream populations of native brook trout in the southern Appalachian Mountains. Transactions of the American Fisheries Society 114:195-203.

Loar, J.M. and ten coauthors. 1985. Application of habitat evaluation models in southern Appalachian trout streams. Oak Ridge National Laboratory, Environmental Sciences Division Publication 2383, Oak Ridge, Tennessee.

Lobón-Cerviá, J. 2003. Spatiotemporal dynamics of brown trout production in a Cantabrian stream: effects of density and habitat quality. Transactions of the American Fisheries Society 132:621-637.

Lohr, S.C. and J.L. West. 1992. Microhabitat selection by brook and rainbow trout in a southern Appalachian stream. Transactions of the American Fisheries Society 121:729-736.

Mann, R.H.K. and T. Penczak. 1986. Fish production in rivers: a review. Polskie Archiwum Hydrobiologii 33:233-247.

McClure, M.S. and C.A.S.-J. Cheah. 1999. Reshaping the ecology of invading populations of hemlock woolly adelgid, *Adelges tsugae* (Homoptera: Adelgidae), in eastern North America. Biological Invasions 1:247-254.

McCracken, G.F., C.R. Parker, and S.Z. Guffey. 1993. Genetic differentiation and hybridization between stocked hatchery and native brook trout in Great Smoky Mountains National Park. Transactions of the American Fisheries Society 122:533-542.

Melquist, W.E. and M.G. Hornocker. 1983. Ecology of river otters in west central Idaho. Wildlife Monographs 83:3-60.

Mesa, M.G. and C.B. Schreck. 1989. Electrofishing mark-recapture and depletion methodologies evoke behavioral and physiological changes in cutthroat trout. Transactions of the American Fisheries Society 118:644-658.

Minns, C.K., J.R.M. Kelso, and R.G. Randall. 1996. Detecting the response of fish to habitat alterations in freshwater ecosystems. Canadian Journal of Fisheries and Aquatic Sciences 53(Supplement 1):403-414.

NCDEHNR (North Carolina Department of Environment, Health, and Natural Resources). 1994. General management plan for Stone Mountain State Park. Division of Parks and Recreation, North Carolina Department of Environment, Health, and Natural Resources, Raleigh, North Carolina.

.

NCSRI (North Carolina Stream Restoration Institute) and SMSRSC (Stone Mountain Stream Restoration Steering Committee). 2000. Stone Mountain State Park stream restoration on the East Prong Roaring River. North Carolina Department of Environment and Natural Resources, Raleigh, North Carolina.

NCWRC (North Carolina Wildlife Resources Commission). 1983. Survey and classification of state-managed trout streams. Federal Aid in Fisheries Project F24-5. Division of Inland Fisheries, North Carolina Wildlife Resources Commission, Raleigh. Volumes l-3.

NCWRC. 1993. First year assessment of delayed harvest trout regulations. Federal Aid in Fish Restoration Project F-24. Division of Boating and Inland Fisheries, North Carolina Wildlife Resources Commission, Raleigh, North Carolina.

NCWRC. 1995. Responses of wild trout populations to supplemental feeding. Federal Aid in Fish Restoration Project F-24. Division of Boating and Inland Fisheries, North Carolina Wildlife Resources Commission, Raleigh, North Carolina.

NCWRC. 2005a. Fisheries and wildlife management plan for the Yadkin-Pee Dee River basin. North Carolina Wildlife Resources Commission, Raleigh, North Carolina.

NCWRC. 2005b. Creel survey of North Carolina's hatchery supported trout fisheries. Federal Aid in Fish Restoration Project F-24-21. Division of Inland Fisheries, North Carolina Wildlife Resources Commission, Raleigh, North Carolina.

NCWRC. 2007. North Carolina trout anglers' participation in and satisfaction with trout fishing and their opinions on specific regulations. Federal Aid in Fish Restoration Project F-86. North Carolina Wildlife Resources Commission, Raleigh, North Carolina.

NCWRC. 2009. The economic impact of mountain trout fishing in North Carolina. Federal Aid in Fish Restoration Project F-86. North Carolina Wildlife Resources Commission, Raleigh, North Carolina.

Neves, R.J. and G.B. Pardue. 1983. Abundance and production of fishes in a small Appalachian stream. Transactions of the American Fisheries Society 112:21-26.

Newman, R.M. and F.B. Martin. 1983. Estimation of fish production rates and associated variances. Canadian Journal of Fisheries and Aquatic Sciences 40:1729-1736.

Newman, R.M. and T.F. Waters. 1989. Differences in brown trout (*Salmo trutta*) production among contiguous sections of an entire stream. Canadian Journal of Fisheries and Aquatic Sciences 46:203-213.

Noble, R.L. and T.W. Jones. 1999. Managing fisheries with regulations. Pages 455-477 *in* C.C. Kohler and W.A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Nordwall, F. 1999. Movements of brown trout in a small stream: effects of electrofishing and consequences for population estimates. North American Journal of Fisheries Management 19:462-469.

Nuhfer, A.J. and G.R. Alexander. 1994. Growth, survival, and vulnerability to angling of three wild brook trout strains exposed to different levels of angler exploitation. North American Journal of Fisheries Management 14:423-434.

O’Connor, J.F. and G. Power. 1976. Production by brook trout (*Salvelinus fontinalis*) in four streams in the Matamek Watershed, Quebec. Journal of the Fisheries Research Board of Canada 33:6-18.

Petty, J.T., P.J. Lamothe, and P.M. Mazik. 2005. Spatial and seasonal dynamics of brook trout populations inhabiting a central Appalachian watershed. Transactions of the American Fisheries Society 134:572-587.

Pine, W.E., K.H. Pollock, J.E. Hightower, T.J. Kwak, and J.A. Rice. 2003. A review of tagging methods for estimating fish population size and components of mortality. Fisheries 28(10):10-23.

Power, G. 1973. Estimates of age, growth, standing crop and production of salmonids in some north Norwegian rivers and streams. Institute of Freshwater Research Drottningholm Report 53:78-111.

Quinn, J.W. 1994. Effects of trout stream habitat rehabilitation projects on nongame fish communities in five southeastern Minnesota streams. Division of Ecological Services, Minnesota Department of Natural Resources.

Quinn, J.W. and T.J. Kwak. 2000. Use of rehabilitated habitat by brown trout and rainbow trout in an Ozark tailwater river. North American Journal of Fisheries Management 20:737-751.

Railsback, S.F., B.D. Holcomb, and M.G. Ryon. 1989. A computer program for estimating fish population sizes and annual production rates. Oak Ridge National Laboratory, Environmental Sciences Division Publication 3245.

Randall, R.G. and C.K. Minns. 2000. Use of fish production per unit biomass ratios for measuring the productive capacity of fish habitats. Canadian Journal of Fisheries and Aquatic Sciences 57:1657-1667.

Rasmussen, G. 1986. The population dynamics of brown trout (*Salmo trutta* L.) in relation to year-class size. Polskie Archiwum Hydrobiologii 33:489-508.

Reimers, N. 1963. Body condition, water temperature, and over-winter survival of hatchery-reared trout in Convict Creek, California. Transactions of the American Fisheries Society 92:39-46.

Reynolds, J.B. 1996. Electrofishing. Pages 221-253 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Ricker, W.E. 1946. Production and utilization of fish populations. Ecological Monographs 16:373-391.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Robinson, A.T., S.D. Bryan, and M.G. Sweetser. 2003. Habitat use by nonnative rainbow trout, *Oncorhynchus mykiss*, and native Little Colorado spinedace, *Lepidomeda vittata*. Environmental Biology of Fishes 68:205-214.

Ross, S.T. 1991. Mechanisms structuring stream fish assemblages: are there lessons from introduced species? Environmental Biology of Fishes 30:359-368.

Scarnecchia, D.L. and E.P. Bergersen. 1987. Trout production and standing crop in Colorado's small streams, as related to environmental features. North American Journal of Fisheries Management 7:315-330.

Schmitt, C.J., A.D. Lemly, and P.V. Winger. 1993. Habitat suitability index model for brook trout in streams of the southern Blue Ridge Province: surrogate variables, model evaluation, and suggested improvements. United States Department of the Interior, Fish and Wildlife Service, Washington, D.C. Biological Report 18.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters, 2nd edition. Charles Griffin, London.

Simonson, T.D. and J. Lyons. 1995. Comparison of catch per effort and removal procedures for sampling stream fish assemblages. North American Journal of Fisheries Management 15:419-427.

Snyder, C.D., J.A. Young, D.P. Lemarié, and D.R. Smith. 2002. Influence of eastern hemlock (*Tsuga Canadensis*) forests on aquatic invertebrate assemblages in headwater streams. Canadian Journal of Fisheries and Aquatic Sciences 59:262-275.

Snyder, C.D., J.A. Young, R.M. Ross, and D.R. Smith. 2005. Long-term effects of hemlock forest decline on headwater stream communities. Pages 42–55 *in* B. Oknen and R. Reardon (Compilers). Third Symposium on Hemlock Woolly Adelgid in the Eastern United States. USDA, Morgantown, West Virginia. Forest Health Technology Enterprise Team report FHTET-2005-01.

Strange, R.J. and J.W. Habera. 1998. No net loss of brook trout distribution in areas of sympatry with rainbow trout in Tennessee streams. Transactions of the American Fisheries Society 127:434-440.

Swift, L.W.Jr., and J.B. Messer. 1971. Forest cuttings raise temperatures of small streams in the southern Appalachians. Journal of Soil and Water Conservation 26:111-116.

Thompson, K.G., E.P. Bergersen, R.B. Nehring, and D.C. Bowden. 1997. Long-term effects of electrofishing on growth and body condition of brown trout and rainbow trout. North American Journal of Fisheries Management 17:154-159.

Thompson, P.D. and F.J. Rahel. 1996. Evaluation of depletion-removal electrofishing of brook trout in small Rocky Mountain streams. North American Journal of Fisheries Management 16:332-339.

Thorn, W.C., C.S. Anderson, W.E. Lorenzen, D.L. Hendrickson, and J.W. Wagner. 1997. A review of trout management in southeast Minnesota streams. North American Journal of Fisheries Management 17:860-872.

Vannote, R.B., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Waters, T.F. 1977. Secondary production in inland waters. Advances in Ecological Research 10:91-164.

Waters, T.F. 1983. Replacement of brook trout by brown trout over 15 years in a Minnesota stream: production and abundance. Transactions of the American Fisheries Society 112:137-146.

Waters, T.F. 1992. Annual production, production/biomass ratio, and the ecotrophic coefficient for management of trout in streams. North American Journal of Fisheries Management 12:34-39.

Waters, T.F. 1999. Long-term trout production dynamics in Valley Creek, Minnesota. Transactions of the American Fisheries Society 128:1151-1162.

Waters, T.F., M.T. Doherty, and C.C. Krueger. 1990. Annual production and production: biomass ratios for three species of stream trout in Lake Superior tributaries. Transactions of the American Fisheries Society 119:470-474.

Webb, R.E., J.R. Frank, and M.J. Raupp. 2003. Eastern hemlock recovery from hemlock woolly adelgid damage following imidacloprid therapy. Journal of Arboriculture 29:298-302.

Whitworth, W.E. and R.J. Strange. 1983. Growth and production of sympatric brook and rainbow trout in an Appalachian stream. Transactions of the American Fisheries Society 112:469-475.

Wydoski, R.S. and E.L. Cooper. 1966. Maturation and fecundity of brook trout from infertile streams. Journal of the Fisheries Research Board of Canada 23:623-649.

Zimmerman, J.K.H. and B. Vondracek. 2006. Interactions of slimy sculpin (*Cottus cognatus*) with native and nonnative trout: consequences for growth. Canadian Journal of Fisheries and Aquatic Sciences 63:1526-1535.

Table 1.—Sampling site locations in and near Stone Mountain State Park with elevation, latitude, and longitude.

Site	Sampling reach length (m)	Elevation (m)	Latitude (N)	Longitude (W)
Garden Creek	209	493.17	36°23'39.2"	81°05'18.2"
Rich Mountain Creek	210	474.57	36°24'20.0"	81°03'34.3"
Bullhead Creek	223	447.75	36°24'10.2"	81°03'44.8"
East Prong Roaring River				
Delayed Harvest Upstream	288	411.79	36°23'39.0"	81°04'07.4"
Delayed Harvest Downstream	303	402.64	36°23'03.4"	81°03'52.7"
Hatchery Supported	286	384.66	36°22'09.1"	81°04'00.7"

Table 2.—Trout angling regulations imposed by the North Carolina Wildlife Resources Commission (NCWRC) according to stream.

