EVALUATION OF THE POST-STOCKING LOSS OF THREE SPECIES OF HATCHERY-READED SALMONIDS IN PENNSYLVANIA

A Dissertation in

Ecology

by

Shawn Michael Rummel

© 2010 Shawn Michael Rummel

Submitted in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

August 2010
The dissertation of Shawn Michael Rummel was reviewed and approved* by the following:

William E. Sharpe  
Professor Emeritus of Forest Hydrology  
Dissertation Advisor  
Chair of Committee

John E. Carlson  
Professor of Molecular Genetics  
Director of the Schatz Center

Duane R. Diefenbach  
Adjunct Professor of Wildlife Ecology  
Leader, PA Cooperative Fish and Wildlife Research Unit

Tyler Wagner  
Adjunct Assistant Professor of Fisheries Ecology  
Assistant Unit Leader, PA Cooperative Fish and Wildlife Research Unit

David M. Eissenstat  
Professor of Woody Plant Physiology  
Chair, Intercollege Graduate Degree Program in Ecology

*Signatures are on file in the Graduate School
Hatchery-reared trout are commonly released into streams throughout the United States, including Pennsylvania, mainly for the purpose of increasing recreational angling opportunities. The loss of hatchery-reared trout from the areas they were initially released has recently become a concern throughout Pennsylvania for cold-water fisheries managers. In order to increase our understanding of the post-stocking loss of hatchery-reared trout, and to improve current management of cold-water fisheries, we examined the survival rates, dispersal, behavior, and great blue heron predation of recently stocked salmonids. The number of trout recaptured after release was low, with the majority of the loss occurring within the first two weeks of release. No interspecific differences in survival and recapture rates were observed among brook, brown, and rainbow trout. Trout remaining within the area of initial release were consistently smaller, in terms of total length and mass, than those that had dispersed beyond the area of initial release. During behavior observations, trout that had remained within the area of initial release initiated more aggressive encounters and were more active than trout that had dispersed to sites beyond the area of release. The loss of hatchery reared trout appeared to be a combination of active dispersal and mortality due to predation. We suggest several possible changes in management plans to limit the post-stocking loss of hatchery-reared trout and associated negative ecological interactions with other fishes.
Table of Contents

LIST OF FIGURES ........................................................................................................... vii
LIST OF TABLES ............................................................................................................. x
ACKNOWLEDGEMENTS ................................................................................................. xiv
Chapter 1 .......................................................................................................................... 1
Introduction ...................................................................................................................... 1
  1.1 Ecological and Socio-economic Importance of Stocked Fishes ......................... 1
  1.2 Dispersal of Hatchery-Reared Trout ................................................................. 7
  1.3 Ecological Consequences of Dispersal .............................................................. 10
  1.4 Objectives of Study ............................................................................................... 13
  1.5 Literature Cited .................................................................................................... 14
Chapter 2 .......................................................................................................................... 22
Post-stockung Residency and Dispersal of Brook, Brown, and Rainbow Trout in Two Pennsylvania Streams .................................................................................................. 22
  2.1 ABSTRACT .............................................................................................................. 22
  2.2 INTRODUCTION .................................................................................................... 23
  2.3 METHODS .............................................................................................................. 24
    2.3.1 Description of Study Sites ............................................................................. 24
    2.3.2 In-stream Habitat and Environmental Variables ........................................ 30
    2.3.3 Study Organisms and Mark-Recapture Study .............................................. 33
    2.3.4 Survival Analyses .......................................................................................... 36
    2.3.5 Dispersal Direction and Distance ................................................................. 37
  2.4 RESULTS ................................................................................................................ 38
    2.4.1 In-stream Habitat, Environmental Variables, and Water Quality .............. 38
    2.4.2 Recapture and Apparent Survival of Hatchery-reared Trout .................... 44
    2.4.3 Dispersal of Hatchery-reared Trout .............................................................. 51
  2.5 DISCUSSION ........................................................................................................... 56
  2.6 LITERATURE CITED ............................................................................................ 62
Chapter 3 .......................................................................................................................... 68
Behavioral Characteristics of Individual Hatchery-Reared Trout as a Determinate of Their Post-Stocking Dispersal ........................................................................... 68
3.1 ABSTRACT .............................................................................................................68
3.2 INTRODUCTION..................................................................................................69
3.3 METHODS.............................................................................................................74
    3.3.1 Watershed Description ..............................................................................74
    3.3.2 Fishery Description ...................................................................................76
    3.3.3 Determination of Residency ....................................................................76
    3.3.4 Experimental Raceway Design .................................................................78
    3.3.5 Behavioral Observations ...........................................................................80
    3.3.6 Movement of Non-Resident Trout ............................................................83
    3.3.7 Data Analysis ............................................................................................83
3.4 RESULTS ...............................................................................................................84
    3.4.1 Total length, Mass, and Fulton’s Condition Factor ....................................84
    3.4.2 Interspecific Differences in Behavior Variables .........................................87
    3.4.3 Movement of Non-resident Trout ..............................................................88
    3.4.4 Resident and Non-Resident Trout Behavior and Classification Analysis ....92
3.5 DISCUSSION .........................................................................................................96
3.6 LITERATURE CITED.............................................................................................100

Chapter 4 ....................................................................................................................108
Downstream Dispersal of Hatchery-Reared Brook, Brown, and Rainbow Trout
Immediately Following Release in Rolling Rock Creek, Pennsylvania .........................108
4.1 ABSTRACT .........................................................................................................108
4.2 INTRODUCTION.................................................................................................109
4.3 METHODS..........................................................................................................111
    4.3.1 Watershed Description ..........................................................................111
    4.3.2 Environmental Variables .........................................................................113
    4.3.3 Fish Trap Construction and Installation ..................................................115
    4.3.4 Trapping Methods ....................................................................................116
    4.3.5 Data Analysis ...........................................................................................119
4.4 RESULTS .............................................................................................................120
    4.4.1 Habitat, Streamflow, and Water Quality ..................................................120
    4.4.2 Tagged Trout Data ....................................................................................122
    4.4.3 Downstream Movement of Trout ..............................................................124
LIST OF FIGURES

Figure 1-1: Illustration of the three most commonly stocked species of trout in the Northeastern United States. ................................................................. 5

Figure 1-2: Map of streams in Pennsylvania classified as “Approved Trout Water” (red streams) and “Class A Wild Trout Streams” (green streams) by the Pennsylvania Fish and Boat Commission (PFBC). Approved Trout Waters are annually stocked with hatchery-reared brook trout for recreational angling by the PFBC. Class A wild trout streams are defined by the PFBC as “waters which support a population of naturally produced trout of sufficient size and abundance to support a long-term and rewarding sport-fishery.” ............................................ 6

Figure 1-3: Location of streams that were reported to have low recapture rates (0-39.9% recaptured) of hatchery-reared trout in a 2006 study by the Pennsylvania Fish and Boat Commission. Green circles represent sites with a recapture rate between 0 and 9.9%. Red triangles represent sites with recapture rates between 10 and 39.9%. Image adapted from Pierce et al. (2006). ............ 9

Figure 2-1: Location of the Sinking Creek and Rolling Rock Creek watersheds in Pennsylvania. ........................................................................................................ 26

Figure 2-2: Detail of Rolling Rock Creek watershed ........................................... 27

Figure 2-3: Detail of the Sinking Creek watershed. Upper and lower study reaches are labeled with red circles. Two major tributaries of Sinking Creek are also included, Boal Gap Run and Potter Run. ......................................................... 29

Figure 2-4: Stream discharge (cubic feet per second; cfs⁻¹) for a) Sinking Creek and b) Rolling Rock Creek for the length of the study period. The vertical lines indicate the time of the first and second release of trout into Sinking Creek and
Rolling Rock Creek. Sixty trout were released into each of the four study reaches at the time of each release in 2007, 2008, and 2009. .................................42

**Figure 2-5:** Maximum daily water temperatures for Sinking Creek and Rolling Rock Creek. The red bar indicates the nominal upper thermal tolerance limit of brook, brown, and rainbow trout. Data are from the temperature logger located on the lower study reach of each stream. .................................................................43

**Figure 2-6:** Recapture locations of tagged trout originally released in the upper and lower study reaches of Rolling Rock Creek. Green squares represent trout released in the upper study reach and pink triangles represent trout released in the lower study reach. Multiple trout were captured at these locations. Arrows and numbers represent the number of trout caught at each location. A total of 29 trout were recaptured within the Rolling Rock watershed. ........................................54

**Figure 2-7:** Recapture locations (red triangles) of tagged trout originally released in the upper and lower study reaches of Sinking Creek. Trout from both study reaches were recaptured at each of these locations. Multiple trout were captured at these locations. The Sinking Creek watershed is outlined in beige. Arrows and numbers represent the number of trout captured at the indicated location. ........................................................................................................55

**Figure 3-1:** a) Location of the Rolling Rock Creek watershed in Pennsylvania. b) Detail of Rolling Rock Creek watershed. ...............................................................75

**Figure 3-2:** Experimental raceway design. a) Schematic of experimental raceway design for behavioral observations. b) Image of experimental raceway looking from observation area two, upstream to the water input. ........................................81
**Figure 3-3:** Map of recapture locations of individual dispersing trout released in Rolling Rock Creek. Green squares represent trout released in the upper study reach and pink triangles represent trout released in the lower study reach. The Rolling Rock Creek watershed is outlined and highlighted in light orange with blue streams. Green streams on the map are waters designated as Approved Trout Waters by the Pennsylvania Fish and Boat Commission and are stocked annually with trout. Red streams (Laughlintown Run and Powderrmill Run) denote waters designated as Class A wild trout waters by the Pennsylvania Fish and Boat Commission and contain sustainable populations of wild trout. 91

**Figure 3-4:** A classification and regression tree that classifies resident (r) and non-resident (nr) trout as a function of observed behavior variables. Terminal nodes are identified by N#. Numbers in terminal nodes are the number of correct classifications per total number of individuals classified into a given node. 95

**Figure 4-1:** a) Location of the Rolling Rock Creek watershed in Westmoreland County, Pennsylvania. b) Detail of Rolling Rock Creek watershed. The upper study reach of Rolling Rock Creek was used for this study. 112

**Figure 4-2:** Fish trap installed on a jack dam at the downstream end of the Rolling Rock upper study reach on Rolling Rock Creek. 116

**Figure 4-3:** Daily discharge measurements during the three trapping trials. Time 0 indicates the date trout were released into the 300 meter study reach. Electrofishing surveys were conducted on day 14 of each trial. Data collection in trial 1 ended at day 5. 122
**Figure 4-4:** The total (cumulative) number of trout captured over time (days) by the downstream trap in each of the three trials. No data were available for days 8 – 14 in trial 1.

**Figure 4-5:** Number of brook, brown, and rainbow trout captured on each day of the three trapping trials. Daily discharge measurements are given along with the mean discharge of each trapping trial.

**Figure 4-6:** Discharge (cfs⁻¹), pH, and total dissolved aluminum (mg Al/l) concentrations during each of the three trapping trials.

**Figure 4-7:** Scatter plot (with fitted linear regression line) of the number of hours trout were in the study reach prior to being trapped and the absolute value of the relative weight (Wr) subtracted from the standard Wr of 100 for trout that were trapped during the three trapping trials. The equation of the fitted regression line was \( y = 4.52 - 0.0463x \) (\( n = 48, r^2 = 0.226, p = 0.001 \)).

**Figure 5-1:** a) Location of the Sinking Creek watershed in Pennsylvania. b) Detail of Sinking Creek watershed.

**Figure 5-2:** Example of a hatchery-reared rainbow trout with FLOY® T-Bar anchor tag inserted below dorsal fin. Each tag was color coded for the location of release and was printed with a unique number for identification of individual trout.

**Figure 5-3:** A FLOY® T-Bar anchor tag in leaf litter below great blue heron nesting location. Red arrow indicates location of tag in photograph.
LIST OF TABLES

Table 2-1: Summary of habitat variables on each of the four study reaches. Mean values are given with standard deviation in parentheses. RR = Rolling Rock, SC = Sinking Creek. ..........................................................40

Table 2-2: Population and biomass estimates for each study reach. ..............44

Table 2-3: Candidate models of apparent survival rate (φ) and recapture probability (p). Akaike’s information criterion corrected for small sample size (AIC_c) was used to select the best candidate model describing apparent survival of tagged trout. The number of parameters estimated (k) for each of the candidate models, AIC_C, ΔAIC, and the AIC_C weight are given. .........................46

Table 2-4: Parameter estimates (standard error) for apparent survival (φ) and recapture probability (p) from the model φ (site x time) p (site x time). .................48

Table 2-5: Mean (± standard deviation) length, mass, Fulton’s condition factor (K), and relative weight (W_r) of trout released into Rolling Rock Creek and Sinking Creek (n = 1,410). Superscripted letters denote statistical differences at p < 0.05. Statistical comparisons were made among species within each stream. ........................................................................................................................................50

Table 2-6: Mean (± standard deviation) total length, mass, condition factor (K) and relative weight (W_r) of resident and non-resident trout. Means were compared using a student’s t-test .................................................................51

Table 3-1: Summary of selected studies comparing behavioral traits between hatchery-reared and wild salmonids. .................................................................71
Table 3-2: Mean ± standard deviation (n = 6) pH, acid neutralizing capacity (µEq/L), and total dissolved aluminum (mg/L) of water used in the experimental raceway.

Table 3-3: Mean (standard deviation) mass (g), total length (mm), and condition factor (K) of trout used in behavioral observations in 2007 and 2008. Superscripted lower case letters denote statistically significant differences at α ≤ 0.05. Comparisons were made between species in 2007.

Table 3-4: Mean (standard error) mass, total length, and condition factor (K) for trout determined to be either resident or non-resident. One-way ANOVA was used to compare means between resident and non-resident trout.

Table 3-5: Median (Interquartile Range) behavioral variables observed in 2007 for brook trout, brown trout, and rainbow trout. Median values among the three species were compared using a non-parametric Kruskal-Wallis test.

Table 3-6: Mean (standard deviation) behavior variables observed by resident and non-resident trout. ** indicate statistically significant differences between resident and non-resident trout at α ≤ 0.05. * indicates statistically significant differences between resident and non-resident trout at α ≤ 0.1. Behavior variables are listed in order of descending r² values.

Table 4-1: Mean (standard error of the mean) length, width, depth, and velocity of each habitat type within the 300 meter study reach on Rolling Rock Creek.

Table 4-2: Descriptive statistics for daily discharge measurements among the three trapping trials. All numbers in the table are in cubic feet per second (cfs⁻¹).
Table 4-3: Mean (standard error of the mean) total length (mm), mass (g), and Fulton’s Condition Factor (K) for trout released in Rolling Rock Creek. Superscripted lower case letters denote statistical comparisons among species within each trial. Superscripted upper case letters denote statistical comparisons among trials within each species. Different letters denote statistical significance at $\alpha = 0.05$.

Table 4-4: Number of trout captured in each trapping trial by species.

Table 4-5: Timing of downstream movements of brook trout, brown trout, and rainbow trout. Data from each trapping trial are combined.

Table 5-1: Tagging scheme used for trout released in Sinking Creek in 2007, 2008 and 2009. Each tag was labeled with a unique number to enable identification of individuals when the tag was found.

Table 5-2: Mean (standard error) mass (g), total length (mm), and Fulton’s condition factor (K) of brook, brown, and rainbow trout from the Elk Creek and Cedar Springs fish hatcheries in 2007, 2008, and 2009.

Table 5-3: Number of tags located below great blue heron nesting location from brook, brown, and rainbow trout 2007 – 2009. * No tags were located in 2009 due to abandonment of the nesting location by great blue herons.
ACKNOWLEDGEMENTS

This project was supported by a grant from the R.K. Mellon Foundation. Foremost, I would like to acknowledge my advisor Dr. Sharpe. Throughout my graduate career, he has provided countless hours of guidance, support and encouragement for which I am especially grateful. I would also like to particularly thank the members of my committee; John Carlson, Duane Diefenbach, and Tyler Wagner. Their collective support and constructive ideas for the direction of research and data analysis have made this dissertation possible and were very much appreciated.

I would like thank Mike Allen and the staff at the Rolling Rock Fish Hatchery for accommodating this project on Rolling Rock Creek. They were always willing to lend a hand with fieldwork in any way they could. The Pennsylvania Fish and Boat commission also provided valuable input and assistance throughout this project. Dan Bringham at the Elk Creek fish hatchery provided the trout used in the Sinking Creek portion of the study and his patience during tagging procedures is appreciated.