Stream	NCWRC Designation	Season	Daily creel limit (number)	Minimum length limit (mm TL)	Receives stocking	Receives feed
Garden Creek	Wild	Year round	4	178 mm	No	No
Rich Mountain Creek*	Catch and release	Year round	0	None	No	No
Bullhead Creek*	Catch and release	Year round	0	None	No	Yes
East Prong Roaring River	Delayed harvest	Oct - May	0	None	Yes	No
		Jun - Sep	7	None	Yes	No
East Prong Roaring River	Hatchery supported	Jan - Feb	7	None	Yes	No
		Mar	0	None	Yes	No
		Apr-Dec	7	None	Yes	No

*Streams managed by the North Carolina Department of Environment and Natural Resources, Division of Parks and Recreation

Table 3.—Species collected from sampling sites in Stone Mountain State Park, North Carolina from April, 2008 - April, 2009.

Family	Common Name	Scientific Name	Sites present
Catostomidae	Striped jumprock	*Moxostoma rupiscartes*	3
	White sucker	*Catostomus commersonii*	3
Cyprinidae	Blacknose dace	*Rhinichthys atratulus*	4
	Bluehead chub	*Nocomis leptocephalus*	3
	Creek chub	*Semotilus atromaculatus*	2
	Highback chub	*Hybopsis hypsinotus*	3
	Mountain redbelly dace	*Phoxinus oreas*	1
	Redlip shiner	*Notropis chiliticus*	3
	Rosyside dace	*Clinostomus funduloides*	3
Centrarchidae	Redbreast sunfish	*Lepomis auritus*	2
	Smallmouth bass	*Micropterus dolomieu*	1
Ictaluridae	Margined madtom	*Noturus insignis*	3
Percidae	Fantail darter	*Etheostoma flabellare*	4
	Tessellated darter	*Etheostoma olmstedi*	3
Salmonidae	Brook trout	*Salvelinus fontinalis*	5
	Brown trout	*Salmo trutta*	6
	Rainbow trout	*Oncorhynchus mykiss*	3

Table 4.—Mean annual density and biomass, annual production, and production to mean biomass ratio $(P/\overline{B})$ for salmonids in unstocked waters in Stone Mountain State Park, North Carolina. Values in parentheses are 2 SE.

Stream	Species	Density (fish/ha)	Biomass (kg/ha)	Production (kg/ha)	$P/\overline{B}$
Garden Creek	Brook trout	234.13 (54.87)	3.73 (0.37)	8.81 (1.25)	2.36 (0.41)
	Brown trout	169.87 (26.75)	8.77 (2.07)	14.07 (2.71)	1.60 (0.49)
	All trout	404.00 (61.04)	12.50 (2.10)	22.88 (2.99)	1.83 (0.39)
Rich Mountain Creek	Brook trout	195.09 (33.17)	3.63 (0.91)	5.91 (1.49)	1.63 (0.58)
	Brown trout	2,038.69 (1833.48)	27.84 (6.33)	64.16 (23.45)	2.30 (0.99)
	All trout	2,233.78 (1833.78)	31.47 (6.39)	70.08 (23.49)	2.23 (0.87)
Bullhead Creek	Brown trout	801.21 (175.02)	22.49 (5.47)	39.93 (8.29)	1.78 (0.57)

Table 5.—Seasonal salmonid density and biomass estimates by date in Bullhead Creek. Values in parentheses are 2 SE.

Date	Species	Age (years)	Density (fish/ha)	Biomass (kg/ha)
Apr 14, 2008	Brown trout	1	458.05 (190.06)	13.24 (5.60)
		2	99.52 (62.59)	9.14 (6.11)
		Total	557.57 (200.10)	22.39 (8.28)
Jun 23, 2008	Brown trout	0	794.84 (492.14)	3.21 (1.79)
		1	582.01 (330.69)	27.75 (15.57)
		2	70.25 (61.32)	9.58 (8.60)
		Total	1,447.11 (596.09)	40.54 (17.87)
Oct 19, 2008	Brown trout	0	729.51 (155.47)	6.13 (1.44)
		1	116.73 (57.93)	7.27 (3.72)
		2	18.22 (23.04)	2.80 (3.67)
		Total	864.45 (167.50)	16.19 (5.42)
Apr 21, 2009	Brown trout	1	375.65 (215.32)	10.73 (6.30)
		2	75.13 (46.16)	7.69 (5.28)
		Total	450.78 (220.21)	18.43 (8.22)

Table 6.—Seasonal salmonid density and biomass estimates by date in Garden Creek. Values in parentheses are 2 SE.

Date	Species	Age (years)	Density (fish/ha)	Biomass (kg/ha)
Apr 14, 2008	Brook trout	1	48.90 (0)	0.83 (0.06)
		2	19.56 (0)	1.27 (0)
		Total	68.46 (0)	2.10 (0.06)
	Brown trout	1	68.46 (39.12)	2.37 (1.35)
		2	78.24 (36.59)	7.99 (4.01)
		Total	146.70 (53.57)	10.35 (4.23)
	All trout	Total	215.16 (53.57)	12.45 (4.23)
Jun 25, 2008	Brook trout	0	449.88 (200.75)	2.13 (0.91)
		1	78.24 (0)	3.00 (0.21)
		2	9.78 (0)	1.00 (0)
		Total	537.90 (200.75)	6.13 (0.93)
	Brown trout	0	166.26 (66.81)	0.88 (0.43)
		1	92.22 (29.27)	6.10 (2.89)
		2	64.26 (29.27)	10.00 (3.66)
		Total	322.74 (78.59)	16.99 (4.68)
	All trout	Total	860.64 (215.59)	23.12 (4.77)
Oct 19, 2008	Brook trout	0	206.47 (41.29)	1.54 (0.37)
		1	9.78 (0)	0.31 (0)
		2	9.78 (0)	0.77 (0)
		Total	226.03 (41.29)	2.63 (0.37)
	Brown trout	0	127.14 (19.56)	1.72 (0.29)
		1	14.67 (22.94)	1.38 (2.16)
		2	14.67 (22.94)	2.16 (3.37)
		Total	156.48 (37.88)	5.25 (4.01)
	All trout	Total	382.51 (56.03)	7.88 (4.03)
Apr 16, 2009	Brook trout	1	166.26 (39.12)	3.76 (1.01)
		2	19.56 (0)	1.55 (0)
		Total	185.82 (39.12)	5.30 (1.01)
	Brown trout	1	92.91 (29.34)	3.44 (1.10)
		2	29.34 (0)	4.39 (0.26)
		Total	122.25 (29.34)	7.83 (1.13)
	All trout	Total	308.07 (48.90)	13.13 (1.52)

Table 7.—Seasonal salmonid density and biomass estimates by date in Rich Mountain Creek. Values in parentheses are 2 SE.

Date	Species	Age (years)	Density (fish/ha)	Biomass (kg/ha)
Apr 17, 2008	Brook trout	1	149.72 (54.70)	2.72 (1.07)
		2	20.94 (0)	1.46 (0)
		Total	170.66 (54.70)	4.18 (1.07)
	Brown trout	1	453.27 (79.78)	14.68 (3.18)
		2	122.50 (48.09)	10.55 (3.89)
		Total	575.77 (93.15)	25.23 (5.02)
	All trout	Total	746.43 (108.02)	29.41 (5.13)
Jun 23, 2008	Brook trout	0	83.76 (68.39)	0.25 (0.21)
		1	119.54 (62.59)	3.70 (2.11)
		2	13.96 (25.48)	0.95 (1.73)
		Total	217.25 (96.14)	4.90 (2.74)
	Brown trout	0	6,742.68 (7,342.69)	18.56 (20.21)
		1	537.01 (243.80)	23.90 (10.44)
		2	130.98 (74.85)	11.62 (6.37)
		Total	7,410.67 (7,347.12)	54.08 (23.62)
	All trout	Total	7,627.92 (7,347.75)	58.98 (23.78)
Oct 19, 2008	Brook trout	0	136.11 (<0.01)	0.81 (0.08)
		1	91.61 (36.64)	2.24 (1.03)
		Total	227.72 (36.64)	3.05 (1.04)
	Brown trout	0	1,236.35 (155.03)	9.18 (1.30)
		1	125.64 (20.94)	4.80 (0.75)
		2	52.35 (0)	5.69 (1.31)
		Total	1,414.34 (156.43)	19.68 (1.99)
	All trout	Total	1,642.06 (160.66)	22.73 (2.25)
Apr 23, 2009	Brook trout	1	157.05 (66.22)	3.26 (1.66)
		2	10.47 (0)	0.54 (0)
		Total	167.52 (66.22)	3.80 (1.66)
	Brown trout	1	595.04 (159.86)	14.89 (4.23)
		2	129.10 (63.78)	13.54 (7.27)
		Total	724.14 (172.12)	28.42 (8.41)
	All trout	Total	891.66 (184.42)	32.22 (8.57)

Table 8.—Seasonal brook trout mean density and biomass, instantaneous rates of growth and mortality, total production, and production to mean biomass ratio $(P/\overline{B})$ by cohort in Garden Creek. Values in parentheses are 2 SE.

Cohort	Mean density (fish/ha)	Mean biomass (kg/ha)	Growth	Mortality	Production (kg/ha)	$P/\overline{B}$
			Apr 14, 2008 - Jun 25, 2008			
2008					2.13 (0.92)	
2007	63.57 (0)	1.92 (0.10)	0.81 (0.10)	-0.47 (0)	1.56 (0.22)	0.81 (0.12)
2006	14.67 (0)	1.13 (0.00)	0.45 (0)	0.69 (0)	0.51 (0)	0.45 (0)
Total	78.24 (0)	3.05 (0.10)	1.26 (0.10)	0.22 (0)	4.20 (0.94)	1.38 (0.32)
			Jun 25, 2008 - Oct 19, 2008			
2008	328.17 (102.48)	1.84 (0.50)	0.46 (0.16)	0.78 (0.48)	0.84 (0.36)	0.46 (0.24)
2007	44.01 (0)	1.66 (0.10)	-0.18 (0.06)	2.08 (0)	0 (0)	0 (0)
2006	9.78 (0)	0.89 (0)	-0.26 (0)	0 (0)	0 (0)	0 (0)
Total	381.96 (102.48)	4.38 (0.50)	0.02 (0.16)	2.86 (0.48)	0.84 (0.36)	0.19 (0.08)
			Oct 19, 2008 - Apr 16, 2009			
2008	186.36 (28.44)	2.65 (0.54)	1.11 (0.16)	0.22 (0.30)	2.93 (0.74)	1.11 (0.36)
2007	14.67 (0)	0.93 (0)	0.90 (0)	-0.69 (0)	0.84 (0)	0.90 (0)
2006						
Total	201.03 (28.44)	3.58 (0.54)	2.01 (0.16)	-0.48 (0.30)	3.77 (0.74)	1.05 (0.26)
			Annual			
2008	194.62 (54.86)	1.87 (0.38)	1.56 (0.22)	1.00 (0.58)	5.90 (1.24)	3.15 (0.90)
2007	33.54 (0)	1.35 (0.06)	1.54 (0.12)	0.92 (0)	2.40 (0.22)	1.77 (0.18)
2006	5.97 (0)	0.50 (0)	0.20 (0)	0.69 (0)	0.51 (0)	1.02 (0)
Total	234.13 (54.86)	3.73 (0.38)	3.29 (0.26)	2.60 (0.58)	8.81 (1.24)	2.36 (0.42)

Table 9.—Seasonal brown trout mean density and biomass, instantaneous rates of growth and mortality, total production, and production to mean biomass ratio $(P/\overline{B})$ by cohort in Garden Creek. Values in parentheses are 2 SE.