I am indebted to the following individuals for their help in the field, without which, this project would not have been completed successfully: Marie Gildow, Josh Mulhollem, Jeffery Law, Robin Heagy, Brandon Frazier, and Chad Voorhees. The support and assistance from the staff at the Penn State Institutes of Energy and the Environment are also much appreciated.

I would like to thank my family and friends for their endless support. Their words of encouragement and prayers have guided me through the highs and
lows of graduate school. They are all loved and appreciated very much. I especially want to thank my loving wife Sheryl Rummel. Her limitless support and encouragement throughout this endeavor have given me the perseverance to have made it this far and I am grateful to have a woman like her in my life.
Chapter 1

Introduction

1.1 Ecological and Socio-economic Importance of Stocked Fishes

The stocking of fish is a popular and widely utilized fisheries management technique (Hickley 1994). Stocking is defined as “the repeated injection of fish into an ecosystem in which a population of that species already exists from one external to it, i.e. a stocked species may be either already native to the recipient water body or exotic to it but previously introduced” (Cowx 1998). An introduction may be deliberate or accidental, however stocking is generally a deliberate management action (IUCN 1987). There are many plausible reasons that stocking may be used in a particular situation, which may be broken into four general categories (as described in Hickley (1994)):

1. “Mitigation, where there is a legal or statutory requirement for fishery protection schemes, such as after reservoir dam construction, land drainage works, or similar habitat perturbation

2. Restoration, where a limiting factor to stock recovery or improvement has been removed or reduced, as in the case of water quality improvements, habitat improvements or easing the passage of migratory fish
3. *Enhancement*, where stocking is the principal method of maintaining or improving populations such as the placing of fish above barriers and the operation of put-and-take fisheries

4. *Creation of new fisheries*, where either fish are transferred into new water bodies or new species are introduced into existing ones” (Hickley 1994).

A study by Welcomme (1988) reported that a total of 1354 introductions of 237 species in 140 different countries have been recorded by the Fisheries and Aquaculture Department of the Food and Agriculture Organization (FAO) of the United Nations. In the United States, stocking has led to the successful re-introduction and recovery of several species. For example, populations of lake sturgeon (*Acipenser fulvescens*) (Schram et al. 1999), other sturgeon species (*Acipenser spp.*) (Williot et al. 2009), American shad (*Alosa sapidissima*) (Hendricks 1995), Snake River sockeye salmon (*Oncorhynchus nerka*) (Flagg et al. 1995), and razorback sucker (*Xyrauchen texanus*) (Modde et al. 1995) have each benefited from the stocking of hatchery-reared fishes. In addition to restoration or enhancement of fisheries, fishes also are commonly stocked for socio-economic reasons such as recreational angling and increased sport-fishery utilization.

The most commonly stocked species of fish in the United States are members of the Salmonidae family. Brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Oncorhynchus mykiss*) are stocked for recreational purposes in the eastern United States (Figure 1-1). The majority of
salmonids stocked throughout the United States are hatchery-reared. Hatchery-reared trout are distributed into rivers, streams, and lakes by federal and state agencies as well as local sportsmen’s and conservation groups. According to a 2009 report from the National Agricultural Statistics Service (NASS), approximately 167.2 million hatchery-reared trout, worth $103 million, were distributed in the United States for the purposes of restoration, conservation, or recreation in 2008 (NASS 2009). Of the 167.2 million hatchery-reared trout, 94.7 million (approximately 57%) were fingerling trout used primarily for fishery enhancement projects (NASS 2009). However, of the 72.5 million trout of catchable size (those greater than 15.24 cm), 42.4 million (approximately 58%) were used in stockings for recreational angling purposes (NASS 2009). The remaining 42% of catchable sized trout were either sold to processors for human consumption or used in fisheries conservation and restoration projects (NASS 2009).

Pennsylvania’s trout management plan utilizes stocked trout to “provide recreation in those waters where fish populations are inadequate to sustain the fishery at desired levels” (Greene et al. 2007). The Pennsylvania Fish and Boat Commission (PFBC) annually produces approximately 3.8 million adult trout with an average size of 28 cm (11 inches) that are subsequently stocked throughout the Commonwealth’s streams, lakes, and rivers that are designated “approved trout waters” (Figure 1-2). In 2009, the total estimated cost per adult trout associated with hatchery-reared trout for recreational angling in Pennsylvania was $2.73 (Wisner 2009).
In order for stocking efforts for the purpose of recreational angling to be cost-effective, the cost associated with rearing trout must be offset by the economic benefits of angling. A 2005 study of angler use and economic impact of stocked trout streams revealed that over 2 million angler trips were made during the initial eight weeks of the trout season (16 April – 12 June), contributing $65.7 million to Pennsylvania’s economy and supporting 1,119 jobs throughout the state (Greene et al. 2005). A similar study by the U.S. Fish and Wildlife Service (2005) determined that the total annual economic output from stocked rainbow trout fisheries in the southeastern United States is approximately $325.1 million. The same study also concluded that each dollar of hatchery budget expenditures was associated with $36.88 of net economic value (Caudill 2005).

In addition to the economic benefits associated with stocking trout, there is a public perception that to maintain a quality trout fishery it is necessary to stock hatchery-reared trout (Wiley, 2006) and that trout fishing opportunities would be significantly diminished if stocking efforts were ceased (Knapp, 1996). Given the economic impact of stocking and the associated public perception, it is not surprising that the stocking of hatchery-reared trout has become common in coldwater fisheries management throughout the United States.
Figure 1-1: Illustration of the three most commonly stocked species of trout in the Northeastern United States.
Figure 1-2: Map of streams in Pennsylvania classified as “Approved Trout Water” (red streams) and “Class A Wild Trout Streams” (green streams) by the Pennsylvania Fish and Boat Commission (PFBC). Approved Trout Waters are annually stocked with hatchery-reared brook trout for recreational angling by the PFBC. Class A wild trout streams are defined by the PFBC as “waters which support a population of naturally produced trout of sufficient size and abundance to support a long-term and rewarding sport-fishery.”
1.2 Dispersal of Hatchery-Reared Trout

In Pennsylvania, the most common use of hatchery-reared trout is to increase recreational angling opportunities in the state. As previously described, a large portion of the trout released must be recovered in the creel for hatchery operations to continue to be economically feasible, maintain angler satisfaction, and reduce the ecological impacts of stocked trout on wild trout and native fishes, such as competition, predation, and interbreeding. According to the PFBC’s hatchery trout subprogram guidelines: “the stocking strategy should provide a 65% return to the creel or total catch of the preseason plant, a 75% return to the creel or total catch of an in-season plant, and one angler trip should be generated per trout stocked following both the preseason and in-season plantings…” (PFBC 1997).

Concerns have recently arisen regarding the loss of hatchery-reared, stocked trout away from stocked stream reaches (Wnuk 2005; Pierce et al. 2006). A 2006 study rated several Pennsylvania streams with very poor to poor (0-39.9% of trout released were recaptured) residency rates (defined as the proportion of trout that were initially stocked or released into a stream reach that remain within the 300 meter stream reach of initial stocking) of recently stocked trout (Figure 1-3) (Pierce et al. 2006). The same study also found many streams throughout Pennsylvania with higher residency rates (40 – 100%) (Pierce et al. 2006).

Early studies of fish movement demonstrated stream-dwelling fishes to be sedentary, rarely leaving a particular habitat (Berra and Gunning, 1972). This
observation was later termed the restricted movement paradigm (RMP) by Gowan et al. (1994). Restricted movement referred to fish being captured in the same area in which they were released (Gerking, 1959). The RMP began to be challenged in 1992, as studies began to demonstrate dispersal in stream dwelling fishes, particularly salmonids (Riley et al. 1992; Gowan et al. 1994; Gowan and Fausch 1996). However, post-stocking movements of hatchery-reared trout have been documented beginning in 1933 (Cobb, 1933). Cresswell (1981) provided an adequate review of the relevant literature at that time. One of the main conclusions from the review was that brook trout and rainbow trout seemed to have a greater tendency to move downstream than brown trout (Cresswell 1981). Cresswell (1981) also noted that only 3–35% of trout stocked were recaptured in the reviewed studies.

More recent studies of post-stocking dispersal of hatchery-reared trout have reached similar conclusions. Bettinger and Bettoli (2002) reported 93% of hatchery-reared rainbow trout released dispersed or died quickly following release into a stream. Aarestrup et al. (2005) reported only 26% of hatchery-reared brown trout were still surviving in a stream five weeks after release. High and Meyer (2009) reported a loss of 85% of marked trout within 30 days of release. In a comparison of hatchery-reared and resident holdover brown trout, hatchery-reared fish displayed the greatest range (4.7 – 5.3 km) and up to 21% of marked trout were not found within the 5.8 km study area (Popoff and Neumann 2005).
Figure 1-3: Location of streams that were reported to have low recapture rates (0-39.9% recaptured) of hatchery-reared trout in a 2006 study by the Pennsylvania Fish and Boat Commission. Green circles represent sites with a recapture rate between 0 and 9.9%. Red triangles represent sites with recapture rates between 10 and 39.9%. Image adapted from Pierce et al. (2006).
1.3 Ecological Consequences of Dispersal

Aside from the loss of recreational angling opportunities and the associated loss of revenue, the dispersal of trout away from the location they were intended to occupy may have a range of ecological effects. The ecological consequences of dispersal include interactions with wild trout and other native fishes, the spread of disease, and genetic effects on wild trout populations.

The stocking of hatchery-reared salmonids may have undesirable consequences on native salmonids through competition. Competition occurs between individuals when multiple organisms exploit a common resource and the fitness of at least one of the organisms is reduced, either because the resource is in short supply or other organisms interfere with its use (Birch 1957). Competitive interactions have been reported between stocked trout and wild or native trout and also between stocked trout and native, non-salmonid species (Symons 1969; Fausch 1984; McGinnity et al. 1997; Weber and Fausch 2003 for review).

Stream salmonids compete for positions that are energetically favorable (high food availability and refuge from current) (Metcalfe 1986; Hughes 1992) and fish that occupy the more favorable stream positions grow at a faster rate than those occupying areas with lower food availability and less refuge from stream current (Fausch 1984). Fish that are displaced from energetically favorable areas are subjected to reduction in fitness. Wild fish have been reported to be displaced from favorable stream positions following the release of hatchery-reared trout (Symons 1969; McGinnity et al. 1997).
In hatchery facilities, hatchery-reared fish are generally selected to grow larger and have higher growth rates than they typically would in a natural environment (Fleming et al. 2002). Larger fish generally have an advantage in competitive ability over smaller fish (McIntosh et al. 1994). An increased competitive ability in hatchery-reared salmonids may cause a decrease in the growth and survival of wild salmonid populations.

Differences in competitive ability between hatchery-reared and wild salmonids may develop due to genetic differences and differences in the rearing environment. Characteristics that differ between hatchery-reared and wild salmonids have been reported to have a genetic basis, but locally adapted wild populations also may differ genetically (Youngson and Verspoor 1998). Genetic differences arise depending on the broodstock that is being used by the hatchery. Local adaptation and selective mortality in the rearing environment also may contribute to genetic differences among hatchery-reared trout. Hatchery-reared fish generally are raised at higher densities, lower water velocities, and under different food and feeding regimes than wild fish. The differences in rearing conditions also may lead to differences in the competitive ability of hatchery-reared fish compared to wild fish.

A major component of the competitive interactions between hatchery-reared and wild salmonids is aggression. In the wild, less aggressive fish are often displaced downstream or into less favorable areas of the stream (Fausch 1984). Previous studies have shown that hatchery-reared salmonids tend to be more aggressive than their wild counterparts (see Weber and Fausch (2003) for
review). For example, the high densities that trout are raised at in the hatchery environment may suppress the establishment of social dominance hierarchies that are common among stream-dwelling fishes (Keenleyside and Yamamoto 1962; Jenkins 1971), which may promote greater levels of aggression following release into a stream. Ruzzante (1994) concluded that hatcheries may select for either high or low rates of aggression by varying the availability and distribution of food resources. Aggression may be selected for when food is limited and spatially patchy (Ruzzante 1994). The movement of hatchery-reared trout to areas beyond their intended site of occupancy may increase competitive interactions with wild salmonids and other native fishes.

Hatchery-reared trout surviving after release into the wild to the time of spawning may also compete with wild trout for mates. Interbreeding between hatchery-reared and wild fish may have negative genetic consequences on wild trout populations by decreasing survival and fitness. Hatchery managers generally select a few individuals with favorable traits (high growth rates, fast maturation time, increased egg production, etc.) and use those individuals as broodstock to produce the offspring that are subsequently released into the wild. This process produces a genetic bottleneck effect in the hatchery and reduces genetic diversity due to the high degree of inbreeding that occurs (Aho et al. 2006). Hatchery-reared trout that were breeding with a wild trout population were estimated to have a 16-19% genetic contribution in 0+ aged trout (Skaala et al. 1996). Therefore, hatchery-reared trout interbreeding with wild trout may pass along genotypic and phenotypic characteristics that are unfavorable to survival in
the stream environment. Survival rates in wild trout were reported to be three times greater than survival rates in hybrids of wild and hatchery-reared trout (Skaala et al. 1996). Interbreeding also may have indirect genetic consequences through changes in population size, pathogens and parasites, predation, and competition (Hindar et al. 1991; Carvalho 1993).

1.4 Objectives of Study

Several studies have examined temporal variation in salmonid dispersal (Crisp 1993; Hutchings and Gerber 2002; Peterson and Fausch 2003), the direction of dispersal (Adams et al. 2000; Peterson and Fausch 2003; Popoff and Neuman 2005), and the dispersal distance (Close and Anderson 1992; Hutchings and Gerber 2002; Schmalz et al. 2002; Peterson and Fausch 2003). However, aside from spawning-related movements (Beard and Carline 1991; Downing et al. 2002; Hutchings and Gerber 2002), few studies have examined the possible biotic causes of trout dispersal.

The primary objective of this study was to evaluate possible causes of post-stockling dispersal in hatchery-reared trout. Specifically, I examined how water quality, habitat availability, fitness, species, and behavior influenced trout dispersal. This study also aimed to determine the direction and distance of dispersal and the timing of downstream dispersal immediately following release into the stream. The study also estimated great blue heron (Ardea herodias) predation of hatchery-reared trout in the wild.
1.5 Literature Cited


IUCN. 1987. IUCN Position Statement on Translocation of Living Organisms. 22nd Meeting of the IUCN Council, Gland, Switzerland.


Skaala, Ø., K.E. Jørstad, R. Borgstrøm. 1996. Genetic impact on two wild brown trout (Salmo trutta) populations after release of non-indigenous hatchery spawners. Canadian Journal of Fisheries and Aquatic Sciences 53:2027-2035.


**Wisner, B.** 2009. Stocked trout program: cost report. The Pennsylvania Fish and Boat Commission, Bureau of Fisheries, Division of Fish Production, Pleasant Gap, PA.


Chapter 2

Post-stocking Residency and Dispersal of Brook, Brown, and Rainbow Trout in Two Pennsylvania Streams

2.1 ABSTRACT

The loss of stocked trout from the area of initial stocking has been documented as a prevalent issue throughout Pennsylvania. The loss of hatchery-reared trout represents a considerable ecological, recreational, and economical issue for areas where the loss of trout is occurring. The purpose of this study was to examine the post-stocking residency, dispersal, and loss of brook, brown, and rainbow trout in two distinct watersheds in Pennsylvania. The Rolling Rock Creek and Sinking Creek watersheds were used for this study. Hatchery-reared trout were tagged and released into two study reaches on each of the two watersheds on two separate occasions annually from 2007 to 2009. An average of 42% of the trout released into the four study reaches each year were lost within two weeks of release and the loss of hatchery-reared trout continued throughout the six-week study period in each year. No statistically significant differences in residency rates (the number of trout remaining within the initial 300 meter stocking reach) were observed among brook, brown, and rainbow trout. Trout that remained within the reach where they were initially released were found to be smaller in terms of total length and mass than trout that dispersed away from the original study reach. Post-stocking dispersal was found to be
predominantly in the downstream direction, although several trout were observed to have dispersed in the upstream direction, and several individuals dispersed over long distances. Fisheries managers may consider stocking hatchery-reared trout close to the time that they are available for exploitation by anglers to possibly increase their utilization by the angling public.

2.2 INTRODUCTION

Brook trout \((Salvelinus fontinalis)\), brown trout \((Salmo trutta)\), and rainbow trout \((Oncorhynchus mykiss)\) are the three species of salmonids most commonly stocked in Pennsylvania and throughout the northeastern United States. These fishes are stocked primarily for the purpose of increasing recreational angling opportunities, but may also be released to enhance current cold-water fisheries or to re-establish historical trout fisheries. In Pennsylvania, 5,119 miles of stream are designated as “Approved Trout Waters” by the Pennsylvania Fish and Boat Commission and are annually stocked with over 3.5 million adult hatchery-reared trout (Pennsylvania Fish and Boat Commission 2006). Trout stocked by the PFBC are reared at hatcheries operated by the PFBC and select trout hatcheries throughout the state. The trout released by the PFBC typically average 28 cm in total length (PFBC 2006).

In recent years, anglers in Pennsylvania have complained about low catch rates of hatchery-reared trout in some streams. The loss of trout from the stocked stream reaches represents a significant economic loss (Greene et al.
2005), a loss of recreational angling opportunities (Knapp 1996), and the potential for negative ecological interactions between hatchery-reared salmonids and native fish species (Weber and Fausch 2003 for review).

The objectives of this study were to 1) estimate recapture rate and apparent survival of hatchery-reared brook, brown, and rainbow trout in Sinking Creek and Rolling Rock Creek, 2) evaluate if apparent survival differed among brook trout, brown trout, and rainbow trout, and 3) estimate the direction and distance of dispersal for trout that had moved from the study reach where they were initially released. The results of this study provide fisheries managers utilizing hatchery-reared trout with additional insight into the management of hatchery-reared trout populations.

2.3 METHODS

2.3.1 Description of Study Sites

Two watersheds in Pennsylvania were used in the study, Rolling Rock Creek and Sinking Creek watersheds (Figure 2-1). The Rolling Rock Creek watershed covers an area of approximately 2,398 hectares on the western slope of the Laurel Hill in Westmoreland County, Pennsylvania (Figure 2-1; Figure 2-2). Rolling Rock Creek originates at the confluence of Bear Run (also referred to as McGinnis Run by previous authors) and Wildcat Run (40.17068 N, 79.18356 W) in the Laurel Highlands region of southwestern Pennsylvania and flows 8.27 km northwest to its confluence with Loyalhanna Creek (40.214053 N, 79.230692 W),
a tributary of the Conemaugh River. Bear Run has been shown to experience acid runoff episodes during times of high stream flow (pH 4.42 – 5.85; alkalinity 0.025 – 0.33 mg CaCO$_3$/L; dissolved aluminum 0.1 – 0.9 mg/L) (Schultz 1988; LeFevre and Sharpe 2002), while Wildcat Run exhibits higher water quality (pH 6.0 – 6.8; dissolved aluminum 0.01 mg/L) (Dinicola 1982; Sharpe et al. 1984). Land use in the area surrounding Rolling Rock Creek is primarily forested, with little impact from development or agriculture. Rolling Rock creek contains small populations of wild brook, brown, and rainbow trout. Only one native fish species, mottled sculpin (*Cottus bairdii*), was commonly encountered in the watershed. In addition, brook trout, brown trout, rainbow trout, and tiger trout (*Salmo trutta* X *Salvelinus fontinalis*), a sterile, intergeneric hybrid of a female brown trout and a male brook trout, are regularly stocked throughout the watershed from April through September of each year by the Rolling Rock Fishing Club. Rolling Rock Creek is maintained as a private fishing club and angling in the watershed is strongly regulated. Anglers are required to report all fish that are harvested and the total number of trout caught on each outing.
Figure 2-1: Location of the Sinking Creek and Rolling Rock Creek watersheds in Pennsylvania.
Figure 2-2: Detail of Rolling Rock Creek watershed.

The Sinking Creek watershed is located in Centre County, Pennsylvania (Figure 2-1; Figure 2-3). Sinking Creek flows approximately 31 km from its origin in Bear Meadows Bog in Rothrock State Forest (Lat: 40.729489; Long: -77.761658) to its confluence with Penn’s Creek in Spring Mills, Pennsylvania (Lat: 40.85474; Long: -77.57293). Parts of Penn’s Creek are classified as a Class A wild brown trout fishery by the PFBC. Land use is mixed throughout the
watershed, consisting of forested, agricultural, and developed tracts of land. The watershed consists of both privately and publicly owned lands. Areas of Sinking Creek that are open to the public are annually stocked with catchable size rainbow and brown trout by the PFBC beginning the first week of March, six weeks prior to the opening day of trout season in Pennsylvania. The PFBC releases approximately 3000 brown trout and rainbow trout throughout the Sinking Creek watershed each year on two separate stocking occasions. Sinking Creek supports wild populations of brown trout throughout the watershed and native brook trout are present in the headwater regions of the watershed as well as two major tributaries, Boal Gap Run and Potter Run. Other commonly encountered native fish species in the watershed include; blacknose dace (*Rhinichthys atratulus*), longnose dace (*Rhinichthys cataractae*), margined madtom (*Noturus insignis*), white sucker (*Catostomus commersonii*), northern hog sucker (*Hypentelium nigricans*), rock bass (*Ambloplites rupestris*), common shiner (*Notropis cornutus*), creek chub (*Semotilus atromaculatus*), and darters (*Etheostoma spp.*). Sinking Creek was among the streams evaluated for the residency rate of hatchery-reared trout in the 2006 PFBC study (Pierce et al. 2006). The residency rate of stocked, hatchery-reared trout on Sinking Creek was observed to be 81% and was rated as “good” by the PFBC study (Pierce et al. 2006).
Figure 2-3: Detail of the Sinking Creek watershed. Upper and lower study reaches are labeled with red circles. Two major tributaries of Sinking Creek are also included, Boal Gap Run and Potter Run.
Two study reaches were established on both Rolling Rock Creek and Sinking Creek in 2007 and used throughout the duration of the study (Figures 2-2 and 2-3). For reference purposes, the study reaches were labeled as the upper and lower study reaches for each stream (i.e. Sinking Creek upper, Sinking Creek lower, Rolling Rock upper, and Rolling Rock lower). Each of the four study reaches were approximately 300 meters in length and contained a mixture of riffle, run, and pool habitat. Study reach length was chosen to correspond with the reach lengths used in the previous studies on hatchery-reared trout residency conducted by the Pennsylvania Fish and Boat Commission (Wnuk 2005; Pierce et al. 2006). Where possible, study reaches were chosen to begin at the head of a riffle and end in a shallow riffle to facilitate greater efficiency during electrofishing surveys. As previously discussed, angling on Rolling Rock Creek was regulated and loss of trout due to angler harvest was minimal. Both study reaches on Sinking Creek were located on private property and the Sinking Creek lower study reach was closed to angling by the public to minimize loss of trout due to angler harvest. Angling on the Sinking Creek upper study reach was permitted with permission from the land owner.

2.3.2 In-stream Habitat and Environmental Variables

Stream habitat was qualified into three main habitat types; riffles, runs, and pools, as previously described by Hawkins et al. (1993). The definitions used to determine the habitat type are given in Box 2-1. The number of riffles, runs, and pools were counted for each of the four 300 meter study reaches. In
addition, the length of each riffle, run, or pool habitat type was measured in the center of the stream. Widths of the water surface were measured at a minimum of three cross-sections of each individual habitat type and an average width for each riffle, run, or pool was calculated. Water depth and water velocity using a Marsh-McBirney Flow-Mate® (Marsh McBirney, Inc., Frederick, Maryland) were recorded at the right bank, center, and left bank of the stream for each individual habitat type using a Marsh-McBirney Flow-Mate® (Marsh McBirney, Inc., Frederick, Maryland). Three cross-sections (upstream end, middle, and downstream end) were used to measure the water velocity and water depth on habitat types with lengths greater than 10 meters as described above. The variables discussed above were measured at a variety of discharges on each study reach in 2007, 2008, and 2009. Mean length, width, depth, and velocity of each riffle, run, and pool habitat type were later calculated and statistically compared for differences among the study reaches using analysis of variance (ANOVA) and Tukey’s HSD test.

**Box 2-1: Definitions of various habitat types.**

- **Riffle**: fast water; rapid, shallow stream sections with steep water surface gradients
- **Run**: shallow water flowing over a variety of different substrates; also termed “glide” or “raceway” by some authors
- **Pool**: slow, deep stream section with nearly flat water surface gradient
Streamflow was measured at the downstream end of each 300 meter study reach in 2007, 2008, and 2009 using a Marsh-McBirney Flo-Mate® (Marsh-McBirney, Inc., Frederick, Maryland) to collect water depth and water velocity at 60% depth. For each total discharge estimate, water depth and velocity were recorded at a minimum of 15 points along a cross-section of the stream. Total discharge for each site was calculated from the summation of each cross-sectional discharge. Continuous stage was recorded on Rolling Rock Creek and Sinking Creek. WL-14 pressure transducers with data logging capacity (Global Water, Gold River, California) were installed on Sinking Creek and Rolling Rock Creek and used to record hourly stage at these locations. A rating curve was developed for both streams to estimate daily total discharge for the duration of the study.

Water temperature was recorded hourly in each study reach using StowAway Tidbit® temperature loggers (Onset Corporation, Pocasset, Massachusetts). Temperature loggers were calibrated prior to being installed in the stream and were all within their expected accuracy of ±0.2°C.

Grab samples were taken periodically on each study reach at varying stream discharges to quantify water quality. Grab samples were analyzed at the water laboratory of the Pennsylvania State Institutes of Energy and the Environment on the campus of the Pennsylvania State University for pH, acid neutralizing capacity (ANC), and total dissolved aluminum, according to standard methods (Eaton et al., 1995). The pH was analyzed using an Orion 901 microprocessor ion analyzer (4500-H+ B Electrometric Method), ANC analysis
was conducted with a Radiometer Titrator using a Gran’s Titration, and total dissolved aluminum was measured with a Perkin Elmer 2380 Spectrophotometer and HGA 500 Graphite Furnace (3500-Al B Atomic Absorption spectrometric method) after filtration (0.1 µm). Water quality data for each watershed were statistically compared using a 2-sample t-test.

2.3.3 Study Organisms and Mark-Recapture Study

Three species of hatchery-reared salmonids were used for this study; brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Oncorhynchus mykiss*). Trout used in the Sinking Creek watershed were obtained from either the Elk Creek (rainbow trout) or Cedar Springs (brook trout and brown trout) fish hatchery, approximately 25 km from the study reaches. Trout from the Cedar Springs hatchery were held at the Elk Creek hatchery until processed as described below. The pH, acid neutralizing capacity, and total dissolved aluminum at the Elk Creek fish hatchery were 7.29, 2,700 µEq/l, and 0.010 mg/l, respectively. Trout used in the Rolling Rock Creek watershed were obtained from the Rolling Rock Creek fish hatchery, located within the watershed (Figure 2-2). The pH, acid neutralizing capacity, and total dissolved aluminum at the Rolling Rock Creek fish hatchery were 7.60, 1,691 µEq/l, and 0.009 mg/l, respectively.

In 2007, 2008, and 2009, 60 1+ aged trout were released evenly throughout each of the four study reaches on two separate occasions. The first release occurred the third week of April to correspond to the opening day of trout
season in Pennsylvania and the second release occurred four weeks later to simulate an in-season stocking, a common practice in Pennsylvania streams that are stocked with hatchery-reared trout. An even mix of brook trout, brown trout, and rainbow trout (20 individuals of each species) were released on each occasion in Sinking Creek in 2007, 2008, and 2009. The study reaches on Rolling Rock Creek received an even mix of the three species in 2007. Only rainbow trout were released into the Rolling Rock Creek study reaches in 2008 and 2009 to facilitate other studies (see subsequent chapters).

Prior to release, each individual trout was weighed to the nearest tenth of a gram and the total length (mm) of the fish was measured. Condition indices (Fulton’s condition factor and relative weight) were calculated for each individual from the length and mass data using Equations 2-1 and 2-2, respectively.

\[ \text{Equation 2-1:} \quad K = \frac{10^5 \times W}{L^3} \]

where \( K \) is Fulton’s condition factor, \( W \) is the mass in grams, and \( L \) is the total length of the fish in millimeters (Ricker 1975).

\[ \text{Equation 2-2:} \quad W_r = \left( \frac{W}{W_s} \right) \times 100 \]

where \( W_r \) is the relative weight, \( W \) is the observed mass of the individual, and \( W_s \) is a length-specific standard weight predicted by a weight-length regression
constructed to represent the species (Anderson and Neumann 1996). Specific weight-length regression curves from wild brook trout, brown trout, and rainbow trout were obtained from Anderson and Neumann (1996). The standard $W_r$ for an individual is 100. Values above 100 indicate individuals above the standard $W_r$ and values below 100 may indicate nutritional stress in the individual. Total length, mass, Fulton’s condition factor, and relative weight were statistically compared among species between the two hatcheries and between resident and non-resident trout using a one-way ANOVA and Tukey’s HSD test.

A T-Bar anchor tag (Floy Tag Mfg., Inc., Seattle, Washington) with a unique number for identification purposes was inserted below the dorsal fin of each individual. Each tag was printed with a contact phone number to allow anglers to notify us of captured trout. The anchor tags also were color coded for the location (study reach) and time of release (first or second release). Trout were held for 12-24 hours at the hatchery facility after processing and tagging to evaluate survival and tag retention. No mortality was observed due to the tagging procedures and the loss of the t-bar anchor tags was minimal (>1%). Trout that lost the t-bar anchor tag were retagged prior to release in the stream.

Trout were transported to the release areas by truck and the trout were acclimated to within $2^\circ$C of the current stream temperature prior to release. Trout were transferred from the transport tanks to the stream in five gallon buckets and all species were randomly and evenly distributed throughout each 300 meter study reach.
After the release of trout in each study reach, electrofishing surveys were conducted every two weeks for six weeks to evaluate the number of tagged trout remaining within the study reach. Each of the four study reaches were sampled using 12-V battery powered, pulsed direct current backpack electrofishing gear (Smith-Root, Inc., Vancouver, Washington) at two, four, and six weeks following release into the stream. Backpack electrofishing gear was operated at the minimum effective voltage and frequency to minimize injury to the fish. Single pass electrofishing effort was maintained constant between 40 and 50 minutes for each study reach and sampling occasion. A blocking seine was used on the Sinking Creek lower study reach to prohibit upstream movement of fish during electrofishing surveys. The remaining three study reaches ended in either a shallow riffle or at a large jack-dam; therefore a blocking seine was not used on these reaches.

Single-pass electrofishing was used for the entire 300 meter study reach and a minimum of 100 meters of each sampling reach was sampled using a three-pass removal technique to obtain population and biomass estimates of untagged trout in each study reach. The total length and mass of each trout captured was measured. Population and biomass estimates were made using MICROFISH 3.0 (Van Deventer and Platts 1985).

2.3.4 Survival Analyses

The Cormack-Jolly-Seber model procedure in program MARK v. 2.1 (White and Burnham 1999) was used to model the survival of hatchery-reared
trout following release into the study reaches. As previously discussed live recaptures of tagged trout were obtained at 2, 4, and 6 weeks after release into each study reach. The CJS model produces parameter estimates for recapture probability and survival. Recapture (p) is defined as the probability that an individual trout will be recaptured during each electrofishing survey. The survival parameter (φ) is defined as the probability of an individual trout surviving and remaining on the study area between sampling periods (defined as two week intervals for this study). The survival parameter is an estimate of apparent survival and incorporates both mortality and dispersal of individuals between sampling occasions.

A set of forty a priori candidate models were fitted to estimate the apparent survival of tagged trout. The a priori models incorporated study reach, species, and time as grouping variables for apparent survival and recapture probability. Akaike’s information criterion corrected for small sample size (AICc; Akaike 1973), ΔAIC, and Akaike weights (Burnham and Anderson 2002) were calculated and used to select the model that best described trout survival. Survival rates and log-normal 95% confidence intervals were calculated.