Cohort	Mean density (fish/ha)	Mean biomass (kg/ha)	Growth	Mortality	Production (kg/ha)	$P/\overline{B}$
Apr 14, 2008 - Jun 25, 2008						
2008					0.88 (0.44)	
2007	80.34 (24.42)	4.23 (1.60)	0.70 (0.24)	-0.30 (0.66)	2.95 (1.48)	0.70 (0.44)
2006	71.25 (23.42)	8.99 (2.72)	0.42 (0.16)	0.20 (0.66)	3.79 (1.86)	0.42 (0.24)
Total	151.59 (33.84	13.23 (3.14)	1.12 (0.28)	-0.10 (0.92)	7.62 (2.42)	0.58 (0.22)
Jun 25, 2008 - Oct 19, 2008						
2008	146.70 (34.80)	1.30 (0.26)	0.91 (0.16)	0.27 (0.44)	1.19 (0.32)	0.91 (0.30)
2007	53.44 (18.60)	3.74 (1.80)	0.35 (0.12)	1.84 (1.60)	1.31 (0.76)	0.35 (0.26)
2006	39.47 (18.60)	6.08 (2.48)	-0.06 (0.14)	1.48 (1.62)	0 (0)	0 (0)
Total	239.61 (43.62)	11.12 (3.08)	1.21 (0.24)	3.58 (2.32)	2.50 (0.84)	0.22 (0.10)
Oct 19, 2008 - Apr 16, 2009						
2008	110.03 (17.64)	2.58 (0.56)	1.01 (0.18)	0.31 (0.36)	2.60 (0.74)	1.01 (0.36)
2007	22.01 (11.46)	2.88 (1.08)	0.46 (0.06)	-0.69 (1.56)	1.34 (0.54)	0.46 (0.26)
2006						
Total	132.03 (21.04)	5.46 (1.22)	1.47 (0.18)	-0.38 (1.60)	3.94 (0.90)	0.72 (0.24)
Annual						
2008	100.03 (20.14)	1.67 (0.32)	1.92 (0.24)	0.58 (0.56)	4.68 (0.92)	2.80 (0.76)
2007	43.39 (12.48)	3.42 (1.14)	1.51 (0.26)	0.85 (2.32)	5.60 (1.76)	1.64 (0.76)
2006	26.54 (12.42)	3.69 (1.70)	0.36 (0.20)	1.67 (1.76)	3.79 (1.86)	1.03 (0.70)
Total	169.87 (26.76)	8.77 (2.08)	3.80 (0.42)	3.10 (2.96)	14.07 (2.72)	1.60 (0.48)

Table 10.—Seasonal brook trout mean density and biomass, instantaneous rates of growth and mortality, total production, and production to mean biomass ratio $(P/\overline{B})$ by cohort in Rich Mountain Creek. Values in parentheses are 2 SE.

Cohort	Mean density (fish/ha)	Mean biomass (kg/ha)	Growth	Mortality	Production (kg/ha)	$P/\overline{B}$
Apr 17, 2008 - Jun 23, 2008						
2008					0.25 (0.22)	
2007	134.63 (41.56)	3.21 (1.18)	0.53 (0.18)	0.23 (0.64)	1.70 (0.84)	0.53 (0.32)
2006	17.45 (12.74)	1.20 (0.86)	-0.02 (0)	0.41 (1.82)	0 (0)	0 (0)
Total	152.08 (43.46)	4.41 (1.46)	0.51 (0.18)	0.63 (1.94)	1.95 (0.86)	0.44 (0.24)
Jun 23, 2008 - Oct 19, 2008						
2008	109.94 (34.20)	0.53 (0.12)	0.68 (0.24)	-0.49 (0.82)	0.36 (0.14)	0.68 (0.32)
2007	105.57 (36.26)	2.97 (1.18)	-0.24 (0.26)	0.27 (0.66)	0 (0)	0 (0)
2006						
Total	215.51 (49.84)	3.50 (1.18)	0.45 (0.34)	-0.22 (1.04)	0.36 (0.14)	0.10 (0.06)
Oct 19, 2008 - Apr 23, 2009						
2008	146.58 (33.10)	2.03 (0.82)	1.25 (0.18)	-0.14 (0.42)	2.55 (1.10)	1.25 (0.74)
2007	51.04 (18.32)	1.39 (0.52)	0.76 (0.24)	2.17 (0.40)	1.05 (0.50)	0.76 (0.46)
2006						
Total	197.62 (37.84)	3.42 (0.98)	2.01 (0.28)	2.03 (0.58)	3.60 (1.20)	1.05 (0.46)
Annual						
2008	108.45 (23.80)	1.19 (0.42)	1.93 (0.28)	-0.63 (0.92)	3.16 (1.12)	2.66 (1.34)
2007	83.48 (22.20)	2.22 (0.68)	1.05 (0.38)	2.66 (1.00)	2.75 (0.98)	1.24 (0.58)
2006	3.15 (6.36)	0.22 (0.44)	-0.02 (0)	0.41 (1.82)	0 (0)	0 (0)
Total	195.09 (33.16)	3.63 (0.90)	2.96 (0.48)	2.44 (2.28)	5.91 (1.48)	1.63 (0.58)

Table 11.—Seasonal brown trout mean density and biomass, instantaneous rates of growth and mortality, total production, and production to mean biomass ratio $(P/\overline{B})$ by cohort in Rich Mountain Creek. Values in parentheses are 2 SE.

Cohort	Mean density (fish/ha)	Mean biomass (kg/ha)	Growth	Mortality	Production (kg/ha)	$P/\overline{B}$
Apr 17, 2008 - Jun 23, 2008						
2008					18.56 (20.22)	
2007	495.14 (128.26)	19.29 (5.46)	0.31 (0.12)	-0.17 (0.48)	5.97 (2.86)	0.31 (0.18)
2006	126.74 (44.48)	11.08 (3.74)	0.03 (0.12)	-0.07 (0.70)	0.33 (1.38)	0.03 (0.12)
Total	621.88 (135.76)	30.37 (6.60)	0.34 (0.18)	-0.24 (0.84)	24.85 (20.46)	0.82 (0.70)
Jun 23, 2008 - Oct 19, 2008						
2008	3,989.52 (3,672.16)	13.87 (10.12)	0.99 (0.12)	1.70 (1.10)	13.68 (10.12)	0.99 (1.02)
2007	331.32 (122.34)	14.35 (5.24)	-0.15 (0.12)	1.45 (0.48)	0 (0)	0 (0)
2006	91.67 (37.42)	8.66 (3.26)	0.20 (0.26)	0.92 (0.58)	1.76 (2.28)	0.20 (0.28)
Total	4,412.50 (3,674.40)	36.88 (11.86)	1.04 (0.30)	4.07 (1.32)	15.44 (10.36)	0.42 (0.32)
Oct 19, 2008 - Apr 23, 2009						
2008	915.70 (11.34)	12.04 (2.22)	1.21 (0.10)	0.73 (0.30)	14.62 (2.92)	1.21 (0.32)
2007	127.38 (33.56)	9.17 (3.66)	1.01 (0.14)	-0.03 (0.52)	9.25 (3.88)	1.01 (0.58)
2006						
Total	1,043.08 (116.30)	21.20 (4.28)	2.22 (0.16)	0.70 (0.60)	23.87 (4.86)	1.13 (0.32)
Annual						
2008	1,727.98 (1,832.26)	10.45 (5.18)	2.20 (0.14)	2.43 (1.14)	46.85 (22.78)	4.49 (3.12)
2007	258.66 (63.84)	12.64 (3.20)	1.17 (0.22)	1.26 (0.86)	15.22 (4.82)	1.20 (0.48)
2006	52.04 (19.16)	4.75 (1.72)	0.23 (0.28)	0.85 (0.90)	2.09 (2.68)	0.44 (0.58)
Total	2,038.69 (1,833.48)	27.84 (6.32)	3.60 (0.38)	4.53 (1.68)	64.16 (23.44)	2.30 (1.00)

Table 12.—Seasonal brown trout mean density and biomass, instantaneous rates of growth and mortality, total production, and production to mean biomass ratio $(P/\overline{B})$ by cohort in Bullhead Creek. Values in parentheses are 2 SE.

Cohort	Mean density (fish/ha)	Mean biomass (kg/ha)	Growth	Mortality	Production (kg/ha)	$P/\overline{B}$
			Apr 14, 2008 - Jun 23, 2008			
2008					3.21 (1.80)	
2007	520.03 (190.70)	20.50 (8.28)	0.49 (0.10)	-0.24 (0.70)	9.95 (4.44)	0.49 (0.30)
2006	84.89 (43.82)	9.36 (5.28)	0.39 (0.24)	0.35 (1.08)	3.69 (3.04)	0.39 (0.40)
Total	604.92 (195.68)	29.86 (9.80)	0.88 (0.26)	0.11 (1.28)	16.85 (5.66)	0.56 (0.26)
			Jun 23, 2008 - Oct 19, 2008			
2008	762.17 (258.06)	4.67 (1.16)	0.75 (0.10)	0.09 (0.66)	3.48 (0.98)	0.75 (0.28)
2007	349.37 (167.86)	17.51 (8.00)	0.28 (0.10)	1.61 (0.76)	4.94 (2.96)	0.28 (0.22)
2006	44.23 (32.76)	6.19 (4.68)	0.12 (0.40)	1.35 (1.54)	0.73 (2.56)	0.12 (0.42)
Total	1,155.78 (309.58)	28.37 (9.34)	1.15 (0.42)	3.04 (1.84)	9.16 (4.04)	0.32 (0.18)
			Oct 19, 2008 - Apr 21, 2009			
2008	552.58 (132.80)	8.43 (3.22)	1.21 (0.12)	0.66 (0.62)	10.20 (4.02)	1.21 (0.66)
2007	95.93 (37.04)	7.48 (3.22)	0.50 (0.18)	0.44 (0.78)	3.72 (2.06)	0.50 (0.34)
2006						
Total	648.51 (137.86)	15.91 (4.56)	1.71 (0.20)	1.10 (1.00)	13.92 (4.52)	0.87 (0.38)
			Annual			
2008	515.08 (149.28)	5.65 (1.72)	1.96 (0.16)	0.75 (0.90)	16.90 (4.50)	2.99 (1.22)
2007	256.13 (89.36)	13.11 (4.44)	1.26 (0.22)	1.81 (1.30)	18.60 (5.72)	1.42 (0.64)
2006	30.01 (19.04)	3.72 (2.70)	0.51 (0.46)	1.70 (1.88)	4.43 (3.96)	1.19 (1.36)
Total	801.22 (175.02)	22.49 (5.48)	3.73 (0.54)	4.26 (2.46)	39.93 (8.28)	1.78 (0.56)

Table 13.—Relative weight (W_r) of trout in unstocked waters by season. Values in parentheses are 2 SE.

	Garden Creek		Rich Mountain Creek		Bullhead Creek
Date	Brook trout	Brown trout	Brook trout	Brown trout	Brown trout
Apr 2008	92.15 (15.57)	96.56 (5.07)	92.13 (3.27)	94.00 (2.13)	94.92 (2.37)
Jun 2008	97.93 (4.34)	95.79 (2.22)	91.03 (5.59)	92.54 (6.01)	94.40 (2.00)
Oct 2008	95.46 (29.10)	96.27 (9.13)	85.38 (4.21)	87.15 (3.33)	86.88 (3.03)
Apr 2009	100.94 (4.89)	103.63 (4.41)	96.59 (4.12)	95.97 (2.74)	99.41 (2.73)
Apr 2009					90.99 (2.36)*

* W_r of fish sampled 2 km upstream of Bullhead Creek study site.

Table 14.—Relative weight (W_r) of trout in delayed harvest waters of the East Prong Roaring River by season. Values in parentheses are 2 SE.

	Delayed harvest upstream			Delayed harvest downstream		
	Brook trout	Brown trout	Rainbow trout	Brook trout	Brown trout	Rainbow trout
Apr, 2008	96.00 (3.54)	97.52 (2.8)	85.29 (2.96)	95.21 (2.08)	96.07 (3.40)	85.95 (2.04)
Jun, 2008	91.35 (4.86)	92.40 (2.56)	77.44 (4.44)	93.62 (3.70)	90.81 (4.28)	82.55 (7.90)
Oct, 2008	93.58 (18.64)	99.24 (3.72)	99.24 (4.16)	81.12 (0)*	92.31 (7.76)	95.05 (1.86)
Apr, 2009	100.53 (2.98)	102.09 (4.90)	78.76 (5.36)	98.35 (3.18)	96.01 (3.50)	84.48 (5.72)

W_r calculated for fish above recommended minimum length only (i.e., brook trout ≥130 mm, brown trout ≥140 mm, rainbow trout ≥120 mm; Anderson and Neumann 1996).

* n=1 for corresponding sample.

Table 15.—Relative weight (W_r) of trout in hatchery supported waters of the East Prong Roaring River by season. Values in parentheses are 2 SE.

	Brook trout	Brown trout	Rainbow trout
Apr 1, 2008	101.37 (3.96)	102.79 (4.00)	93.86 (10.46)
Apr 17, 2008	86.39 (21.04)	95.23 (4.76)	83.07 (17.44)
Jul 18, 2008		92.17 (3.16)	
Oct 21, 2008		88.45 (10.56)	
Apr 16, 2009	105.02 (5.20)	101.94 (8.30)	81.52 (0)*

W_r calculated for fish above recommended minimum length only (i.e., brook trout ≥130 mm, brown trout ≥140 mm, rainbow trout ≥120 mm; Anderson and Neumann 1996).
* n=1 for corresponding sample.

Table 16.—Estimates of trout density and biomass in the East Prong Roaring River delayed harvest upstream site. Values in parentheses are 2 SE.

Date	Species	Density (fish/ha)	Biomass (kg/ha)
Apr 16, 2008	Brook trout	145.41 (33.74)	35.03 (8.80)
	Brown trout	236.28 (74.10)	28.05 (9.74)
	Rainbow trout	84.60 (0)	17.85 (0.88)
	All trout	466.28 (81.42)	80.92 (13.16)
Jun 23, 2008	Brook trout	53.35 (31.38)	8.16 (5.46)
	Brown trout	262.90 (116.40)	29.23 (18.08)
	Rainbow trout	53.50 (20.58)	5.95 (2.66)
	All trout	369.75 (122.38)	43.34 (19.08)
Oct 21, 2008	Brook trout	9.18 (0)	3.01 (0)
	Brown trout	230.54 (37.04)	41.65 (5.76)
	Rainbow trout	258.19 (40.22)	52.31 (7.36)
	All trout	497.91 (54.68)	96.96 (9.34)
Apr 22, 2009	Brook trout	180.24 (39.50)	37.48 (7.10)
	Brown trout	153.66 (40.94)	22.02 (6.40)
	Rainbow trout	93.97 (44.84)	13.30 (6.78)
	All trout	427.86 (72.42)	72.80 (11.72)

Table 17.—Estimates of trout density and biomass in the East Prong Roaring River delayed harvest downstream site. Values in parentheses are 2 SE.

Date	Species	Density (fish/ha)	Biomass (kg/ha)
Apr 15, 2008	Brook trout	337.20 (124.20)	73.96 (26.70)
	Brown trout	265.32 (140.88)	28.13 (16.48)
	Rainbow trout	246.08 (93.38)	60.26 (24.00)
	All trout	848.60 (209.74)	162.36 (39.50)
Jun 25, 2008	Brook trout	71.64 (0)	11.44 (0.76)
	Brown trout	91.54 (19.50)	12.17 (2.22)
	Rainbow trout	55.72 (23.88)	10.20 (3.94)
	All trout	218.90 (30.82)	33.81 (4.60)
Oct 21, 2008	Brook trout	3.93 (0)	0.78 (0)
	Brown trout	128.94 (27.98)	19.10 (5.80)
	Rainbow trout	319.45 (50.92)	78.83 (13.06)
	All trout	452.32 (58.10)	98.71 (14.28)
Apr 22, 2009	Brook trout	211.28 (142.88)	43.34 (27.50)
	Brown trout	132.24 (75.88)	20.59 (14.04)
	Rainbow trout	21.28 (0)	2.80 (0.42)
	All trout	364.80 (161.78)	66.73 (30.88)

Table 18.—Estimates of trout density and biomass in the East Prong Roaring River hatchery supported site. Values in parentheses are 2 SE.

Date	Species	Density (fish/ha)	Biomass (kg/ha)
Apr 1, 2008	Brook trout	256.15 (143.08)	60.66 (33.74)
	Brown trout	36.45 (16.20)	3.53 (2.12)
	Rainbow trout	59.40 (13.50)	18.29 (4.08)
	All trout	352.00 (144.62)	82.47 (34.06)
Apr 17, 2008	Brook trout	7.84 (0)	1.56 (0)
	Brown trout	23.52 (0)	2.17 (0.16)
	Rainbow trout	11.76 (0)	1.49 (0)
	All trout	43.12 (0)	5.23 (0.16)
Jul 18, 2008	Brown trout	30.72 (0)	5.42 (0.06)
Oct 21, 2008	Brown trout	18.85 (0)	2.31 (<0.01)
Apr 16, 2009	Brook trout	11.01 (0)	1.84 (<0.01)
	Brown trout	40.37 (14.68)	11.26 (1.60)
	Rainbow trout	3.67 (0)	0.35 (0)
	All trout	55.05 (14.68)	13.46 (1.60)

Table 19.—Estimates of density and biomass of nongame fishes in delayed harvest and hatchery supported designated waters in the East Prong Roaring River. Values in parentheses are 2 SE.

	Delayed harvest upstream		Delayed harvest downstream		Hatchery supported	
Species	Density (fish/ha)	Biomass (kg/ha)	Density (fish/ha)	Biomass (kg/ha)	Density (fish/ha)	Biomass (kg/ha)
Blacknose dace	740.88 (102.06)	2.36 (0.36)	89.48 (0)	0.10 (0)	19.12 (0)	0.02 (0)
Bluehead chub	4,374.88 (120.86)	15.77 (1.24)	14,017.35 (1,385.60)	51.43 (6.38)	2,014.49 (405.74)	5.30 (1.05)
Creek chub	500.04 (32.26)	3.98 (0.80)			111.79 (206.44)	1.07 (2.10)
Fantail darter	795.08 (54.02)	1.81 (0.18)	6,734.45 (712.14)	7.63 (1.16)	111.79 (206.44)	0.27 (0.50)
Highback chub	1,946.03 (57.60)	3.30 (0.28)	4,859.30 (22.04)	4.57 (0.46)	4,491.05 (3,743.64)	8.12 (6.82)
Margined madtom	486.88 (62.88)	4.63 (1.18)	281.68 (51.26)	2.17 (0.86)	3,442.13 (15,393.02)	35.34 (158.16)
Mountain redbelly dace			22.37 (0)	0.09 (0)		
Redbreast sunfish			48.73 (33.08)	0.43 (0.30)	950.38 (493.02)	16.99 (11.58)
Redlip shiner	7,075.50 (321.86)	6.58 (1.36)	13,555.01 (735.90)	14.28 (2.00)	1,766.81 (1,385.06)	2.30 (1.82)
Rosyside dace	5,432.77 (131.00)	15.79 (2.20)	2,533.60 (429.96)	7.49 (1.64)	429.93 (118.46)	1.28 (0.46)
Smallmouth bass					182.15 (204.26)	4.09 (4.98)
Striped jumprock	26.01 (0)	0.10 (0)	898.84 (193.04)	18.44 (7.68)	1,554.30 (9,504.14)	28.43 (174.12)
Tessellated darter	352.65 (76.92)	0.26 (0.10)	1,016.34 (73.44)	0.92 (0.10)	41.65 (28.26)	0.05 (0)
White sucker	453.28 (108.76)	4.74 (1.42)	689.09 (158.64)	9.92 (1.14)	58.79 (13.68)	0.96 (0.24)
Total	22,184.00 (418.04)	59.32 (3.54)	44,746.24 (1,795.96)	117.47 (10.50)	15,174.38 (18,540.68)	104.22 (235.68)

Table 20.—Estimates of density and biomass of nongame fishes in Bullhead Creek. Values in parentheses are 2 SE.

Species	Density (fish/ha)	Biomass (kg/ha)
Blacknose dace	1,255.16 (113.26)	0.76 (0.68)
Fantail darter	1,291.00 (636.76)	2.23 (1.18)
Total	2,546.16 (646.75)	2.99 (1.36)

Table 21.—Summary of instream habitat characteristics for sampling sites in Stone Mountain State Park, North Carolina in July 2009. UB=undercut bedrock, SB=small boulder, BR=bedrock, MG=medium gravel, VCG=very coarse gravel, SC=small cobble, SI=silt.

				East Prong Roaring River		
Habitat variable	Garden Creek	Rich Mountain Creek	Bullhead Creek	Delayed harvest upstream	Delayed harvest downstream	Hatchery supported
Mean depth (m)	0.09	0.10	0.14	0.15	0.20	0.27
Mean water velocity at bottom (m/s)	0.09	0.16	0.11	0.15	0.15	0.11
Mean column water velocity (m/s)	0.12	0.19	0.14	0.23	0.26	0.20
Mean width (m)	5.18	4.38	5.49	8.19	8.39	10.00
Mean width/mean depth	57.36	44.74	38.47	55.53	43.03	37.59
Discharge (m^3/s)	0.06	0.08	0.11	0.28	0.43	0.53
Gradient (%)	6.09	9.88	8.93	0.86	0.86	0.58
Mean bank angle (°)	146.50	143.75	153.75	146.25	146.50	133.25
Overhead shading (%)	97.21	97.17	91.45	83.20	22.74	93.74
Instream cover (%)	16.95	18.92	40.78	72.81	21.30	21.95
Dominant instream cover	UB	UB	SB	SB	SB	SB
Dominant substrate (1st/2nd)	BR/MG	BR/MG	BR/MG	VCG/SC	VCG/SC	SI/VCG

Table 22.—Water quality measurements in sampling sites on 7-9 July 2009.

Parameter	Garden Creek	Rich Mountain Creek	Bullhead Creek	East Prong Roaring River		
				Delayed harvest upstream	Delayed harvest downstream	Hatchery supported
pH	7.54	7.32	7.48	7.62	7.76	7.84
Dissolved oxygen (mg/L)	9.35	9.28	9.38	8.99	9.29	9.33
Specific conductivity (µS/cm)	18.20	22.30	15.30	20.40	19.50	20.20
Alkalinity (mg/L as $CaCO_3$)	4.20	6.70	3.10	4.40	4.00	5.40
Nitrate (mg/L NO_3^--N)	0.04	0.12	0.07	0.05	0.07	0.06
Orthophosphorus (mg/L as PO_4^{3-})	0.10	0.17	0.13	0.15	0.11	2.37

Table 23.—Selected estimates of ranges of salmonid production.

Region	Location	Annual production (kg/ha)	Reference
Southern Appalachia	Virginia, USA	5-19	Neves and Pardue 1983
	Tennessee, USA	18-48	Whitworth and Strange 1983
	Tennessee, USA	4-5*	Ensign et al. 1990
	North Carolina and Tennessee, USA	1-67	Loar et al. 1985
	North Carolina, USA	23-70	Present study
Northeast	Pennsylvania, USA	58-300	Cooper and Scherer 1967
Midwest	Wisconsin, USA	106-129	Hunt 1974
	Wisconsin, USA	23-396	Brynildson and Mason 1975
	Wisconsin, USA	16-360	Brynildson and Brynildson 1984
	Minnesota, USA	44-190	Waters 1983
	Minnesota, USA	72-258	Newman and Waters 1989
	Minnesota, USA	58-139	Waters et al. 1990
	Minnesota, USA	37-280	Kwak and Waters 1997
West	Colorado, USA	15-184	Scarnecchia and Bergersen 1987
	Idaho, USA	110-125	Goodnight and Bjornn 1971
Canada	Quebec, Canada	15-66	O'Connor and Power 1976
	Newfoundland, Canada	10-65	Clarke and Scruton 1999
	Newfoundland, Canada	3-110	Cote 2007
Europe	England	89-339	Elliott 1993
	Norway	1-61	Power 1973
	Denmark	169-264	Rasmussen 1986
	Poland	88-165	Debowski 1991
	Spain	26-403	Lobón-Cerviá 2003
	Spain	47-182	Almodóvar et al. 2006

*Estimate of production from July through October

Table 24.—Stream and fishery attributes and management options in Stone Mountain State Park coldwater streams by sampling site.

Attribute	Garden Creek	Rich Mountain Creek	Bullhead Creek	East Prong Roaring River		
				Delayed harvest upstream	Delayed harvest downstream	Hatchery supported
Temperature suitable for wild trout	Yes	Yes	Yes	Marginal	Marginal	No
Access type	Wilderness	Wilderness	Wilderness	Roadside	Roadside	Roadside
Access fee	None	Daily	Daily	None	None	None
Fishing pressure	Low	Low	Low	High	High	High
Mean annual trout density (fish/ha)	404.00	2,233.78	801.21	445.21	409.45	41.01
Mean annual trout biomass (kg/ha)	12.50	31.47	22.49	73.44	80.45	7.85
Wild trout production (kg/ha/yr)	22.88	70.08	39.93	Minimal	Minimal	0
Sustainable wild trout harvest						
(kg/ha/yr)	5.72	17.52	9.98	0	0	0
(kg/km/yr)[a]	2.96	7.67	5.48	0	0	0
(fish/km/yr)[b]	34.82	174.32	109.60	0	0	0
(fish/stream/yr)[c]	260.11	601.40	556.77	0	0	0
Management options						
Wild or hatchery	Wild	Wild	Wild	Delayed harvest or hatchery supported	Delayed harvest or hatchery supported	Hatchery supported
Harvest regulations	Catch and release or limited creel	Catch and release or limited creel	Catch and release or limited creel	Liberal Creel	Liberal Creel	Liberal Creel
Entry	Open or limited	Open or limited	Open or limited	Open	Open	Open

[a] Based on mean stream width at sampling site.
[b] Based on mean weight of age 1-2 fish.
[c] Based on stream length from USGS 7.5-min quadrangle map.