2.3.5 Dispersal Direction and Distance

Anglers were asked to report the tag number, tag color, the date of capture or harvest, and location where the trout was recaptured. Anglers were also asked to report if the trout was released unharmed or harvested. Angler returns of tagged trout were used to estimate the dispersal distance of tagged
trout beyond the study reaches and assess apparent survival in areas where electrofishing efficiency may have been low (ex. deep pools). In addition to angler returns, spot-electrofishing surveys were also used to recapture tagged trout that had dispersed to various points on the watershed. Spot-electrofishing surveys were conducted at several locations, including sites upstream and downstream of the study reaches. Global positioning system (GPS) coordinates were recorded at the middle of the stream for each location of recapture and geographic information software (ArcView Version 9.3.1) was used to measure the distance traveled by an individual trout from its original release point to the location of recapture (ESRI 2009).

2.4 RESULTS

2.4.1 In-stream Habitat, Environmental Variables, and Water Quality

Each study reach contained a mixture of riffle, run, and pool habitat types. The results of the habitat measurements made for the present study are given in Table 2-1. Daily discharge (cfs⁻¹) and maximum daily water temperatures (°C) for the duration of the study are shown in Figures 2-4 and 2-5.

The pH, ANC and TDAI of Rolling Rock Creek had means (± standard deviation) of 6.84 (± 0.35), 229.55 (± 274.35) μEq/l, and 0.03 (± 0.02) mg Al/l, respectively. The pH of Rolling Rock Creek ranged from 6.05 to 7.60. Acid neutralizing capacity ranged from a minimum of 7.0 to 1691 μEq/l and TDAI
ranged from 0 to 0.09 mg Al/l on Rolling Rock Creek. The minimum values of pH and ANC and maximum value of TDAI were observed during periods of high stream discharge. Acid neutralizing capacity and pH of Rolling Rock Creek were lower ($p < 0.05$) than the ANC and pH of Sinking Creek. There was no statistically significant difference between the TDAI of Rolling Rock Creek and Sinking Creek ($p = 0.78$). Sinking Creek pH, ANC, and TDAI had means ($\pm$ standard deviation) of 7.49 ($\pm$ 0.2), 881.22 ($\pm$ 102.51) $\mu$Eq/l, and 0.03 ($\pm$ 0.02) mg Al/l, respectively. Sinking Creek pH ranged from 7.11 to 7.77, ANC ranged from 719.0 to 1,027.0 $\mu$Eq/l, and TDAI ranged from 0.02 to 0.07 mg Al/l.
Table 2-1: Summary of habitat variables on each of the four study reaches.

Mean values are given with standard deviation in parentheses. RR = Rolling Rock, SC = Sinking Creek.

<table>
<thead>
<tr>
<th>Habitat Type</th>
<th>Study Reach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RR UPPER</td>
</tr>
<tr>
<td>% Habitat (% of Total Reach Length)</td>
<td></td>
</tr>
<tr>
<td>Riffle</td>
<td>50.2</td>
</tr>
<tr>
<td>Run</td>
<td>39.9</td>
</tr>
<tr>
<td>Pool</td>
<td>9.9</td>
</tr>
<tr>
<td>Mean Widths (m)</td>
<td></td>
</tr>
<tr>
<td>All Habitats</td>
<td>7.6 (1.5)</td>
</tr>
<tr>
<td>Riffle</td>
<td>6.5 (0.9)</td>
</tr>
<tr>
<td>Run</td>
<td>7.3 (0.9)</td>
</tr>
<tr>
<td>Pool</td>
<td>8.7 (1.6)</td>
</tr>
<tr>
<td>Mean Depth (ft)</td>
<td></td>
</tr>
<tr>
<td>All Habitats</td>
<td>1.5 (1.0)</td>
</tr>
<tr>
<td>Riffle</td>
<td>0.5 (0.1)</td>
</tr>
<tr>
<td>Run</td>
<td>1.2 (0.2)</td>
</tr>
<tr>
<td>Pool</td>
<td>2.7 (0.6)</td>
</tr>
<tr>
<td>Mean Velocity (m/s)</td>
<td></td>
</tr>
<tr>
<td>All Habitats</td>
<td>0.4 (0.5)</td>
</tr>
<tr>
<td>Riffle</td>
<td>1.0 (0.3)</td>
</tr>
<tr>
<td>Run</td>
<td>0.2 (0.2)</td>
</tr>
<tr>
<td>Pool</td>
<td>0.1 (0.1)</td>
</tr>
<tr>
<td>Maximum Width (m)</td>
<td></td>
</tr>
<tr>
<td>All Habitats</td>
<td>11.8</td>
</tr>
<tr>
<td>Riffle</td>
<td>7.4</td>
</tr>
<tr>
<td>Run</td>
<td>8.6</td>
</tr>
<tr>
<td>Pool</td>
<td>11.8</td>
</tr>
<tr>
<td>Maximum Depth (ft)</td>
<td></td>
</tr>
<tr>
<td>All Habitats</td>
<td>4.0</td>
</tr>
<tr>
<td>Riffle</td>
<td>0.9</td>
</tr>
<tr>
<td>Run</td>
<td>1.7</td>
</tr>
<tr>
<td>Pool</td>
<td>4.0</td>
</tr>
<tr>
<td>Maximum Velocity (m/s)</td>
<td></td>
</tr>
<tr>
<td>All Habitats</td>
<td>1.8</td>
</tr>
<tr>
<td>Riffle</td>
<td>1.8</td>
</tr>
<tr>
<td>Run</td>
<td>0.7</td>
</tr>
<tr>
<td>Pool</td>
<td>0.8</td>
</tr>
<tr>
<td>Minimum Width (m)</td>
<td></td>
</tr>
<tr>
<td>All Habitats</td>
<td>5.1</td>
</tr>
<tr>
<td>Riffle</td>
<td>5.1</td>
</tr>
<tr>
<td>Run</td>
<td>5.1</td>
</tr>
<tr>
<td>Pool</td>
<td>6.5</td>
</tr>
<tr>
<td>Minimum Depth (ft)</td>
<td></td>
</tr>
<tr>
<td>All Habitats</td>
<td>0.3</td>
</tr>
<tr>
<td>Riffle</td>
<td>0.7</td>
</tr>
<tr>
<td>Run</td>
<td>0.8</td>
</tr>
<tr>
<td>Pool</td>
<td>1.6</td>
</tr>
<tr>
<td>Minimum Velocity (m/s)</td>
<td></td>
</tr>
<tr>
<td>All Habitats</td>
<td>-0.3</td>
</tr>
<tr>
<td>Riffle</td>
<td>-0.3</td>
</tr>
<tr>
<td>Run</td>
<td>-0.1</td>
</tr>
<tr>
<td>Pool</td>
<td>-0.2</td>
</tr>
</tbody>
</table>
Figure 2-4: Stream discharge (cubic feet per second; cfs\(^1\)) for a) Sinking Creek and b) Rolling Rock Creek for the length of the study period. The vertical lines indicate the time of the first and second release of trout into Sinking Creek and Rolling Rock Creek. Sixty trout were released into each of the four study reaches at the time of each release in 2007, 2008, and 2009.
Figure 2-5: Maximum daily water temperatures for Sinking Creek and Rolling Rock Creek. The red bar indicates the nominal upper thermal tolerance limit of brook, brown, and rainbow trout. Data are from the temperature logger located on the lower study reach of each stream.
2.4.2 Recapture and Apparent Survival of Hatchery-reared Trout

Electrofishing surveys were conducted at two week intervals for a total of six weeks after trout were release into the four study reaches. Table 2-2 summarizes the total trout population and biomass estimates from each study reach. The density of trout and trout biomass were the greatest on the Rolling Rock lower study reach. The Sinking Creek lower study reach had the lowest observed densities and biomass of trout. Density and biomass were relatively constant for each study reach throughout the duration of the study.

Table 2-2: Population and biomass estimates for each study reach.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Site</th>
<th>Trout Population Estimates (trout/ha)</th>
<th>Biomass (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower 95% C.I.</td>
<td>Mean</td>
</tr>
<tr>
<td>Sinking Creek</td>
<td>Upper</td>
<td>258.8</td>
<td>301.5</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>144.6</td>
<td>154.4</td>
</tr>
<tr>
<td>Rolling Rock Creek</td>
<td>Upper</td>
<td>356.9</td>
<td>371.8</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>645.2</td>
<td>657.7</td>
</tr>
</tbody>
</table>
The results of the Cormack-Jolly-Seber model selection for survival rate ($\varphi$) and recapture probability ($p$) are shown in Table 2-3. The best fit for apparent survival and recapture probability was the model in which apparent survival and recapture probability varied over time (2, 4, and 6 weeks) and by site (study reach) ($\varphi$(site x time) $p$ (site x time)). The parameter estimates ($\pm$ standard error) for the best model are given in Table 3-4. There was little support for the next best model ($\varphi$(time) $p$(site x time)) (Table 3-3). Survival for the first two week interval after release was under 50% for the Rolling Rock Upper, Sinking Creek Upper, and Sinking Creek Lower site (44.3%, 42.3%, and 19.9%, respectively; see Table 3-4). The Rolling Rock Lower site had the highest survival rate (63.3%, 95% CI = 29.2 – 87.8%) during the first two weeks of initial release (Table 3-4). Survival increased on all sites with the exception of Rolling Rock lower over the next 4 week period (Table 3-4). Survival rate did not vary among the three species of trout.
Table 2-3: Candidate models of apparent survival rate (φ) and recapture probability (p). Akaike’s information criterion corrected for small sample size (AICc) was used to select the best candidate model describing apparent survival of tagged trout. The number of parameters estimated (k) for each of the candidate models, AICc, ΔAIC, and the AICc weight are given.
<table>
<thead>
<tr>
<th>Model</th>
<th>k</th>
<th>AICc</th>
<th>Delta AICc</th>
<th>AICc Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi(\text{site} \times \text{time}) \ p(\text{site} \times \text{time})$</td>
<td>32</td>
<td>2662.73</td>
<td>0.00</td>
<td>0.99</td>
</tr>
<tr>
<td>$\phi(\text{time}) \ p(\text{site} \times \text{time})$</td>
<td>20</td>
<td>2671.74</td>
<td>9.02</td>
<td>0.01</td>
</tr>
<tr>
<td>$\phi(\text{species} \times \text{time}) \ p(\text{site} \times \text{time})$</td>
<td>28</td>
<td>2682.31</td>
<td>15.59</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species} \times \text{time}) \ p(\text{site} \times \text{time})$</td>
<td>64</td>
<td>2683.04</td>
<td>20.31</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species}) \ p(\text{site} \times \text{time})$</td>
<td>20</td>
<td>2684.47</td>
<td>21.74</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species} \times \text{time}) \ p(\text{site} \times \text{time})$</td>
<td>28</td>
<td>2687.87</td>
<td>25.15</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{species}) \ p(\text{site} \times \text{time})$</td>
<td>19</td>
<td>2689.64</td>
<td>26.91</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(.) \ p(\text{site} \times \text{time})$</td>
<td>17</td>
<td>2690.72</td>
<td>27.99</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{time}) \ p(.)$</td>
<td>19</td>
<td>2693.74</td>
<td>31.01</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{time}) \ p(\text{site})$</td>
<td>20</td>
<td>2695.78</td>
<td>33.06</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species} \times \text{time}) \ p(\text{site} \times \text{time})$</td>
<td>64</td>
<td>2698.05</td>
<td>35.32</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{time}) \ p(\text{site})$</td>
<td>8</td>
<td>2699.51</td>
<td>36.79</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{time}) \ p(\text{site} \times \text{species} \times \text{time})$</td>
<td>52</td>
<td>2701.81</td>
<td>39.08</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{species} \times \text{time}) \ p(\text{site})$</td>
<td>16</td>
<td>2703.89</td>
<td>41.6</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{time}) \ p(\text{site} \times \text{species})$</td>
<td>28</td>
<td>2705.05</td>
<td>42.33</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{time}) \ p(\text{site} \times \text{species} \times \text{time})$</td>
<td>16</td>
<td>2706.85</td>
<td>44.13</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{species} \times \text{time}) \ p(\text{site} \times \text{species} \times \text{time})$</td>
<td>60</td>
<td>2708.10</td>
<td>45.37</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{species} \times \text{time}) \ p(\text{site} \times \text{species})$</td>
<td>24</td>
<td>2711.16</td>
<td>48.43</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species} \times \text{time}) \ p(\text{site} \times \text{time})$</td>
<td>52</td>
<td>2716.89</td>
<td>54.16</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{species} \times \text{time}) \ p(\text{site} \times \text{species})$</td>
<td>49</td>
<td>2721.47</td>
<td>58.74</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species} \times \text{time}) \ p(\text{site} \times \text{species})$</td>
<td>51</td>
<td>2721.99</td>
<td>59.26</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species} \times \text{time}) \ p(\text{site} \times \text{species} \times \text{time})$</td>
<td>60</td>
<td>2723.88</td>
<td>61.15</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species}) \ p(\text{site} \times \text{species} \times \text{time})$</td>
<td>52</td>
<td>2726.53</td>
<td>63.8</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species} \times \text{time}) \ p(\text{site} \times \text{species} \times \text{time})$</td>
<td>96</td>
<td>2731.43</td>
<td>68.7</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species} \times \text{time}) \ p(\text{site} \times \text{species} \times \text{time})$</td>
<td>60</td>
<td>2734.82</td>
<td>72.1</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{time}) \ p(.)$</td>
<td>17</td>
<td>2751.53</td>
<td>88.80</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{time}) \ p(.)$</td>
<td>5</td>
<td>2766.60</td>
<td>103.87</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{species} \times \text{time}) \ p(.)$</td>
<td>13</td>
<td>2773.18</td>
<td>110.45</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species} \times \text{time}) \ p(.)$</td>
<td>49</td>
<td>2780.26</td>
<td>117.53</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{species} \times \text{time}) \ p(\text{site} \times \text{species})$</td>
<td>15</td>
<td>2827.38</td>
<td>164.65</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{species}) \ p(\text{site})$</td>
<td>7</td>
<td>2828.33</td>
<td>165.61</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species}) \ p(\text{site})$</td>
<td>16</td>
<td>2830.33</td>
<td>167.60</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site}) \ p(\text{site})$</td>
<td>8</td>
<td>2830.96</td>
<td>168.23</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site}) \ p(\text{site} \times \text{species})$</td>
<td>16</td>
<td>2831.08</td>
<td>168.35</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(.) \ p(\text{site} \times \text{species})$</td>
<td>13</td>
<td>2833.49</td>
<td>170.77</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(.) \ p(\text{site})$</td>
<td>5</td>
<td>2834.97</td>
<td>172.24</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site} \times \text{species}) \ p(\text{site} \times \text{species})$</td>
<td>24</td>
<td>2836.87</td>
<td>174.15</td>
<td>0.00</td>
</tr>
<tr>
<td>$\phi(\text{site}) \ p(.)$</td>
<td>5</td>
<td>2915.32</td>
<td>252.59</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Table 3-4: Parameter estimates (standard error) for apparent survival (φ) and recapture probability (p) from the model φ (site x time) p (site x time).

<table>
<thead>
<tr>
<th>Time Interval (weeks)</th>
<th>Rolling Rock Upper</th>
<th>Rolling Rock Lower</th>
<th>Sinking Creek Upper</th>
<th>Sinking Creek Lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survival (φ)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-2</td>
<td>0.44 (0.11)</td>
<td>0.63 (0.17)</td>
<td>0.42 (0.04)</td>
<td>0.20 (0.03)</td>
</tr>
<tr>
<td>2-4</td>
<td>0.48 (0.14)</td>
<td>0.50 (0.18)</td>
<td>0.78 (0.08)</td>
<td>0.80 (0.16)</td>
</tr>
<tr>
<td>4-6</td>
<td>0.93 (0.21)</td>
<td>0.41 (0.11)</td>
<td>0.68 (0.07)</td>
<td>0.72 (0.15)</td>
</tr>
<tr>
<td>Recapture (p)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-2</td>
<td>0.18 (0.05)</td>
<td>0.15 (0.05)</td>
<td>0.60 (0.06)</td>
<td>0.50 (0.09)</td>
</tr>
<tr>
<td>2-4</td>
<td>0.25 (0.06)</td>
<td>0.22 (0.06)</td>
<td>0.59 (0.07)</td>
<td>0.42 (0.10)</td>
</tr>
<tr>
<td>4-6</td>
<td>0.46 (0.09)</td>
<td>0.77 (0.09)</td>
<td>0.92 (0.04)</td>
<td>0.65 (0.12)</td>
</tr>
</tbody>
</table>

The mean length, mass, Fulton’s condition factor, and relative weight of hatchery-reared trout released into Rolling Rock and Sinking Creeks in the present study are given in Table 2-4. Statistical comparisons were made among the three species of trout released into Rolling Rock Creek and Sinking Creek. The three species of trout obtained from the Elk Creek fish hatchery and released into Sinking Creek varied significantly (p < 0.05) among each species in terms of total length and mass (Table 2-4). Rainbow trout from the Elk Creek fish hatchery were found to have a greater mean Fulton’s condition factor and relative weight than brook trout and brown trout from the Cedar Springs hatchery (Table
Trout obtained from the Rolling Rock Creek fish hatchery and released into Rolling Rock Creek also varied among species. Brook trout from the Rolling Rock Creek fish hatchery had a greater total length than brown trout and rainbow trout from the same hatchery. Rainbow trout and brook trout had a greater mass, than brown trout released into Rolling Rock Creek. Fulton’s condition factor and relative weight of rainbow trout was greater than that of brook trout and brown trout.