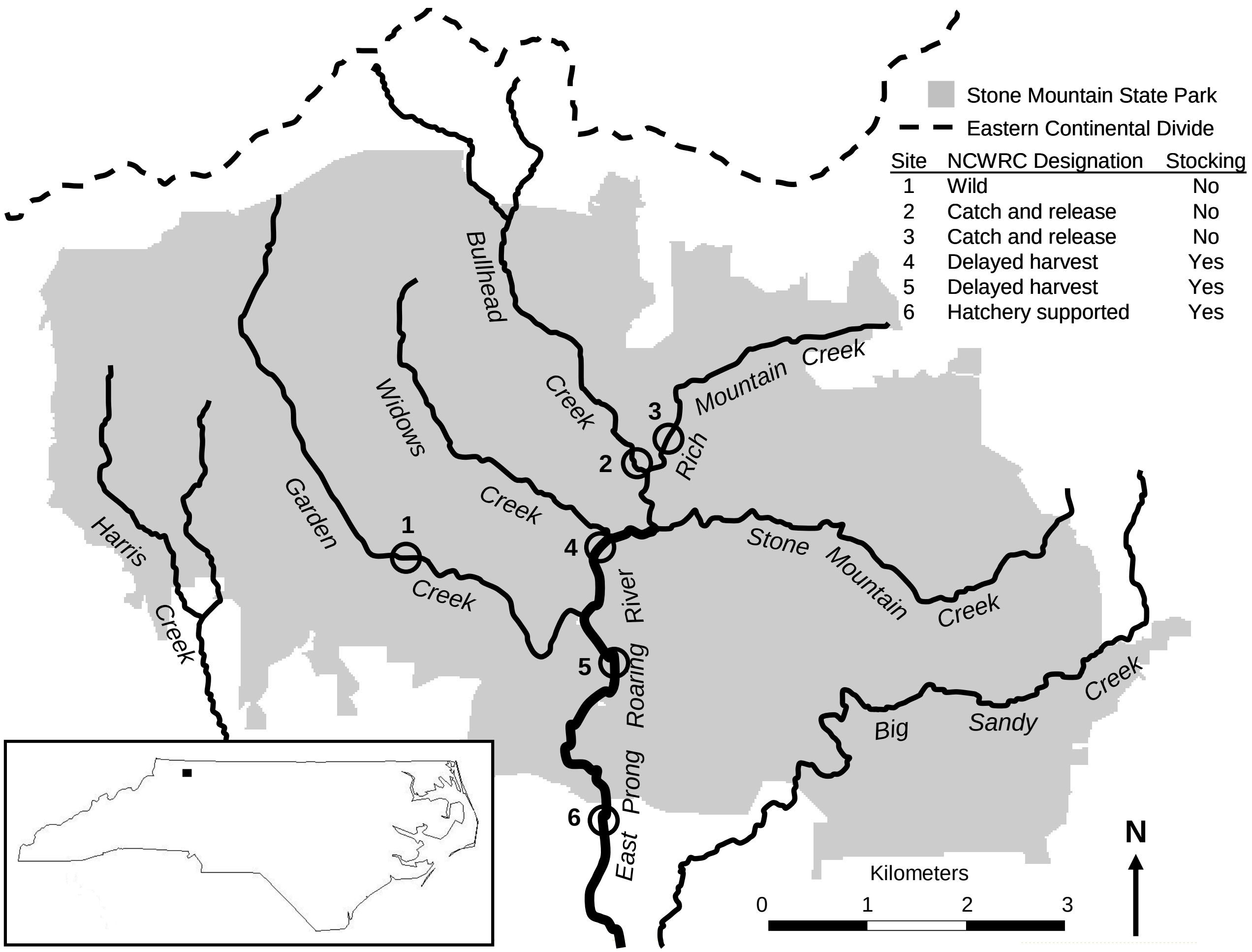

Figure 1.—Map of study site locations in and near Stone Mountain State Park, North Carolina.

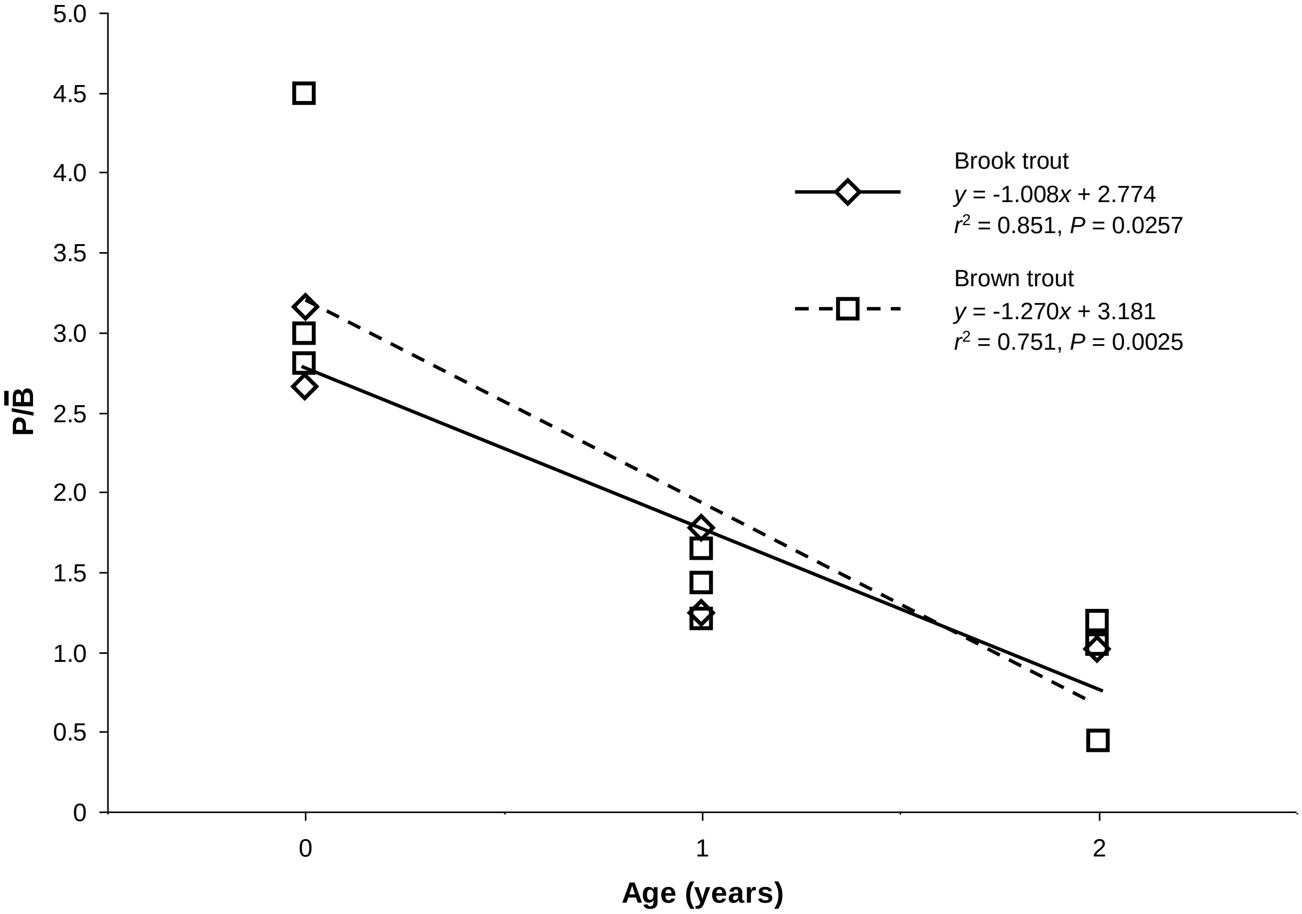

Figure 2.—Annual production to mean biomass by age of brook trout and brown trout in three wild trout designated streams in Stone Mountain State Park, North Carolina.

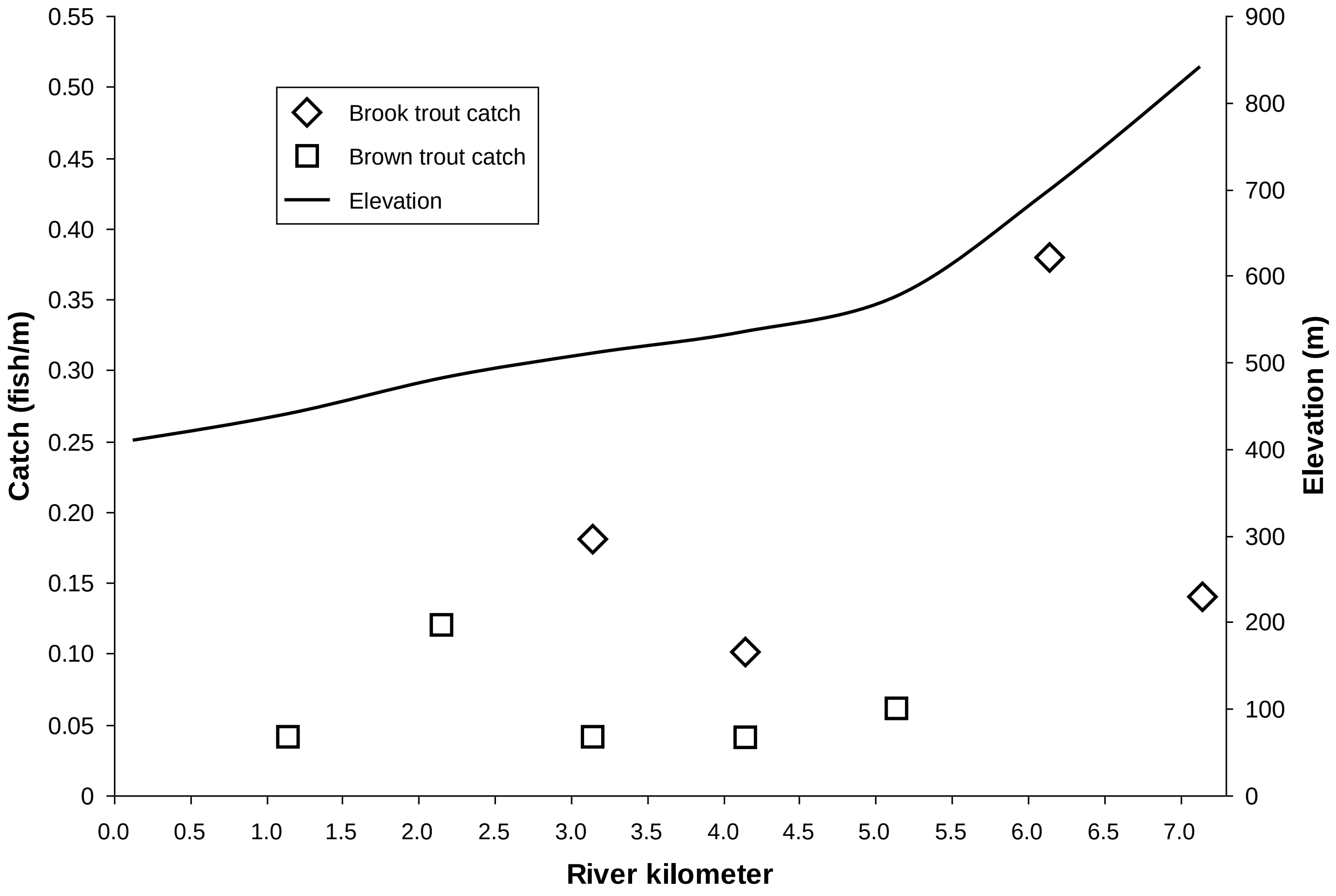

Figure 3.—Trout species distribution in relation to elevation in Garden Creek.

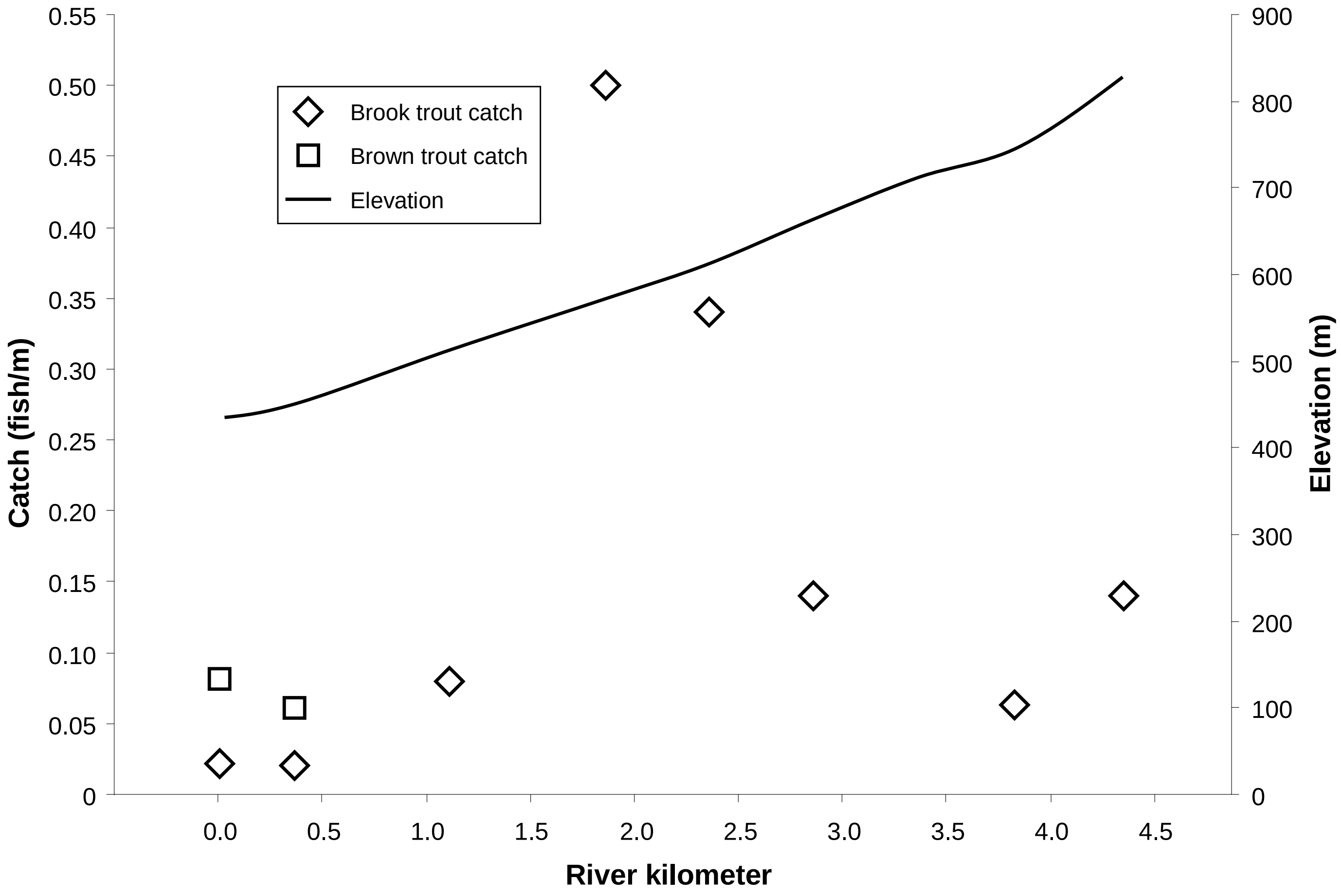

Figure 4.—Trout species distribution in relation to elevation in Rich Mountain Creek.

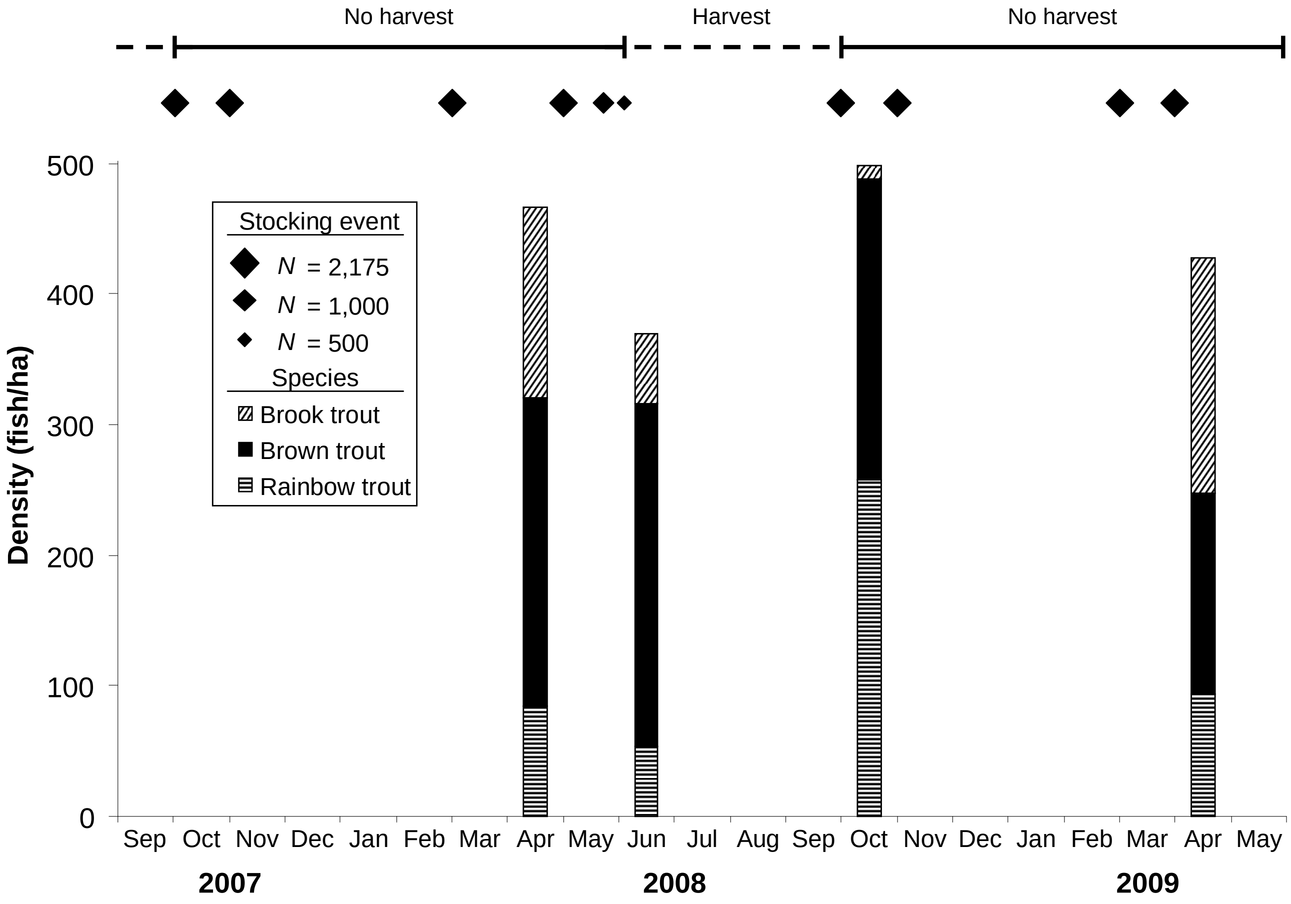

Figure 5.—Trout density in relation to stocking events and time of allowable harvest in the East Prong Roaring River delayed harvest upstream site.

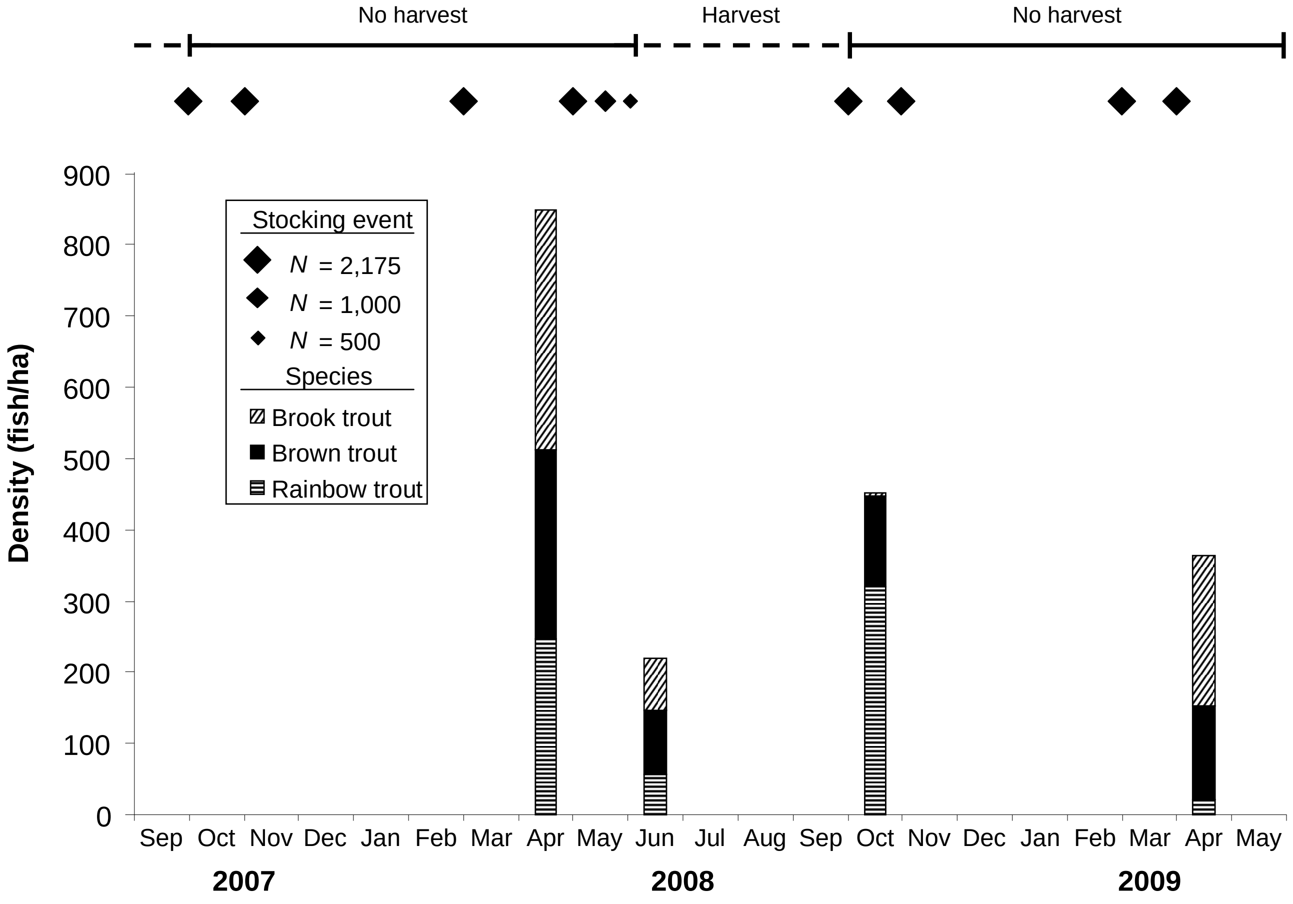

Figure 6.—Trout density in relation to stocking events and time of allowable harvest in the East Prong Roaring River delayed harvest downstream site.

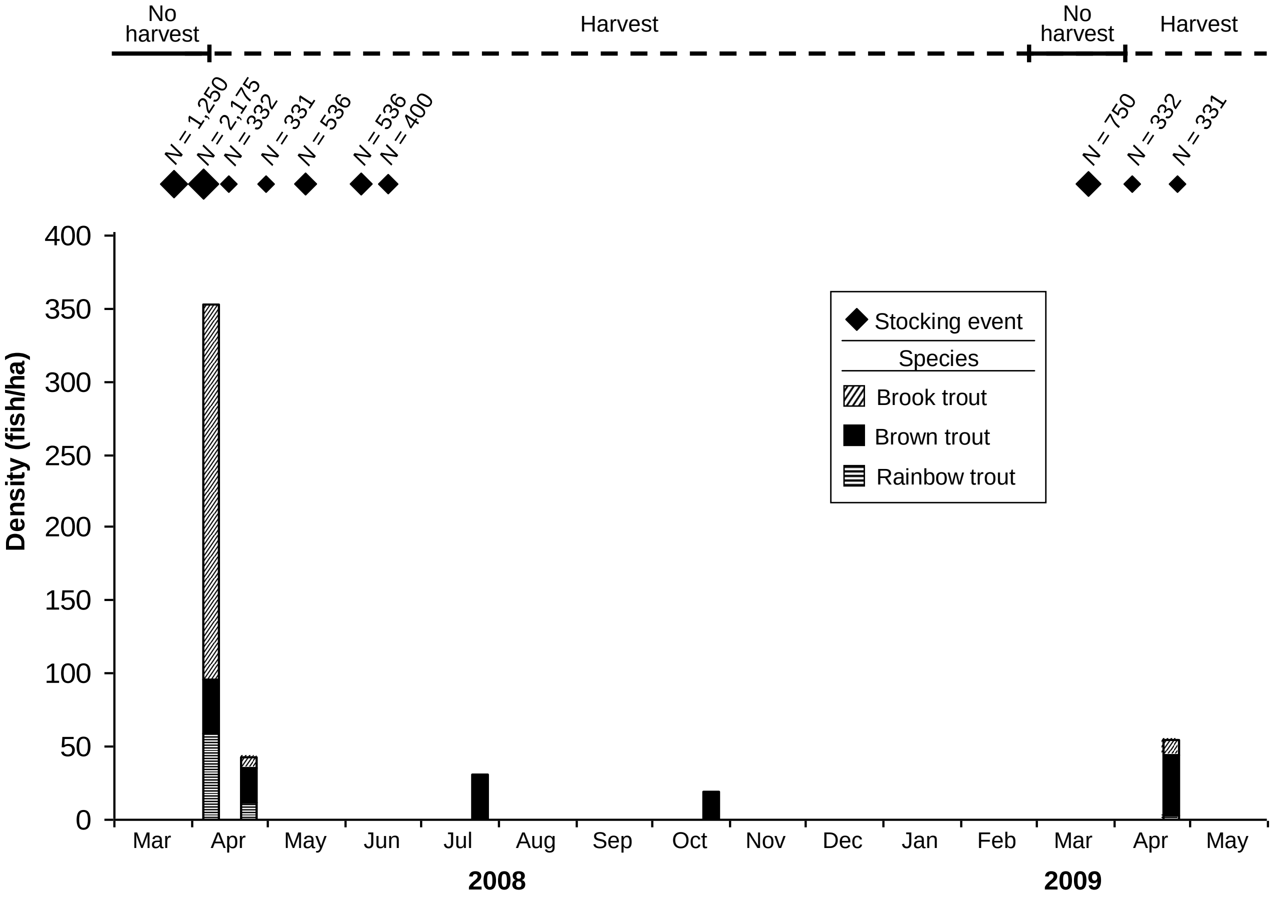

Figure 7.—Trout density in relation to stocking events and time of allowable harvest in the East Prong Roaring River hatchery supported site.