Statistical comparisons of length, mass, condition factor, and relative weight also were made between resident and non-resident trout (Table 2-5). Resident trout were considered to be trout recaptured within the 300 meter study reach of initial release by electrofishing surveys or by angling. Non-resident trout were trout left the study reach of initial release. Differences between mean total length and mass of resident and non-resident trout were statistically significant (Table 2-5), with resident trout averaging lower total length and mass. No statistically significant differences were observed between the condition factor and the relative weight of resident and non-resident trout (Table 2-5).
Table 2-5: Mean (± standard deviation) length, mass, Fulton’s condition factor (K), and relative weight (W_r) of trout released into Rolling Rock Creek and Sinking Creek (n = 1,410). Superscripted letters denote statistical differences at p < 0.05. Statistical comparisons were made among species within each stream.

### Sinking Creek (Elk Creek and Cedar Springs Fish Hatcheries)

<table>
<thead>
<tr>
<th>Species</th>
<th>Total Length (mm)</th>
<th>Mass (g)</th>
<th>K</th>
<th>W_r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brook</td>
<td>235.7 (41.6) a</td>
<td>213.8 (50.3) a</td>
<td>2.29 (2.60) a</td>
<td>222.0 (257.3) a</td>
</tr>
<tr>
<td>Brown</td>
<td>225.2 (41.0) b</td>
<td>201.7 (59.4) b</td>
<td>2.48 (3.19) a</td>
<td>224.9 (283.2) a</td>
</tr>
<tr>
<td>Rainbow</td>
<td>260.9 (28.9) c</td>
<td>258.1 (27.0) c</td>
<td>1.60 (0.80) b</td>
<td>148.0 (74.9) b</td>
</tr>
</tbody>
</table>

### Rolling Rock Creek (Rolling Rock Creek Fish Hatchery)

<table>
<thead>
<tr>
<th>Species</th>
<th>Total Length (mm)</th>
<th>Mass (g)</th>
<th>K</th>
<th>W_r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brook</td>
<td>276.5 (22.5) a</td>
<td>268.4 (57.0) a</td>
<td>1.27 (0.23) a</td>
<td>121.1 (21.8) a</td>
</tr>
<tr>
<td>Brown</td>
<td>246.6 (18.1) b</td>
<td>193.1 (37.5) b</td>
<td>1.28 (0.15) a</td>
<td>117.4 (13.5) a</td>
</tr>
<tr>
<td>Rainbow</td>
<td>248.3 (59.7) b</td>
<td>282.3 (41.8) a</td>
<td>2.74 (2.86) b</td>
<td>254.1 (268.7) b</td>
</tr>
</tbody>
</table>
Table 2-6: Mean (± standard deviation) total length, mass, condition factor (K) and relative weight (W_r) of resident and non-resident trout. Means were compared using a student’s t-test.

<table>
<thead>
<tr>
<th></th>
<th>Resident</th>
<th>Non-Resident</th>
<th>T</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Length (mm)</td>
<td>240.5 (43.4)</td>
<td>248.6 (47.0)</td>
<td>3.03</td>
<td>0.003</td>
</tr>
<tr>
<td>Mass (g)</td>
<td>228.7 (57.6)</td>
<td>250.6 (55.2)</td>
<td>6.37</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>K</td>
<td>2.18 (2.25)</td>
<td>2.21 (2.64)</td>
<td>0.19</td>
<td>0.848</td>
</tr>
<tr>
<td>W_r</td>
<td>203.6 (214.3)</td>
<td>205.3 (243.2)</td>
<td>0.13</td>
<td>0.898</td>
</tr>
</tbody>
</table>

2.4.3 Dispersal of Hatchery-reared Trout

A total of 146 tagged trout were confirmed to have dispersed beyond the study reach where the trout was initially released by spot electrofishing surveys and angler reports. The majority of movements occurred in the downstream direction of the study reach of initial release (115 out of 146; 78.8%). Movements in the upstream direction accounted for 21.2% (31 of 146) of the trout confirmed to disperse.

For Rolling Rock Creek, the majority of dispersing trout were recaptured within the Rolling Rock watershed. However, several trout were captured in Loyalhanna Creek, downstream of its confluence with Rolling Rock Creek. One individual was recaptured by an angler in Linn Run, the watershed adjacent to
the Rolling Rock Creek watershed. Figure 2-9 shows the recapture locations of individual trout release in Rolling Rock Creek. The mean distance moved by recaptured dispersing trout released in Rolling Rock Creek was 5.22 km (standard deviation = 1.66 km). The minimum and maximum distances moved by recaptured trout released in Rolling Rock Creek were 0.62 km and 29.77 km, respectively, from the center of the study reach where the trout was originally released. Figure 2-10 shows the recapture locations of individual trout released in Sinking Creek. The minimum and maximum distances moved by recaptured trout released in Sinking Creek were 0.04 and 27.29 km, respectively. The mean (± standard error) distance moved by recaptured dispersing trout released into Sinking Creek was 2.32 (± 1.02) km.
Figure 2-6: Recapture locations of tagged trout originally released in the upper and lower study reaches of Rolling Rock Creek. Green squares represent trout released in the upper study reach and pink triangles represent trout released in the lower study reach. Multiple trout were captured at these locations. Arrows and numbers represent the number of trout caught at each location. A total of 29 trout were recaptured within the Rolling Rock watershed.
Figure 2-7: Recapture locations (red triangles) of tagged trout originally released in the upper and lower study reaches of Sinking Creek. Trout from both study reaches were recaptured at each of these locations. Multiple trout were captured at these locations. The Sinking Creek watershed is outlined in beige. Arrows and numbers represent the number of trout captured at the indicated location.
2.5 DISCUSSION

The results of this study indicated that the majority of hatchery-reared trout were lost from the study reaches following release into fluvial systems, a major concern for fisheries managers attempting to manage populations of hatchery-reared trout for recreational angling or re-establishment of wild trout populations. The loss of hatchery-reared trout from the site of initial release has been previously documented (see Cresswell 1981 for review). High discharge events (Erman and Leidy 1975; Heggenes 1988; Clapp et al. 1990), unfavorable water temperatures (Wnuk 2005), acidic water conditions (Gagen et al. 1993; Baker et al. 1996; Baldigo and Murdoch 1997), inadequate pool habitat (Hearn 1987), high stocking densities (North et al. 2006), species differences (Wnuk 2005), predation (see Chapter 5; Parkhurst et al. 1992; Dieperink et al. 2001), increased stress from transport and release (Schreck 1989), and behavioral differences in populations of hatchery-reared trout (see Chapter 3) have been suggested as possible causes for the post-stocking loss of hatchery-reared trout. A single cause for the loss has not been identified.

Adequate water quality including favorable water temperatures in the stream receiving hatchery-reared trout are probably the most important criteria for their post-stocking survival. Low pH coupled with high concentrations of total dissolved aluminum has been shown to cause movement and mortality in salmonids (Gagen et al. 1993; Baker et al. 1996; Baldigo and Murdoch 1997). These conditions are typical of streams in Pennsylvania that are prone to acid
episodes during periods of high discharge (Gagen et al. 1993; Baker et al. 1996). Baker (1982) determined the threshold concentration of total dissolved aluminum for brook trout to be 0.2 mg/L and Baker et al. (1996) observed net downstream movements of brook trout caused by poor water quality (pH and total dissolved aluminum) during acid episodes. The highest concentrations of total dissolved aluminum observed in the present study were during periods of high discharge on Rolling Rock Creek. Observed concentrations of total dissolved aluminum in the present study were not above the 0.2 mg/L threshold, however sublethal concentrations may induce movements in salmonids due to increased physiological stress related to acidic waters. Changes in water quality in Rolling Rock Creek may have caused a portion of the loss of hatchery-reared trout in the watershed. However, the loss of trout continued during periods of low discharge and adequate water quality, indicating that this was not the primary mechanism causing the loss of trout. The Sinking Creek watershed is well buffered against acidity (mean ANC of 881.22 µEq/l), therefore poor water quality was unlikely a cause of the loss of hatchery-reared trout in this watershed. In addition, survival was not shown to differ among the study reaches, suggesting that variations in habitat and water quality among the study reaches were not the primary cause of post-stocking loss of hatchery-reared trout.

The upper temperature tolerance of trout varies by the length of exposure and temperature fluctuations, but generally ranges between 21°C and 27°C (Wehrly et al. 2007). Water temperatures during the study period were generally within the thermal tolerance of trout. High water temperatures were observed on
Sinking Creek near the end of the study period most years, however, the majority of the loss of hatchery-reared trout released in the watershed had occurred prior to the observed increase in water temperature. Minimum water temperatures at the time of stocking are also a concern (Brett 1956) because stocking operations in Pennsylvania typically begin the first week of March each year. Some studies have shown that hatchery-reared trout move downstream when water temperatures are below 10°C. Wnuk (2005) evaluated minimum stream temperatures and acclimation of fish to stream water temperatures at the time of stocking as a possible cause of the loss of hatchery-reared trout but the results were inconclusive. He concluded that acclimation to water temperatures was not a factor influencing the movement of hatchery-reared trout.

However, the Wnuk (2005) study did indicate a difference in post-stock movement among brook trout, brown trout, and rainbow trout. Rainbow trout were observed to leave the stocking area within the first three days of stocking. Brown trout and brook trout remained within the stocking area for a longer period of time, but the loss of all species was high (0.001% return rate of 4,000 tagged trout) within the 10 day time period of the study. The results of this study showed no differences in residency or recapture rates among brook trout, brown trout, and rainbow trout within the study reach where the trout were initially released. However, species differences in movement times may be detectable within a shorter time period (see Chapter 4). In the present study, the three species of trout were lost from the study reach of initial release at a similar rate within the first two weeks of release and losses continued throughout the six week duration.
of each study period. Therefore, manipulating the proportion of species stocked to favor one species or another is unlikely to reduce the loss of hatchery-reared trout or increase residency within stocked reaches of a particular stream. Based on the results of this study and the others presented, angling should be permitted on stream reaches immediately following the release of hatchery-reared trout to maximize harvest rates and utilization of the hatchery trout resource.

It is well documented that hatchery-reared salmonids perform less well in the wild than wild salmonids. Trout with higher growth rates are typically selected for in the hatchery. In the present study, trout remaining within the study reach where they were initially released were found to have lower total length and mass than trout that had dispersed away from the study reach. Trout with higher growth rates have been shown to exhibit decreased aerobic swimming performance (Gregory and Wood 1999), which may influence their performance in the wild at higher water velocities than those in the hatchery. Hatchery trout are typically reared in conditions with near zero water velocity, at high densities, and are fed ad libitum. The combination of these conditions may lead to fish with less muscle composition than wild trout. Hatchery-reared trout in the present study were observed to have much higher relative weights (mean $W_r$ of 204) than what would be expected for the wild counterpart of each species ($W_r$ of approximately 100). Although not directly examined in this study, it would be expected that these trout had a higher fat content than wild trout. Rearing fish at lower densities and slightly higher water velocities (approximately 4 cm/s) has resulted in significant increases in the muscle composition and aerobic swimming
ability of salmonids (McDonald et al. 1998). A change in the current hatchery practices towards rearing trout closer to the condition of wild trout may increase muscle composition and swimming performance of hatchery-reared trout once released in the wild, possibly increasing the survival and residency of trout in the wild. However, prior to any changes being adopted, further research is needed to evaluate if changes in hatchery management would increase the residency rates and survival of hatchery-reared trout in the wild.

The results of this study indicated that hatchery-reared trout disperse throughout the watershed where they are released as well as over longer distances to adjacent watersheds. Dispersal of hatchery-reared trout away from the site of initial release may decrease recreational angling opportunities if trout move to areas closed to angling. High rates of dispersal and low survival may also reduce the potential to re-establish a trout fishery for a given watershed. In addition, dispersal may increase ecological interactions such as the spread of disease, increased competition for resources and interbreeding with wild trout and other native fishes (White et al. 1995). The movement of hatchery-reared trout was predominately downstream, as suggested by other studies (Bjornn and Mallet 1964; Cresswell 1981; Helfrich and Kendall 1982). However, dispersal upstream of the site of release also was documented. Therefore, limiting the release of hatchery-reared trout to sites downstream of wild trout populations will not necessarily prohibit ecological interactions between hatchery and wild populations as previously thought.
Dispersal was unlikely the only cause of the loss of hatchery-reared trout from the original release sites. Predation of hatchery-reared trout in the hatchery is known to occur at a high rate (Glahn et al. 1999; Dieperink et al. 2001) and it is likely that a large number of the trout unaccounted for in the present study were predated. Predators of adult trout were observed within each study watershed and included; the belted kingfisher (*Ceryle alcyon*), American crow (*Corvus brachyrhynchos*), osprey (*Pandion haliaetus*), green-backed heron (*Butorides striatus*), great blue heron (*Ardea herodias*), mallard duck (*Anas platyrhynchos*), muskrat (*Ondatra zibethicus*), mink (*Neovison vison*), snapping turtle (*Chelydra serpentine*), chain pickerel (*Esox niger*), northern water snake (*Nerodia sipedon*), and larger trout. Predation of hatchery-reared trout in the wild by great blue herons is examined in Chapter 5.

In conclusion, based on the results of this study and the relevant scientific literature, fishery managers utilizing hatchery-reared trout should expect high post-stockling loss of these trout. In situations where hatchery-reared trout are used to enhance recreational angling opportunities, streams should be open to angling at the time of stocking to optimize harvest rates of hatchery-reared trout. Fishery managers may also want to consider more frequent stockings of smaller numbers of fish as opposed to less frequent stockings of large numbers of fish. Prior to the release of hatchery-reared trout, water quality for each area of release should be evaluated, especially during high discharge events in areas prone to the effects of acidic deposition, such as high elevation sites with a sandstone parent material. Hatcheries may also be able to manipulate rearing
conditions to favor fish better adapted to the conditions they will experience after release into the wild, which may increase survival and residency rates of the trout released. Further research is needed to evaluate the effectiveness of rearing trout with a condition closer to that of wild trout.

### 2.6 LITERATURE CITED


Chapter 3

Behavioral Characteristics of Individual Hatchery-Reared Trout as a Determinate of Their Post-Stocking Dispersal

3.1 ABSTRACT

The release of hatchery-reared trout is a common practice in the United States for recreational purposes and the restoration of cold-water fisheries. The dispersal of hatchery-reared trout from the area of initial release has become a concern among fishery managers. Dispersal may cause a loss of recreational benefit and/or an increase in the potential of negative interactions among hatchery-reared trout and wild fishes. Understanding the causes of post-stocking dispersal may lead to more effective fishery management in cold-water ecosystems. The purpose of this study was to investigate the role of individual behavior in the dispersal of hatchery-reared trout. Behavioral observations were conducted on individual trout determined to be either residents (individuals remaining within a 300 meter study area of initial release for a minimum of six weeks) or non-residents (individuals dispersing beyond study reach of initial release). Behavioral differences between brook, brown, and rainbow trout were also investigated. Movements of non-resident trout ranged from 0.62 km to 29.77 km from the point of initial release. There were no statistically significant correlations between behavioral characteristics and the distance that an individual trout dispersed. Resident trout were found to move more often and for longer periods of time than non-resident trout during behavioral observations.
Resident trout were also found to be more aggressive than non-resident trout. Classification and regression tree (CART) analysis was used to classify individual trout as either resident or non-resident based on the observed behavioral characteristics and correctly predicted the residency status of 57 of the 72 (79.2%) individuals used in the study.

### 3.2 INTRODUCTION

The release of hatchery-reared fishes, particularly salmonids, has become a standard practice in fisheries management (Cowx 1994). Salmonids and other fishes are typically released for the purposes of mitigation or restoration of cold-water fisheries, enhancement of an existing fishery, the creation of a new fishery, or increased recreational angling opportunities (Hickley 1994). Hatchery-rearing has led to the domestication of several species of fish (Ruzzante 1994).

Domestication of a species invokes an evolutionary response due to changes in gene frequencies from selectively breeding for favorable phenotypic traits (Ruzzante 1994). Hatchery-reared fish are typically selected for a high growth rate, decreased age at maturation, increased egg production, and disease resistance (Hynes et al. 1981). However, because single traits generally do not evolve in isolation, pleiotropy (a single gene influencing multiple phenotypic traits) is common (Ruzzante 1994; Falconer 1996). In addition to changes in gene frequencies, hatchery-reared fish also are subject to natural selection in the rearing environment (Doyle 1983). Behavioral traits are typically
among the first traits to be affected by the domestication process (Mayr, 1963; Kohane and Parsons 1988).

The majority of studies examining behavior in hatchery-reared salmonids have concentrated on understanding the differences in behavior (specifically agonistic behavior) between hatchery-reared and wild salmonids. Differences in agonistic behaviors (bites, nips, chases, charges, lateral or frontal displays, etc.) have been observed between hatchery-reared and wild salmonids. Table 3.1 summarizes the major studies comparing behavioral traits, predominantly agonistic encounters, between hatchery-reared and wild salmonids. Many studies have concluded that hatchery-reared trout tend to be more aggressive than their wild counterparts, although some studies have suggested that wild salmonids are better competitors than hatchery-reared individuals (Table 3.1).
Table 3-0-1: Summary of selected studies comparing behavioral traits between hatchery-reared and wild salmonids.

<table>
<thead>
<tr>
<th>Citation</th>
<th>Species</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deverill et al. (1999)</td>
<td>brown trout (Salmo trutta)</td>
<td>introduced hatchery trout more aggressive than introduced wild trout; established wild brown trout initiated 44% of aggressive encounters, 34% initiated by hatchery-reared trout, and 22% by introduced wild trout</td>
</tr>
<tr>
<td>Fenderson &amp; Carpenter (1971)</td>
<td>Atlantic salmon (Salmo salar)</td>
<td>wild Atlantic salmon were most aggressive at low densities; hatchery salmon were most aggressive at high or intermediate densities</td>
</tr>
<tr>
<td>Holm &amp; Femo (1986)</td>
<td>Atlantic salmon (Salmo salar)</td>
<td>hatchery-reared Atlantic salmon parr were less aggressive than wild Atlantic salmon parr</td>
</tr>
<tr>
<td>Mesa (1991)</td>
<td>cutthroat trout (Oncorhynchus clarki)</td>
<td>increased aggression in hatchery-reared trout compared to wild trout</td>
</tr>
<tr>
<td>Metcalfe et al. (2003)</td>
<td>Atlantic salmon (Salmo salar)</td>
<td>domesticated fish were generally more dominant over wild-origin fish when raised in a common hatchery environment; however wild fish were more dominant if given a 2 day residence period in the stream</td>
</tr>
<tr>
<td>Moyle (1969)</td>
<td>brook trout (Salvelinus fontinalis)</td>
<td>hatchery-reared brook trout were more aggressive than wild brook trout</td>
</tr>
<tr>
<td>Rhodes &amp; Quinn (1998)</td>
<td>coho salmon (Oncorhynchus kisutch)</td>
<td>hatchery-reared salmon dominant over naturally spawned salmon; greater size and rearing experience of hatchery produced salmon were sufficient to overcome a wild salmon's advantage of prior residence</td>
</tr>
<tr>
<td>Sundstrom et al. (2003)</td>
<td>brown trout (Salmo trutta)</td>
<td>hatchery environment produced more aggressive individuals; pairs of hatchery trout initiated contests sooner, fought longer and were more aggressive during the contest than pairs of wild trout</td>
</tr>
<tr>
<td>Swain &amp; Riddell (1990)</td>
<td>coho salmon (Oncorhynchus kisutch)</td>
<td>increased aggression in hatchery-reared salmon compared to wild salmon</td>
</tr>
<tr>
<td>Tatara et al. (2008)</td>
<td>steelhead/rainbow trout (Oncorhynchus mykiss)</td>
<td>no differences in rates of aggression between steelhead reared in natural or hatchery conditions</td>
</tr>
<tr>
<td>Wessel et al. (2006)</td>
<td>chinook salmon (Oncorhynchus tshawytscha)</td>
<td>hatchery salmon made significantly greater numbers of charges, displays, and nips than wild salmon in a 20 minute observation period</td>
</tr>
</tbody>
</table>
Agonistic behavior in salmonids is important due to its role in competition among fish for food and space in the stream environment (Huntingford and Turner 1987). Stream-dwelling salmonids seek to acquire the optimal territories in a stream (Bachman 1984; Fausch 1984; Adams and Huntingford 1996). Optimal territories are those that provide the best balance of energy gained from the environment and the energy required for metabolism, growth, and reproduction (Bachman 1984; Fausch 1984; Adams and Huntingford 1996; Deverill et al. 1999). Because individual salmonids vary in their ability to compete (Metcalfe et al. 1989), individuals that are the best competitors are the individuals that are most likely to obtain optimal territories and have a greater likelihood to survive and reproduce (Fausch 1984; Metcalfe et al. 1995).

While most studies have focused on the behavioral differences between hatchery-reared and wild salmonids (Table 3-1) and little attention has been given to behavioral differences that may exist between individuals within the hatchery-reared population. Behavioral variation among individuals in the hatchery-reared population may lead to important differences in post-stocking behavior once the fish are released into flowing waters, such as movement away from the desired stocking areas (Cresswell 1981).

Concerns have recently arisen in Pennsylvania about the movement of hatchery-reared, stocked trout out of stocked stream reaches (Wnuk 2005; Pierce et al. 2006). A 2006 Pennsylvania Fish and Boat Commission study concluded that residency rates (defined as the proportion of trout remaining within a 300 meter stream reach of initial stocking) on several Pennsylvania
streams were low, between 0 and 39.9% of the original number of trout released (Pierce et al. 2006). Post-stockling movement in hatchery-reared trout has also been reported by several other authors (Cobb 1933; Cresswell 1981; Cresswell and Williams 1982; Riley et al 1992; Gowan and Fausch 1996; Bettinger and Bettoli 2002; Weber and Fausch 2003; Aarestrup et al. 2005; Runge et al. 2008). In a review paper, Cresswell (1981) concluded that only 3-35% of hatchery-reared trout released were recaptured by subsequent surveys or anglers. Understanding the behavior of hatchery-reared trout populations is valuable information for the future management of hatchery-reared populations for restoration and recreational purposes and the future management of cold-water fisheries. If behavioral differences exist within hatchery populations, managers may be able to selectively breed or artificially select for individuals displaying a set of desired behavioral characteristics.

The objective of this study was to compare resident and non-resident trout behavior. Resident trout were defined as those that remained within the 300 meter study reach for a minimum of six weeks following release into the stream. Non-resident trout were defined as trout that had dispersed outside of the 300 meter study reach in an upstream or downstream direction. This study also aimed to determine if behavioral differences could be used to predict (based on CART analysis) the residency status (resident or non-resident) of individual trout.
3.3 METHODS

3.3.1 Watershed Description

The Rolling Rock Creek watershed covers an area of approximately 2,398 hectares on the western slope of the Laurel Hill in Westmoreland County, Pennsylvania (Figure 3.1). Rolling Rock Creek originates at the confluence of Bear Run (also referred to as McGinnis Run by previous authors) and Wildcat Run (40.17068 N, 79.18356 W) in the Laurel Highlands region of southwestern Pennsylvania and flows 8.27 km northwest to its confluence with Loyalhanna Creek (40.214053 N, 79.230692 W), a tributary of the Conemaugh River. Bear Run has been shown to experience acid runoff episodes during high flows (pH 4.42 – 5.85; alkalinity 0.025 – 0.33 mg CaCO$_3$/L; dissolved aluminum 0.1 – 0.9 mg/L) (Schultz 1988; LeFevre and Sharpe 2002), while Wildcat Run exhibits better water quality (pH 6.0 – 6.8; dissolved aluminum 0.01 mg/L) (Dinicola 1982; Sharpe et al. 1984). Land use in the area surrounding Rolling Rock Creek is primarily forested, with minimal impact from development or agriculture.
Figure 3-1: a) Location of the Rolling Rock Creek watershed in Pennsylvania. b) Detail of Rolling Rock Creek watershed.
3.3.2 Fishery Description

The Rolling Rock Creek watershed contains both native and stocked cold water species of fish. Brook trout (*Salvelinus fontinalis*) and mottled sculpin (*Cottus bairdii*) are the only native fishes present on the watershed. Brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), brook trout, and tiger trout (*Salmo trutta X Salvelinus fontinalis* hybrid) are regularly released for recreational purposes during the angling season (April – September). Released trout were reared within the watershed at the Rolling Rock creek fish hatchery (Figure 3.1). Rolling Rock Creek also supports small, wild (stream-bred) populations of brown trout and rainbow trout. Rolling Rock Creek is maintained as a private fishing club. Angling on the stream is highly regulated and harvest rates are low (approximately 10% of total catch; Rolling Rock fishing club records 2005) due to an increase in catch-and-release practices among anglers.

3.3.3 Determination of Residency

Two 300 meter study reaches were established on Rolling Rock Creek for this study. For reference purposes, these were labeled as the upper (Lat: 40.17187; Long: -79.18822) and lower (Lat: 40.17556; Long: -79.19743) study reaches. Each study reach was comprised of a variety of riffle, run, and pool habitat. All trout used in this study were obtained from the Rolling Rock Creek hatchery.
In 2007, a total of 60 1+ aged trout (20 brook trout, 20 brown trout, and 20 rainbow trout) were released evenly throughout each 300 meter study reach (120 trout total) on 24 April 2007. This procedure was replicated on 21 May 2007, yielding a total of 240 tagged trout released into Rolling Rock Creek. Prior to release, each trout was weighed to the nearest tenth of a gram and the total length (mm) was measured. Fulton’s condition factor was then calculated using Equation 3.1:

\[ K = \frac{10^5 x W}{L^3} \]

where \( K \) is Fulton’s condition factor, \( W \) is the fish’s weight in grams, and \( L \) is the total length in millimeters (Ricker 1975).

Each individual trout was tagged with a FLOY® t-bar anchor tag (FLOY® Tag and Mfg. Inc., item #: FD-94) below the dorsal fin on the left side of the trout (Dell 1968). Each tag was printed with a unique number for individual identification. A telephone number was added to each tag in 2008 to enable anglers to report the capture and/or harvest of tagged trout. Tags were color coded based on the location and time of release. Tagged trout were held for a minimum of 24 hours prior to release to evaluate mortality due to the tagging procedure and to ensure tag retention. Six weeks following release into the stream, the study reaches were sampled using backpack electrofishing equipment. Angling was permitted throughout the study reaches during the six
week study period. Single-pass electrofishing surveys were conducted at the end of the six week period in each of the study reaches. In addition, spot-electrofishing surveys were used at various locations throughout the watershed to attempt to recapture tagged trout that had moved beyond the 300 meter study reach. Trout that were recaptured within the 300 meter study reach (site of original release) were designated as “resident” trout. Trout captured outside of the 300 meter study reach were designated as “non-resident” trout. At this time, both resident and non-resident trout were removed from Rolling Rock Creek and held in an experimental raceway (Figure 2). Trout were acclimated for a minimum of one week prior to the start of behavioral observations. A total of 12 non-resident (6 brook trout, 1 brown trout, and 5 rainbow trout) and 20 resident trout (4 brook trout, 6 brown trout, and 10 rainbow trout) were recaptured for behavioral observations in 2007.

**3.3.4 Experimental Raceway Design**

The experimental raceway was originally used to rear trout as part of the Rolling Rock fish hatchery facilities. The raceway was completely enclosed with mesh fencing to deter predation of fish being held in the raceway. The floor of the raceway was concrete and uniform. Water entered the raceway from a mix of sources including Bear Run and natural springs and flowed gradually through each of the three chambers/holding areas. Water quality for water in the raceway is given in Table 3.2.
Table 3-2: Mean ± standard deviation (n = 6) pH, acid neutralizing capacity (µEq/L), and total dissolved aluminum (mg/L) of water used in the experimental raceway.

<table>
<thead>
<tr>
<th>Water Quality Variable</th>
<th>Mean ± Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.74 ± 0.16</td>
</tr>
<tr>
<td>Acid Neutralizing Capacity (µEq/L)</td>
<td>354.3 ± 106.1</td>
</tr>
<tr>
<td>Total Dissolved Aluminum (mg/L)</td>
<td>0.021 ± 0.02</td>
</tr>
</tbody>
</table>

The raceway had three compartments, each of which was 8.5 meters long and 3.3 meters wide (area = 28.1 m²). Water depth and velocity were maintained constant at 0.5 m and 0.02 m/sec, respectively, in each of the three compartments. Plastic mesh screens were placed between the compartments to prevent the movement of trout between compartments. The first two compartments were used for behavioral observations and the third was used as a holding area for trout yet to be observed. A grid was created above the first two compartments of the raceway using mason line to quantify movements (Jenkins 1971; Seghers 1974) (Figure 3.2). Each block of the grid had an area of 0.37m². The observer was located in a tree on a platform located between the two compartments approximately three meters above the surface of the water.
3.3.5 Behavioral Observations

A completely randomized study design was used for behavioral observations. Four randomly chosen resident trout and four randomly chosen non-resident trout were placed into one of the compartments also chosen at random prior to the onset of the experiment. In 2007, all three species were mixed randomly during the behavioral observations. Four trout per compartment yielded a density of 0.14 trout/m² and an approximate biomass of 35.81 g/m² (based on a mean mass of 251.6 g per trout). The density and biomass in the raceway was comparable to the density (0.09 trout/m²) and biomass (24.13 g/m²) of stream-dwelling salmonids previously measured in Rolling Rock creek by three-pass removal electrofishing surveys.

Each individual trout was observed continuously for 15 minutes (the observation order of individuals was randomly selected) from a portable platform located approximately three meters above the raceway between the two observational compartments. Each trout was color coded using uniquely colored waterproof tape attached to the pre-existing t-bar anchor tag. These markings allowed for differentiation among individuals and ensured that each individual was observed only once during the study. This procedure was repeated in trials of four trout until all trout had been observed.

During each observation the duration of each movement, the total number of grid blocks moved per individual movement, the number of individual movements, and agonistic behaviors initiated and received were recorded using digital voice recorders. Agonistic behaviors were categorized into three separate aggressive behaviors; charging, biting/nipping, and avoidance behaviors. The
data from the voice recorders were later transcribed. The operational definitions used for the behavioral study are given in Box 3.1.

Figure 3-2: Experimental raceway design. a) Schematic of experimental raceway design for behavioral observations. b) Image of experimental raceway looking from observation area two, upstream to the water input.
In 2008 the procedures previously discussed were repeated with slight modification. In an effort to increase the sample size, behavioral observations were completed on each individual trout prior to release into Rolling Rock Creek. Therefore, the fate of each individual was unknown at the time of behavioral observation. Trout were chosen randomly from the Rolling Rock fish hatchery for each observation trial. A total of 240 rainbow trout were observed using the behavioral observation methods previously described. Due to the small sample sizes among species in 2007, only rainbow trout were used in 2008 to avoid possible interspecific variation in the results. After observation, trout were released evenly throughout the two study reaches on two separate occasions (60

<table>
<thead>
<tr>
<th>Box 3.1: Operational definitions used in the behavioral study.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resident trout:</strong> trout that remained in the study area for a minimum of six weeks</td>
</tr>
<tr>
<td><strong>Non-Resident trout:</strong> trout that were captured outside of 300 meter study areas after the six week study period</td>
</tr>
<tr>
<td><strong>Movement into a block:</strong> defined by the entry of the head of the trout into a new block of the grid</td>
</tr>
<tr>
<td><strong>Charge:</strong> rapid swimming toward target fish</td>
</tr>
<tr>
<td><strong>Bite/nip:</strong> fish attempted and/or succeeded to bite another fish (usually directed at fins)</td>
</tr>
<tr>
<td><strong>Avoidance:</strong> flight or appeasement; trout moves in response to another</td>
</tr>
</tbody>
</table>
trout at each location as previously described). Subsequent single-pass electrofishing surveys at six weeks, spot-electrofishing surveys at various locations in the watershed, and angler recapture records throughout the study period provided the recapture location and fate (resident or non-resident) of individual trout. Only trout that were recaptured live and whose location and fate were confirmed by electrofishing surveys or angler reports were used in subsequent analyses (n = 40; 19 resident, 21 non-resident).