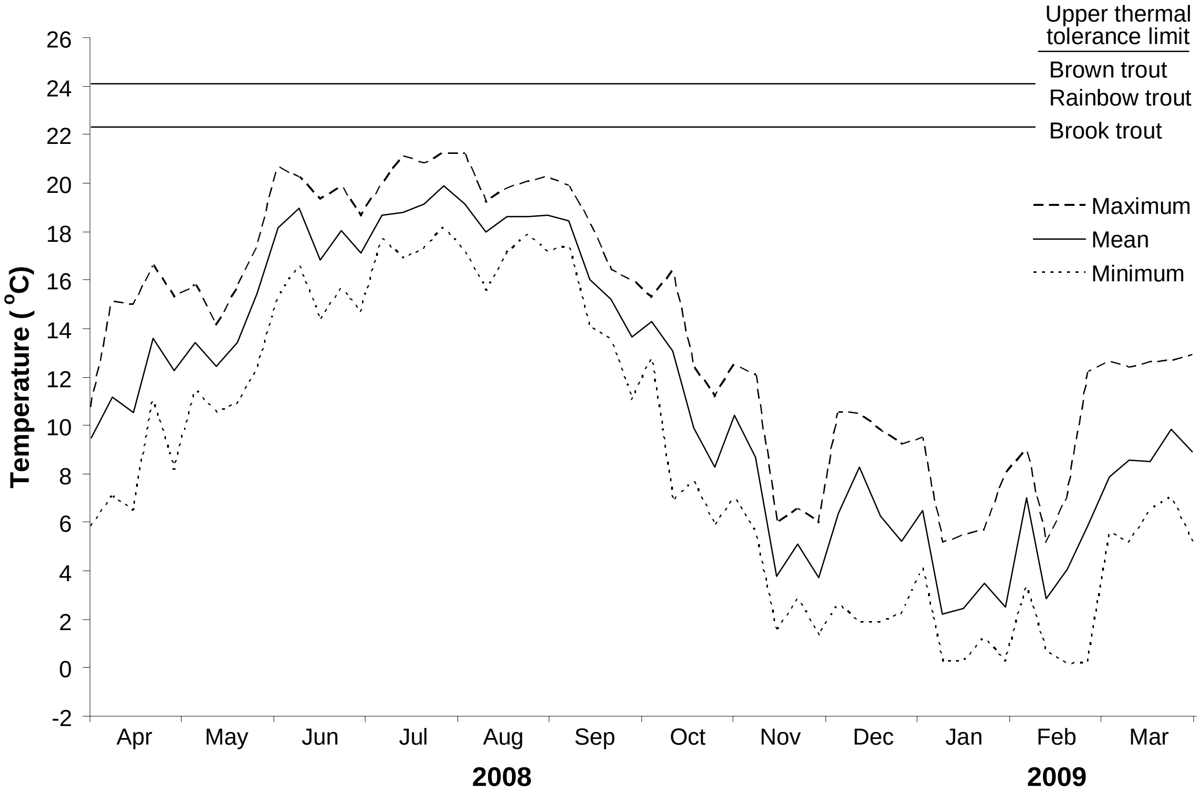

Figure 8.—Minimum, mean, and maximum weekly stream temperatures in Garden Creek, relative to upper thermal tolerance limits of trout species (Eaton et al. 1995).

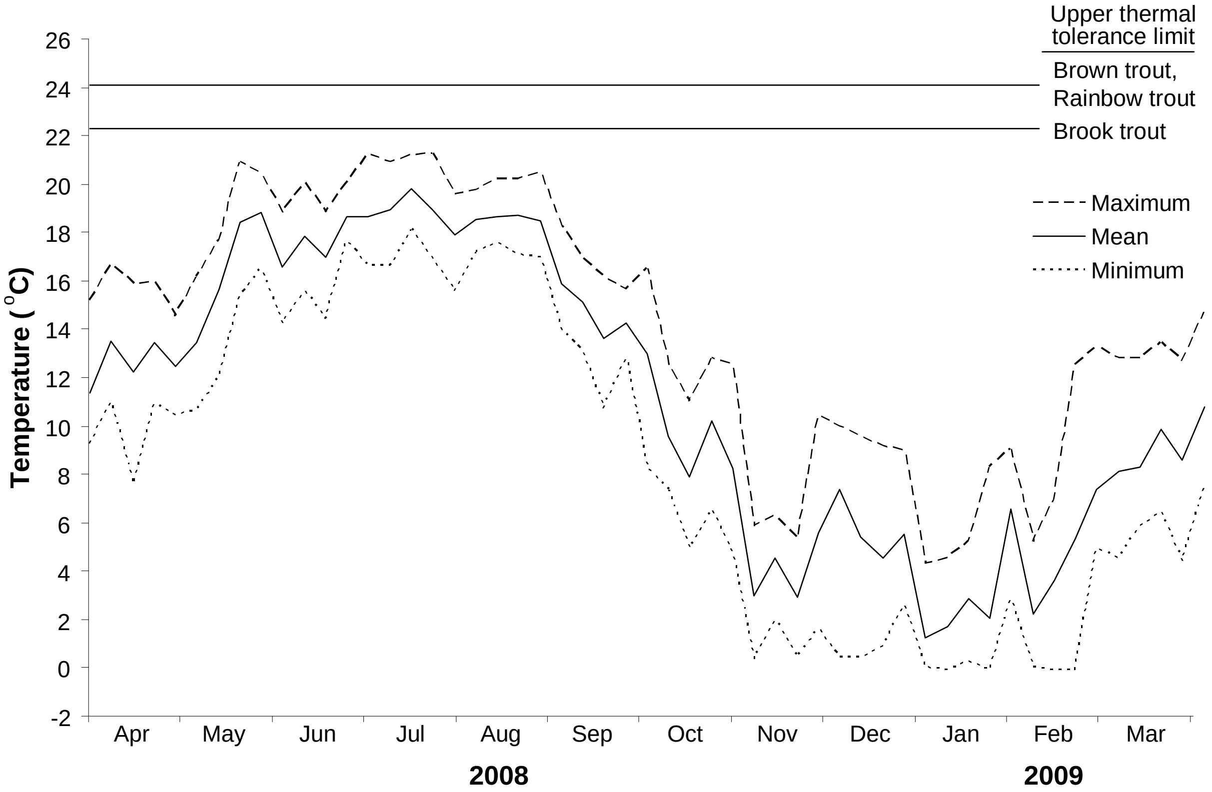

Figure 9.—Minimum, mean, and maximum weekly stream temperatures in Rich Mountain Creek, relative to upper thermal tolerance limits of trout species (Eaton et al. 1995).

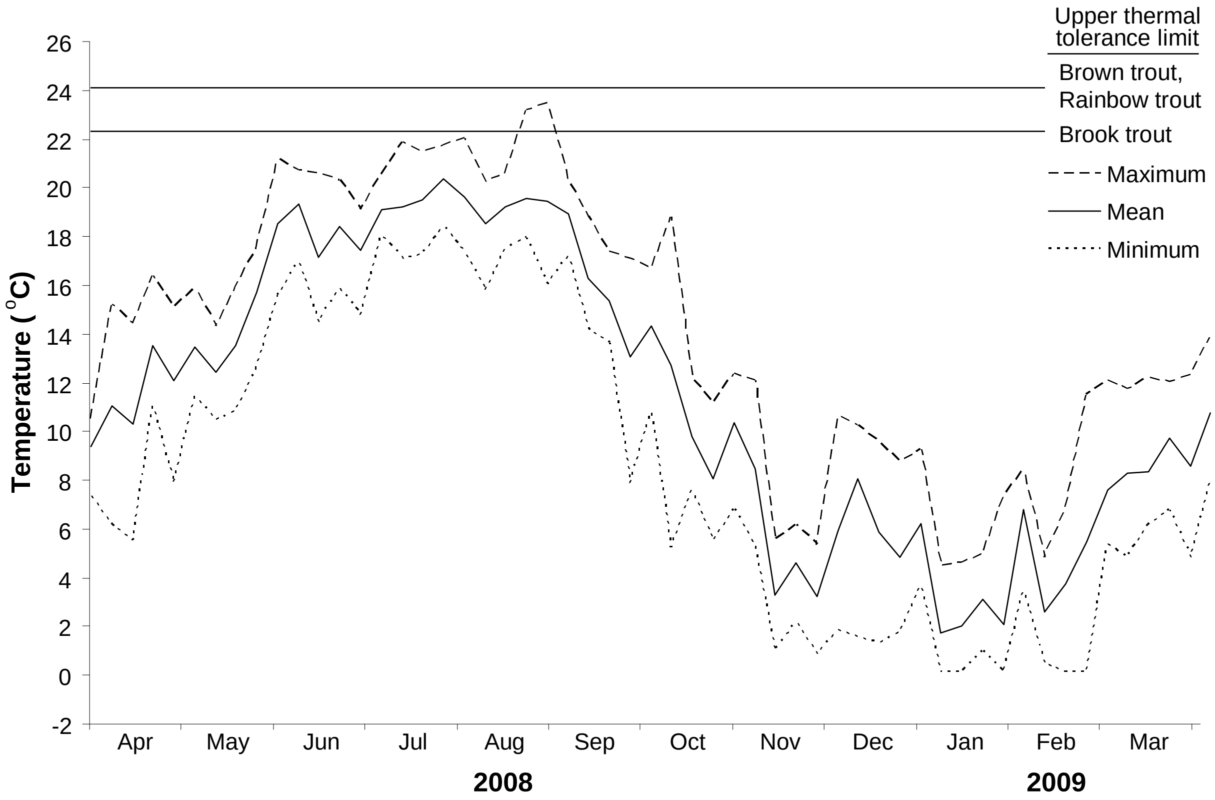

Figure 10.—Minimum, mean, and maximum weekly stream temperatures in Bullhead Creek, relative to upper thermal tolerance limit of trout species (Eaton et al. 1995)