### 3.3.6 Movement of Non-Resident Trout

spot-electrofishing surveys and angler returns provided locations of trout that had dispersed beyond the 300 meter study reach of initial release. Global positioning system (GPS) coordinates were later recorded at the middle of the stream for each of these locations and geographic information software (ArcView Version 9.3.1) was used to measure the stream distance traveled by an individual trout from the original release point to the point of recapture (ESRI 2009).

### 3.3.7 Data Analysis

Comparisons of the total length, mass, and condition factor between species were made using analysis of variance (ANOVA). Pairwise comparisons were made using Tukey’s HSD test with 95% confidence intervals. Comparisons of the total length, mass, and condition factor between resident and non-resident
trout were made using one-way ANOVA. Comparisons of the observed behavioral variables between resident and non-resident trout were also made using ANOVA and Tukey's HSD test with a 95% confidence interval. A Kruskal-Wallis test was used to evaluate interspecific differences in behavior because the data did not meet the normality assumption of parametric tests. Pearson moment of correlation coefficients were used to detect linear relationships between the dispersal distance of non-resident trout and the ten behavior variables observed for each dispersing individual in this study. Classification and regression tree (CART) analysis were used to classify individual trout as resident or non-resident based on the observed behavior variables (Breiman et al. 1984). The R package rpart (R Development Core Team 2006) was used for the CART analysis. Variables included in the final model generally had to meet the Wald $\chi^2$ criterion of $P \leq 0.15$. Data analysis was completed using R (R Development Core Team 2006).

3.4 RESULTS

3.4.1 Total length, Mass, and Fulton’s Condition Factor

The mean (standard error) total length (mm), mass (g), and condition factor (K) for the trout used for behavioral observations in 2007 and 2008 are shown in Table 3.3. There were no statistically significant differences in mass among species in 2007 ($p = 0.245; F = 1.50; r^2 = 0.12$). Statistically significant
differences in mean total length were observed among the three species of trout
\( p = 0.031; F = 3.97; r^2 = 0.27 \). Pairwise comparisons revealed that the total
length of rainbow trout was greater than the total length of brown trout \( p = \\
0.0261; t = 2.82 \) and no statistically significant difference in total length was
observed between brook trout and brown trout \( p = 0.205; t = 1.76 \) and brook
tROUT and rainbow trout \( p = 0.79; t = 0.66 \) (Table 3-3). Similar results were
observed with the mean condition factors of the three species (Table 3-3).
Rainbow trout had a lower mean condition factor than brown trout \( p = 0.028; t = \\
2.78 \) while no statistically significant difference was observed between brown
tROUT and brook trout \( p = 0.189; t = 1.81 \) or brown trout and rainbow trout \( p = \\
0.841; t = 0.56 \).

Mean mass, total length, and condition factor were compared between
tROUT that were resident for six weeks following release and those that were
determined to be non-resident trout. Non-resident trout were larger in terms of
mass and total length (Table 3.4). There were no significant differences in the
Fulton’s condition factor of resident and non-resident trout.
Table 3-3: Mean (standard deviation) mass (g), total length (mm), and condition factor (K) of trout used in behavioral observations in 2007 and 2008. Superscripted lower case letters denote statistically significant differences at $\alpha \leq 0.05$. Comparisons were made between species in 2007.

<table>
<thead>
<tr>
<th>Year</th>
<th>Species</th>
<th>n</th>
<th>Mass (g)</th>
<th>Total Length (mm)</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Brook</td>
<td>10</td>
<td>266.5 (90.6)</td>
<td>281.0 (34.1)</td>
<td>1.15 (0.10) ab</td>
</tr>
<tr>
<td></td>
<td>Brown</td>
<td>7</td>
<td>211.7 (41.0)</td>
<td>251.2 (16.9)</td>
<td>1.35 (0.36) a</td>
</tr>
<tr>
<td></td>
<td>Rainbow</td>
<td>15</td>
<td>276.6 (74.3)</td>
<td>290.1 (26.6)</td>
<td>1.11 (0.08) b</td>
</tr>
<tr>
<td>2008</td>
<td>Rainbow</td>
<td>240</td>
<td>317.1 (45.5)</td>
<td>322.3 (18.5)</td>
<td>1.01 (0.16)</td>
</tr>
</tbody>
</table>

Table 3-4: Mean (standard error) mass, total length, and condition factor (K) for trout determined to be either resident or non-resident. One-way ANOVA was used to compare means between resident and non-resident trout.

<table>
<thead>
<tr>
<th></th>
<th>Resident</th>
<th>Non-Resident</th>
<th>F</th>
<th>p</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (g)</td>
<td>284.4 (58.4)</td>
<td>321.4 (69.3)</td>
<td>5.46</td>
<td>0.023</td>
<td>7.98</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>297.4 (30.0)</td>
<td>311.2 (27.6)</td>
<td>3.61</td>
<td>0.062</td>
<td>5.42</td>
</tr>
<tr>
<td>K</td>
<td>1.09 (0.23)</td>
<td>1.05 (0.12)</td>
<td>0.66</td>
<td>0.419</td>
<td>1.09</td>
</tr>
</tbody>
</table>
3.4.2 Interspecific Differences in Behavior Variables

The 2007 data were used to evaluate if differences in the behavioral variables measured existed between brook, brown, and rainbow trout. Few statistically significant behavioral differences were observed between species in 2007 (Table 3.5). The difference among the three species for median total duration of each individual movement and total number of individual movements were statistically significant at $\alpha = 0.05$. In addition, the difference among species for the median number of charges initiated was statistically significant at $\alpha = 0.1$. Brown trout exhibited the largest median value for each of these three behavioral variables.
Table 3-5: Median (Interquartile Range) behavioral variables observed in 2007 for brook trout, brown trout, and rainbow trout. Median values among the three species were compared using a non-parametric Kruskal-Wallis test.

<table>
<thead>
<tr>
<th>Behavior Variable</th>
<th>Brook (n = 10)</th>
<th>Brown (n = 7)</th>
<th>Rainbow (n = 15)</th>
<th>Kruskal Wallis p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of Squares Moved</td>
<td>112.0 (301.0)</td>
<td>261.5 (149.0)</td>
<td>100.5 (156.5)</td>
<td>0.163</td>
</tr>
<tr>
<td>Total Duration of Movements</td>
<td>485.0 (819.0)</td>
<td>891.0 (263.0)</td>
<td>552.7 (488.5)</td>
<td>0.039</td>
</tr>
<tr>
<td>Total Number of Movements</td>
<td>4.0 (12.8)</td>
<td>2.0 (2.8)</td>
<td>12.5 (8.3)</td>
<td>0.015</td>
</tr>
<tr>
<td>Agonistic Behaviors Initiated</td>
<td>2.5 (6.0)</td>
<td>6.0 (17.5)</td>
<td>0.0 (5.75)</td>
<td>0.167</td>
</tr>
<tr>
<td>Charges Initiated</td>
<td>1.5 (4.5)</td>
<td>4.5 (13.0)</td>
<td>0.0 (4.0)</td>
<td>0.099</td>
</tr>
<tr>
<td>Bites Initiated</td>
<td>0.0 (0.3)</td>
<td>1.0 (4.5)</td>
<td>0.0 (0.25)</td>
<td>0.235</td>
</tr>
<tr>
<td>Agonistic Behaviors Received</td>
<td>1.5 (3.3)</td>
<td>4.0 (10.3)</td>
<td>2.5 (6.0)</td>
<td>0.625</td>
</tr>
<tr>
<td>Charges Received</td>
<td>1.0 (3.0)</td>
<td>2.5 (8.8)</td>
<td>2.0 (4.25)</td>
<td>0.606</td>
</tr>
<tr>
<td>Bites Received</td>
<td>0.0 (0.3)</td>
<td>0.0 (0.0)</td>
<td>0.0 (1.0)</td>
<td>0.712</td>
</tr>
<tr>
<td>Avoidance Behavior</td>
<td>0.0 (3.8)</td>
<td>1.0 (4.8)</td>
<td>0.0 (3.3)</td>
<td>0.555</td>
</tr>
</tbody>
</table>

3.4.3 Movement of Non-resident Trout

Of the 33 trout confirmed as non-residents in 2007 and 2008, 90% (n = 30) of the trout moved in a downstream direction and 9% (n = 3) moved in an upstream direction. The majority of dispersing trout were recaptured within the Rolling Rock watershed. However, nine tagged trout were recaptured in Loyalhanna Creek, downstream of its confluence with Rolling Rock Creek. One individual was recaptured by an angler in Linn Run, the watershed adjacent to the Rolling Rock Creek watershed. Figure 3.3 shows the recapture locations of individual trout. The mean distance moved by recaptured dispersing trout was 5.22 km (standard error = 1.66 km). The minimum and maximum distances
moved by recaptured trout were 0.62 km and 29.77 km, respectively, from the center of the study reach where the trout were originally released.
**Figure 3-3:** Map of recapture locations of individual dispersing trout released in Rolling Rock Creek. Green squares represent trout released in the upper study reach and pink triangles represent trout released in the lower study reach. The Rolling Rock Creek watershed is outlined and highlighted in light orange with blue streams. Green streams on the map are waters designated as Approved Trout Waters by the Pennsylvania Fish and Boat Commission and are stocked annually with trout. Red streams (Laughlintown Run and Powdermill Run) denote waters designated as Class A wild trout waters by the Pennsylvania Fish and Boat Commission and contain sustainable populations of wild trout.
3.4.4 Resident and Non-Resident Trout Behavior and Classification Analysis

Resident and non-resident trout observed in 2007 and 2008 differed with respect to several of the behavioral variables observed. Table 3-7 lists the mean (standard deviation) and the associated statistics of these differences. Statistically significant ($p \leq 0.05$) differences were observed between resident and non-resident trout for the following behavioral variables: the total number of grid squares moved (distance travelled), the total duration of individual movements, the total number of agonistic behaviors initiated, the number of charges initiated, and the number of charges received. The total number of agonistic behaviors received and the number of bites initiated were also statistically significant at the $\alpha \leq 0.1$ level. No statistically significant results were observed between resident and non-resident trout in avoidance behaviors, the total number of individual movements, and the number of bites received.
Table 3-6: Mean (standard deviation) behavior variables observed by resident and non-resident trout. ** indicate statistically significant differences between resident and non-resident trout at $\alpha \leq 0.05$. * indicates statistically significant differences between resident and non-resident trout at $\alpha \leq 0.1$. Behavior variables are listed in order of descending $r^2$ values.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Resident Mean (St.Dev.)</th>
<th>Non-Resident Mean (St.Dev.)</th>
<th>F</th>
<th>p</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Number Squares Moved**</td>
<td>187.71 (107.25)</td>
<td>95.87 (81.06)</td>
<td>15.86</td>
<td>&lt;0.001</td>
<td>18.47</td>
</tr>
<tr>
<td>Total Duration (s)**</td>
<td>559.2 (296.7)</td>
<td>299.0 (244.6)</td>
<td>15.61</td>
<td>&lt;0.001</td>
<td>18.23</td>
</tr>
<tr>
<td>Agonistic Behaviors Initiated**</td>
<td>4.42 (7.37)</td>
<td>0.74 (1.46)</td>
<td>7.45</td>
<td>0.008</td>
<td>9.62</td>
</tr>
<tr>
<td>Charges Initiated**</td>
<td>2.85 (5.29)</td>
<td>0.45 (1.26)</td>
<td>6.1</td>
<td>0.016</td>
<td>8.02</td>
</tr>
<tr>
<td>Charges Received**</td>
<td>2.37 (3.83)</td>
<td>0.83 (1.42)</td>
<td>4.35</td>
<td>0.041</td>
<td>5.93</td>
</tr>
<tr>
<td>Agonistic Behaviors Received*</td>
<td>2.88 (4.19)</td>
<td>1.23 (2.06)</td>
<td>3.91</td>
<td>0.052</td>
<td>5.36</td>
</tr>
<tr>
<td>Bites Initiated*</td>
<td>1.27 (2.51)</td>
<td>0.39 (1.02)</td>
<td>3.39</td>
<td>0.07</td>
<td>4.61</td>
</tr>
<tr>
<td>Avoidance Behavior</td>
<td>1.39 (3.04)</td>
<td>2.77 (2.08)</td>
<td>2.3</td>
<td>0.134</td>
<td>3.18</td>
</tr>
<tr>
<td>Total Number of Movements</td>
<td>7.39 (5.38)</td>
<td>8.68 (6.48)</td>
<td>0.85</td>
<td>0.381</td>
<td>1.2</td>
</tr>
<tr>
<td>Bites Received</td>
<td>0.39 (0.97)</td>
<td>0.32 (0.91)</td>
<td>0.09</td>
<td>0.764</td>
<td>0.13</td>
</tr>
</tbody>
</table>

The CART analysis utilized four of the ten observed behavior variables (Figure 3-5). Overall, the CART analysis correctly classified 57 of 72 individuals used in the analysis as either resident or non-resident (79.2% correct classification). The CART analysis split individual trout into two major groups based on the total number of squares that the individual moved within the 15
minute observation period (Figure 3-5). Individuals that moved ≥ 150.5 squares were grouped as resident trout (N5; Figure 3-5; n = 32; 27 correctly classified). Individuals that moved < 150.5 squares (N1 – N4, the right side of the classification tree in Figure 3-5) were further classified based on the number of agonistic behaviors initiated by the individual, avoidance behaviors, and the total number of squares during the observation period on the left side of the classification tree. Aggressive individuals that initiated ≥ 0.5 agonistic behaviors were classified as non-resident trout (N1; Figure 3-5; n = 7; 7 correctly classified). Individual trout initiating < 0.5 agonistic behaviors were further classified by avoidance behavior. Trout were classified as non-residents if ≥ 3.5 avoidance behaviors were observed during the observation period (N2; Figure 3-5; n = 8; 7 correctly classified). Individuals with < 3.5 avoidance behaviors observed were again classified by the total number of squares the trout moved within the 15 minute observation period (N3 – N4 in Figure 3-5). Trout that moved less than 73.5 squares were classified as non-resident trout (N3; Figure 3-5; n = 17; 10 correctly classified) and those which moved ≥ 73.5 squares were classified as residents (N4; Figure 3-5; n = 8; 6 correctly classified).
Figure 3-4: A classification and regression tree that classifies resident (r) and non-resident (nr) trout as a function of observed behavior variables. Terminal nodes are identified by N#. Numbers in terminal nodes are the number of correct classifications per total number of individuals classified into a given node.
3.5 DISCUSSION

Few differences in the length, mass, and Fulton’s condition factor between trout were expected due to the similar age, rearing environment, and feeding regimen of the trout. Interspecific variation was observed for the total length of brook, brown, and rainbow trout and may be attributed to differences in growth rates among the species.

Non-resident trout were larger, in terms of mass and total length, and also less aggressive than resident trout. Contrary to the results of this study, previous research has demonstrated that larger fish with higher growth rates tend to be more dominant than smaller fish (Metcalf et al. 1986; Gilmour et al. 2005; DiBattista et al. 2006; Tirra et al. 2009). In these studies, the increased growth rate of dominant individuals has been attributed to the individual’s competitive advantage in obtaining food (Metcalf et al. 1986; Gilmour et al. 2005; DiBattista et al. 2006; Tirra et al. 2009).

The results of the present study indicated that resident trout were more aggressive than non-resident trout and spent a greater amount of time moving and moved longer distances (total number of squares moved) during behavior observations than non-resident trout. Several authors have found dominant individuals to have lower growth rates because increased aggressive or territorial behavior may lead to higher metabolic expenditure by the dominant fish and result in lower rates of food consumption (Li and Brocksen 1977; Doyle and Talbot 1986; Ruzzante and Doyle 1991). This type of behavior (increased aggressive encounters coupled with greater time spent moving and moving
longer distances) may account for the smaller size of resident trout compared to non-resident trout observed in this study.