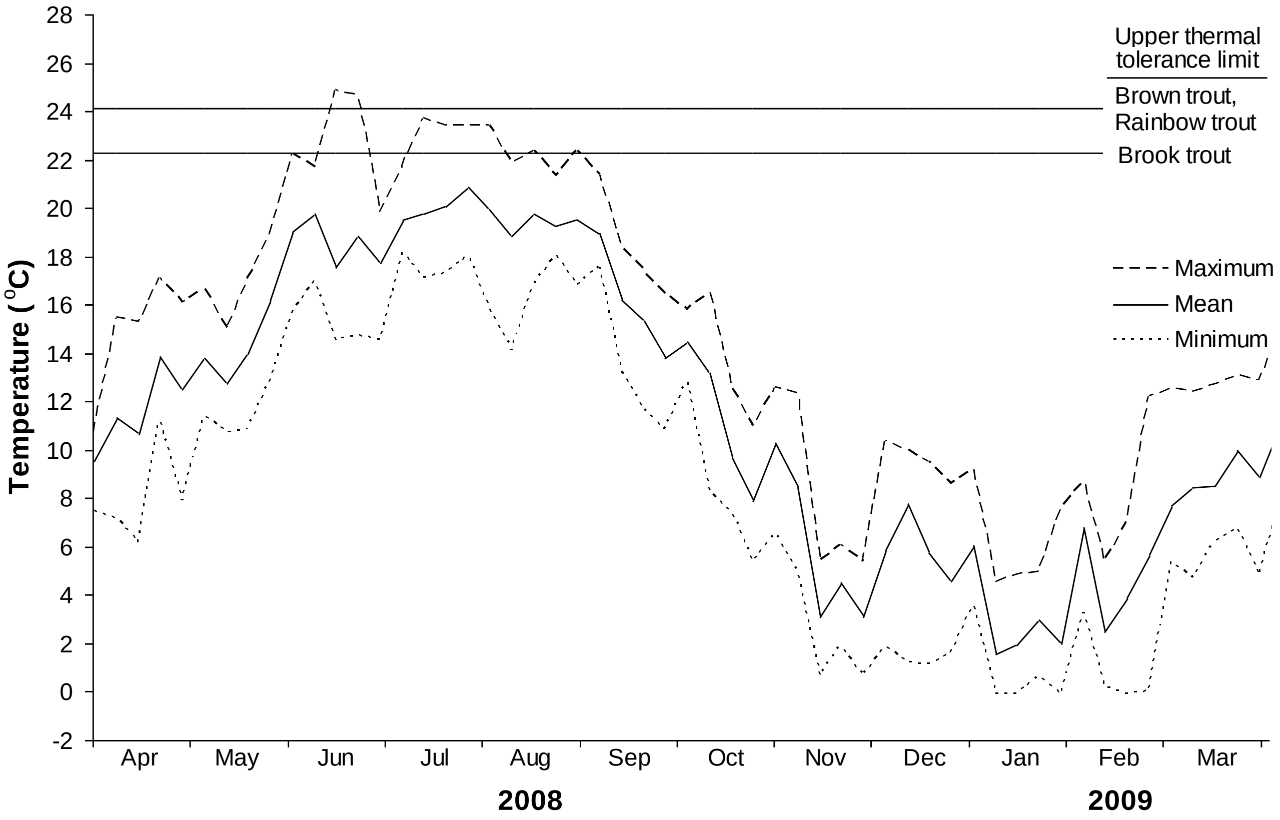

Figure 11.—Minimum, mean, and maximum weekly stream temperatures in the East Prong Roaring River delayed harvest upstream site, relative to upper thermal tolerance limits of trout species (Eaton et al. 1995).

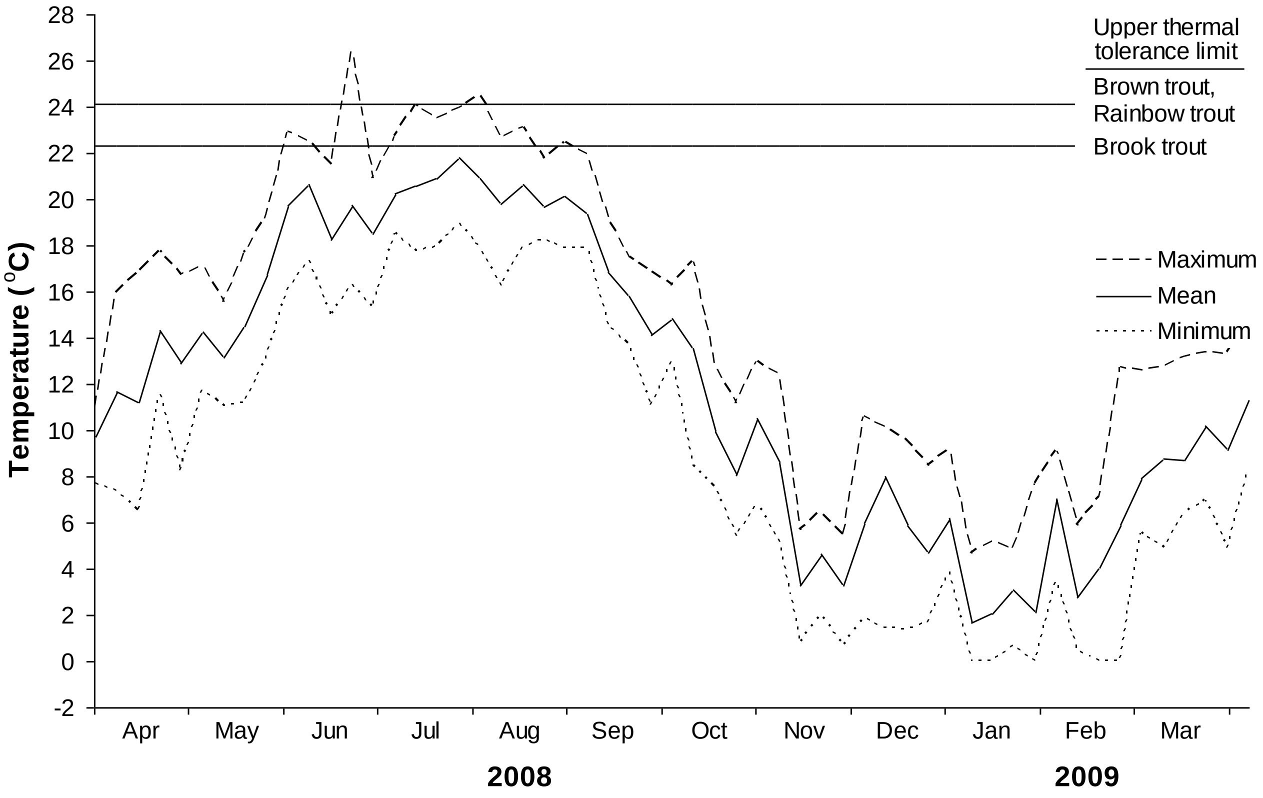

Figure 12.—Minimum, mean, and maximum weekly stream temperatures in the East Prong Roaring River delayed harvest downstream site, relative to upper thermal tolerance limits of trout species (Eaton et al. 1995).

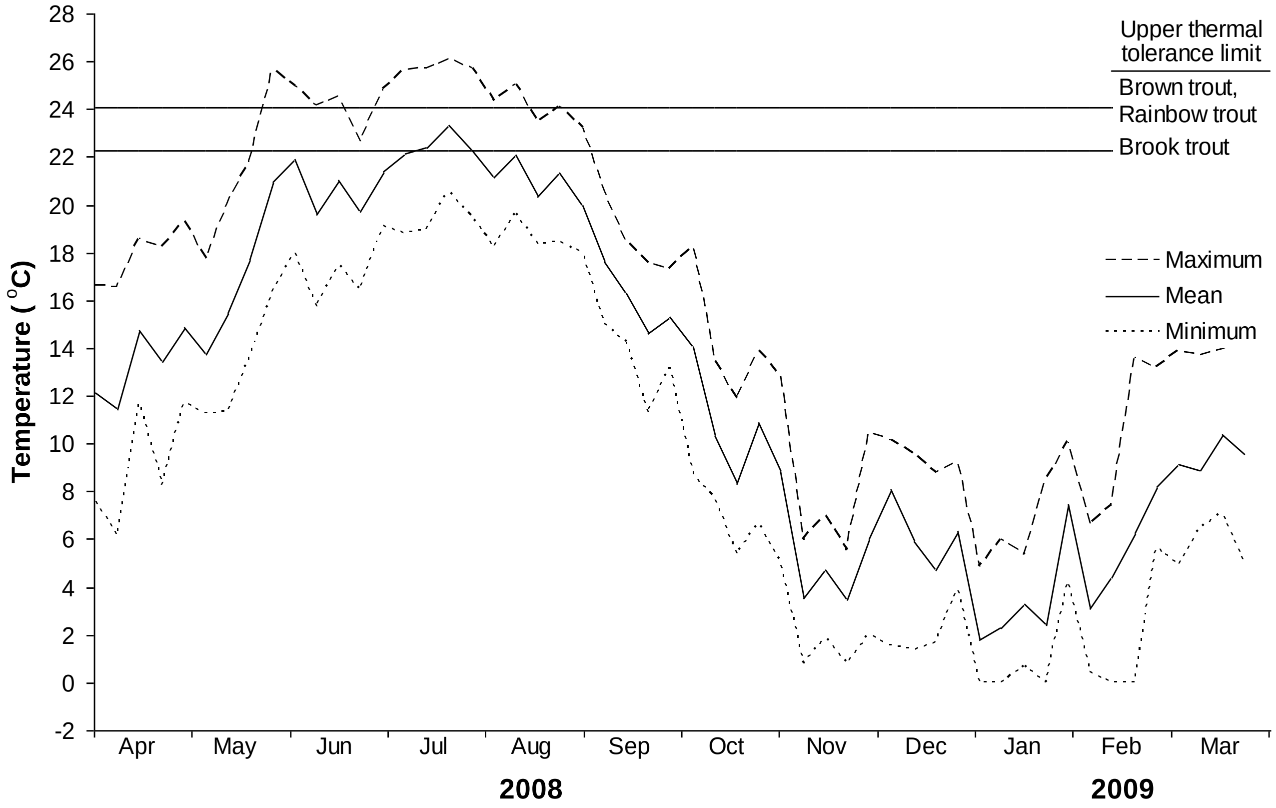

Figure 13.—Minimum, mean, and maximum weekly stream temperatures in the East Prong Roaring River hatchery supported site, relative to upper thermal tolerance limits of trout species (Eaton et al. 1995).

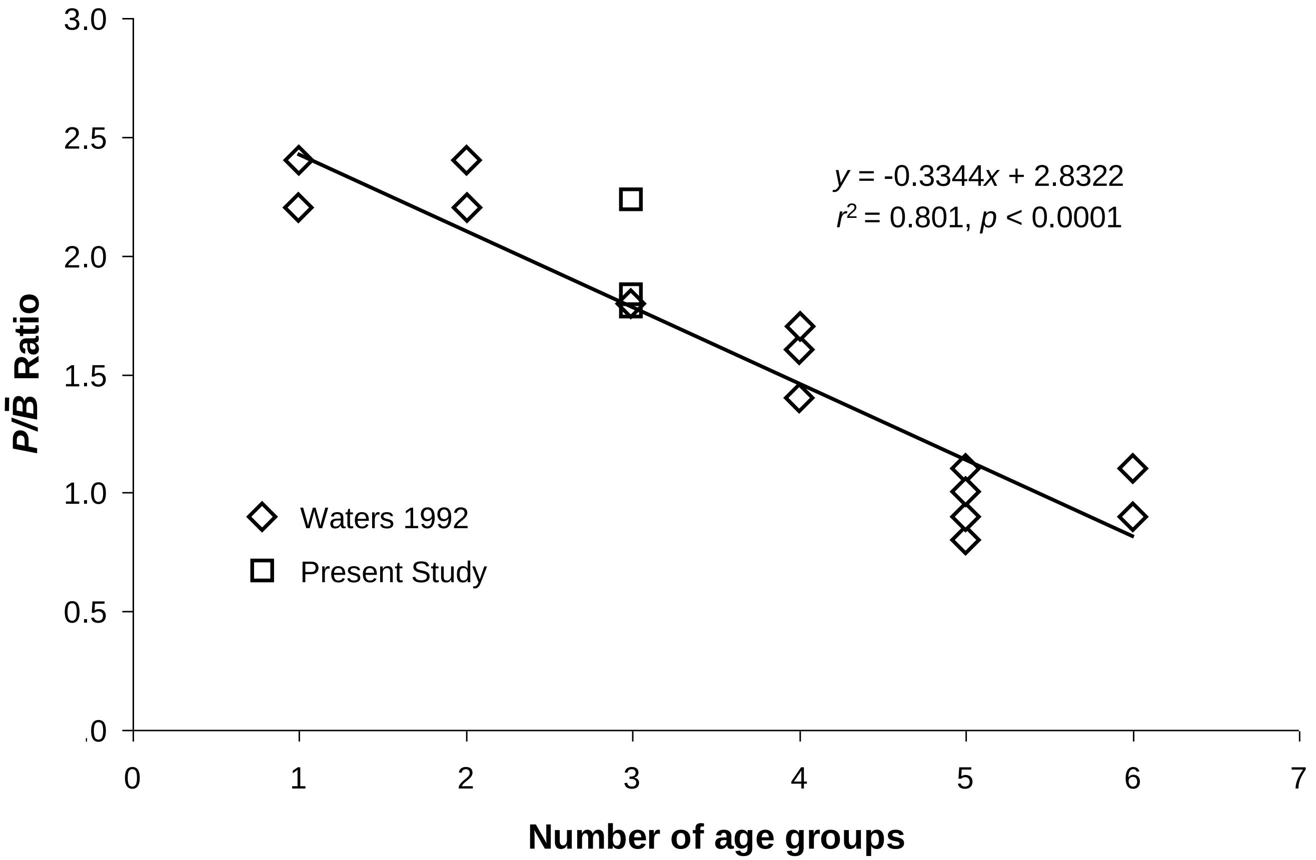

Figure 14.—Production to mean biomass ratios relative to the number of age groups present in salmonid populations. Data compiled by Waters 1992.