Few statistically significant differences in behavior were observed among brook, brown, and rainbow trout. Behavioral differences between species of trout have been shown to exist (Newman 1956; Fausch and White 1986). The small sample size available in this study to compare interspecific differences in behavior may explain the lack of statistically significant results. However, abiotic conditions may also influence behavioral interactions between salmonid species (Magoulick and Wilzbach 1998). Individuals used in this study were reared in similar environments and exposed to similar abiotic conditions, which may have depressed behavioral differences among the three trout species.

Tagged trout dispersed both upstream and downstream of the initial release point. However, the majority of individuals were recaptured downstream of the initial release point. These results indicate that although most individuals move downstream, releasing hatchery-reared fish downstream of wild populations may not eliminate possible interactions between hatchery-reared and wild fish. The results also demonstrated that hatchery-reared trout were capable of long-range (approx. 30 km) movements in a relatively short period of time (within six weeks) from initial release. Hatchery-reared trout may also disperse to adjacent watersheds as demonstrated by the present study, also enhancing the possibility of interactions with wild fish populations.

Resident trout were found to initiate more agonistic encounters (charges, nips, etc.) than non-resident trout. Agonistic encounters have a major role in
deciding territorial outcomes in salmonids. Dominant, or more aggressive, individuals tend to be better competitors for food and space in the stream and will typically occupy more favorable feeding and resting locations than subordinate individuals. Because space and food resources may be limited, the results of this study indicate that subordinate individuals may be displaced by dominant individuals to other areas of the stream due to a lack of competitive ability.

The CART analysis was accurate in predicting residency of hatchery-reared trout based on behavioral variables. This information may possibly be used to segregate individuals that are more likely to remain in the stocking reach prior to release. However, this practice may be time intensive and therefore impractical. Selectively breeding hatchery-reared trout for behavior characteristic of resident trout (more aggressive) may be an alternative. However, more aggressive trout may be undesirable in situations where interaction with wild fishes is a concern because aggressive hatchery-reared trout may be better competitors than their wild counterparts.

Movement of hatchery-reared trout may increase the probability of interactions with wild trout, even if hatchery-reared trout are not released in an area containing wild trout. Negative interactions between hatchery-reared and wild trout that may be of concern to fisheries managers include genetic contamination, predation, competition, predator attraction, and disease transmission (White et al. 1995). Ruzzante (1994) concluded that hatcheries may be able to select for more or less aggressive fish based on the availability and distribution of food. If food is limited or patchy in the hatchery, managers
may be able to select for increased aggression in hatchery-reared trout. However, if food is abundant and distributed evenly, less aggressive fish may result due to reduced competition for food resources. The dispersal of hatchery-reared trout released into the wild may be a major concern for the management of trout fisheries, especially if the management objectives include high rates of return to angler’s creel, population rehabilitation, or minimizing impact to wild trout populations. Therefore, it may be worthwhile for hatchery and fishery managers utilizing hatchery-reared trout to consider the results of this study and other studies prior to setting management objectives.

The differences in behavior observed between resident and non-resident trout may be attributed to differences in genetic composition because the trout used in this experiment were reared in similar conditions, exposed to similar densities, and similar environmental conditions. Although not directly addressed in the present study, an understanding of the genetic differences within hatchery populations and their possible influence on behavior or adaptability to the natural environment is one area that future research may be directed.
3.6 LITERATURE CITED


Swain, D.P. and B.E. Riddell. 1990. Variation in agonistic behavior between newly emerged juveniles from hatchery and wild populations of coho salmon, Oncorhynchus kisutch. Canadian Journal of Fisheries and Aquatic Science 47:566-571.


Wessel, M.L., W.W. Smoker, R.M. Fagen, J. Joyce. 2006. Variation of agonistic behavior among juvenile Chinook salmon (Oncorhynchus tshawytscha) of
hatchery, hybrid, and wild origin. Canadian Journal of Fisheries and Aquatic Science 63:438-447.


Chapter 4

Downstream Dispersal of Hatchery-Reared Brook, Brown, and Rainbow Trout Immediately Following Release in Rolling Rock Creek, Pennsylvania

4.1 ABSTRACT

The post-stocking loss of hatchery-reared trout represents a substantial economic loss as well as lost recreational angling opportunities and potential negative interactions between hatchery-reared trout and wild fishes. Based on our previous research (Chapter 2), a significant portion of the loss of stocked trout occurs within the first two weeks post-stocking. A fish trap was installed on Rolling Rock Creek in Westmoreland County, Pennsylvania to evaluate post-stocking downstream movements of hatchery-reared trout occurring within the first two weeks of release into the stream. The fish trap was monitored for 14 days after the release of brook trout, brown trout, and rainbow trout. The downstream dispersal of trout began within 24 hours of release and dispersal was predominately nocturnal. Stream discharge appeared to be important to the downstream movement of trout. The relative weight of hatchery-reared trout was also correlated with the length of time a trout remained in the study reach prior to dispersal. The results of this study will assist fisheries managers in maximizing creel returns on hatchery-reared trout. This study also provides insights into the dispersal patterns and ecology of hatchery-reared trout.
4.2 INTRODUCTION

Hatchery-reared salmonids are commonly released into rivers, streams, and lakes throughout the United States for the purposes of increasing recreational opportunities, the mitigation or restoration of cold-water fisheries, enhancement of existing salmonid fisheries, or the creation of new fisheries (Hickley 1994). In Pennsylvania, the Pennsylvania Fish and Boat Commission (PFBC) annually produce and release approximately 3.8 million adult trout of catchable size (approximate length of 18 cm). Hatchery-reared trout are also released by many privately operated hatcheries and sportsman's associations throughout the state.

The post-stocking dispersal of hatchery-reared trout has been previously reported in the scientific literature (Cresswell 1981; Bettinger and Bettoli 2002; Aarestrup et al. 2005; High and Meyer 2009). However, concerns have recently arisen in Pennsylvania relating to the loss of hatchery-reared trout from the stream reaches where they were initially released (Wnuk 2005; Pierce et al. 2006). The dispersal of hatchery-reared trout leads to a loss of recreational opportunities and an associated loss of revenue to local economies that benefit from recreational angling. In addition, dispersal of hatchery-reared trout may elicit a range of ecological effects, including interactions with wild trout and other native fishes (Symons 1969; Fausch 1984; McGinnity et al. 1997; Weber and Fausch 2003), disease transmission (Håstein and Lindstad 1991), and genetic effects on wild trout populations (Skaala et al. 1996; Aho et al. 2006).
As reported in previous chapters, the majority of post-stocking movements by hatchery-reared trout have been in the downstream direction (see Chapters 2 and 3). Previous authors also have reported downstream movement of trout at some point following release (see Cresswell 1981 for review). However, few authors have concentrated on the fate of stocked trout immediately following their release into a stream. The purpose of this study was to evaluate the downstream movements of hatchery-reared brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Oncorhynchus mykiss*) within the first 14 days of release.

The objectives of the present study were to 1) determine whether the loss of hatchery-reared trout from the area of initial stocking was due to active downstream dispersal or mortality following initial release, 2) estimate the length of time after release that movements begin, 3) determine if dispersal was occurring diurnally, nocturnally, or at all times of the day, 4) determine if interspecific differences existed in the downstream movement of brook, brown, and rainbow trout, and 5) examine possible environmental and biological causes of downstream dispersal in hatchery-reared trout.
4.3 METHODS

4.3.1 Watershed Description

The 300 meter upper study reach (Lat: 40.17187; Long: -79.18822) of Rolling Rock creek in Westmoreland County, Pennsylvania was used for this study (Figure 4-1). The Rolling Rock Creek watershed covers an area of approximately 2,398 hectares on the western slope of the Laurel Hill in Westmoreland County, Pennsylvania (Figure 4-1). Rolling Rock Creek originates at the confluence of Bear Run (also referred to as McGinnis Run by previous authors) and Wildcat Run (40.17068 N, 79.18356 W) in the Laurel Highlands region of southwestern Pennsylvania and flows 8.27 km northwest to its confluence with Loyalhanna Creek (40.214053 N, 79.230692 W), a tributary of the Conemaugh River. Bear Run has been shown to experience acid runoff episodes during high flows (pH 4.42 – 5.85; alkalinity 0.025 – 0.33 mg CaCO₃/L; dissolved aluminum 0.1 - 0.9 mg/L) (Schultz 1988; LeFevre and Sharpe 2002), while Wildcat Run exhibits better water quality (pH 6.0 – 6.8; dissolved aluminum 0.01 mg/L) (Dinicola 1982; Sharpe et al. 1984). Land use in the area surrounding Rolling Rock Creek is primarily forested, with little development or agricultural impact.
Figure 4-1: a) Location of the Rolling Rock Creek watershed in Westmoreland County, Pennsylvania. b) Detail of Rolling Rock Creek watershed. The upper study reach of Rolling Rock Creek was used for this study.
4.3.2 Environmental Variables

Streamflow measurements were taken at the downstream end of the 300 meter study reach throughout 2008 and 2009 using a Marsh-McBirney Flo-Mate® (Marsh-McBirney, Inc., Frederick, Maryland) to collect water depth and velocity measurements. For each flow estimate, depth and velocity were recorded for a minimum of 15 cross-sections. Total discharge for the site was calculated from the summation of each cross-sectional discharge. Continuous stage was recorded on Rolling Rock Creek downstream of the study reach. A WL14 pressure transducer with data logging capacity was used to record stage at this location (Global Water, Gold River, California). A rating curve was developed to estimate the total daily discharge (cubic feet per second; cfs⁻¹) on the study site for the duration of each trapping trial.

Water quality sampling was conducted from 2007-2009 on the study reach. Grab samples were taken at low and high flow conditions during this time. Grab samples were analyzed at the water lab of the Environmental Resources Research Institute on the campus of the Pennsylvania State University for pH, acid neutralizing capacity (ANC), and total dissolved aluminum (TDAI) according to standard methods (Eaton et al., 1995). The pH was analyzed using an Orion 901 microprocessor ion analyzer (4500-H+ B Electrometric Method), ANC analysis was conducted with a Radiometer Titrator using a Gran's Titration, and TDAI was measured with a Perkin Elmer 2380 Spectrophotometer and HGA 500 Graphite Furnace (3500-Al B Atomic Absorption spectrometric Method) after filtration (0.1 µm).
Stream habitat was qualified into three main habitat types; riffles, runs, and pools as described by Hawkins et al. (1993). The definitions used to determine habitat type are given in Box 4-1. The number of riffles, runs, and pools were counted for the 300 meter study reach. In addition, the length of each individual habitat type was measured. The width of the water surface was measured at a minimum of three cross-sections of each individual habitat type. Water depth and water velocity measurements were recorded at a minimum of 15 points along a cross-section of each individual habitat type. Three cross-sections (upstream end, middle, and downstream end) were used to measure velocity on habitat types with lengths greater than 10 meters. Mean length, width, depth, and velocity of each habitat type were calculated.

**Box 4-1: Definitions of various habitat types.**

- **Riffle:** fast water; rapid, shallow stream sections with steep water surface gradients

- **Run:** shallow water flowing over a variety of different substrates; also termed “glide” or “raceway” by some authors

- **Pool:** slow, deep stream section with nearly flat water surface gradient
4.3.3 Fish Trap Construction and Installation

A fish trap was constructed using wood and plastic mesh. The dimensions of the trap were 2.4 m x 1.5 m x 1.2 m (length x height x width). The trap was installed on a jack dam located at the downstream end of the 300 meter study reach and secured with bungee cords and eye bolts (Figure 4-2). The water depth inside the trap was maintained at approximately 0.5 m to avoid injury to the fish as they entered the trap. The trap was capable of containing the entire flow of water over the jack-dam under low to moderate flow conditions that are typical on Rolling Rock creek in July and August (approximately 8 – 16 cfs$^{-1}$). Large rocks and lumber were secured upstream of the jack dam to form a weir to encourage movement into the trap during periods of increased stream flow.

A portable, waterproof PIT tag antenna with an extendable handle was secured to the trap and was powered by two 12 volt deep-cycle marine batteries. The electronics and batteries for the PIT tag system were housed in a small wooden box located above the flood plain of Rolling Rock Creek. The date, time, and PIT tag number of each individual trout that was captured was recorded and stored in the PIT tag reader. These data were downloaded every two days to a laptop computer throughout the duration of each trapping trial.
116

Figure 4-2: Fish trap installed on a jack dam at the downstream end of the Rolling Rock upper study reach on Rolling Rock Creek.

4.3.4 Trapping Methods

The fish trap was monitored for three individual trials and a total of 33 days. The first trial began 11 August 2008 and ended 15 August 2008. Trials 2 and 3 were extended to 14 days, beginning 29 July 2009 and 19 August 2009, respectively. For each trapping trial, 60 trout (20 brook trout, 20 brown trout, and 20 rainbow trout) were obtained from the Rolling Rock Creek fish hatchery for the purposes of this study. The total length (mm) and mass (g) of each individual
trout was recorded. Using the total length and mass data, Fulton’s condition factor was calculated (Anderson and Neumann 1996) for each individual trout. The relative weight ($W_r$) of each individual trout was also calculated. The relative weight of each individual trout was calculated using Equation 1.

Equation 4-1: $W_r = (W/W_s) \times 100$

Where $W_r$ is the relative weight, $W$ is the mass of the individual, and $W_s$ is a length-specific stand weight predicted by a weight-length regression constructed to represent the species (Anderson and Neumann, 1996). Specific weight-length regressions for wild brook, brown, and rainbow trout were obtained from Anderson and Neumann (1996). The standard $W_r$ for an individual is 100. Values above 100 indicate individuals above the standard $W_r$ and values below 100 may indicate nutritional issues in the individual. The absolute deviation from the standard $W_r$ of 100 was also calculated for each individual by subtracting 100 from the calculated $W_r$ of each individual and taking the absolute value of the result.

A FLOY T-Bar anchor tag (FLOY® Tag and Mfg. Inc., item #: FD-94) with a unique number for identification purposes was inserted below the dorsal fin of each individual. In addition, each individual was implanted with a Destron Fearing TX1211SST 12.5 mm passive integrated transponder (PIT) tag. The PIT tags were implanted into the peritoneal cavity using MK7 implanters from BioMark® (Boise, Idaho), via the ventral surface of the trout, between the
posterior tips of the pectoral fins, with the caudal fin oriented away from the researcher, as specified in the instructions provided by BioMark®. This procedure ensured that the PIT tag implantation process did not cause damage to sensitive internal organs. To maximize PIT tag retention, the needle was held at a 60° angle, and initially inserted into the peritoneal cavity bevel-side up. The needle was then rotated 180° as the tag was inserted and the needle withdrawn, permitting the tag to be positioned as far away as possible from the insertion point. All trout were held for a minimum of 48 hours following tagging in a concrete raceway at the hatchery to ensure survival and tag retention prior to being released.

Following the installation of the trap, as previously described, the 60 tagged trout were released throughout the 300 meter upper study reach. The trap was monitored every four hours for the first three days of the study and every two days for the remainder of the study. Trout that had moved downstream and were contained in the trap were removed and the species and FLOY tag number was recorded. Trout were then released unharmed downstream of the trap. As previously described, date and time data recorded by the PIT tag reader were downloaded to a laptop computer every two days throughout the duration of the study.

A single pass electrofishing survey was completed on the entire 300 meter reach at the conclusion of each 14 day trapping trial to determine the number of individuals remaining within the study reach and quantify the number of tagged trout that remained unaccounted for by trapping and electrofishing surveys. The
species and FLOY tag number of each trout captured during the electrofishing surveys were recorded. The electrofishing surveys also provided an estimate of the capture efficiency of the trap.

4.3.5 Data Analysis

Analysis of variance (ANOVA) and Tukey’s HSD test were used to compare total length, mass, Fulton’s condition factor (K), and relative weight (Wr) among species of trout (brook, brown, and rainbow) and among trapping trials. Daily discharges for each trapping trial were compared using a student’s t-test. Linear regression was used to examine the relationship between the amount of time individual trout remained within the study reach prior to moving downstream into the trap and the variation of each trout from the predicted relative weight of 100. The number of hours that a trout was in the stream prior to downstream movement was natural log transformed prior to analysis to meet the assumption of normality associated with linear regression.
4.4 RESULTS

4.4.1 Habitat, Streamflow, and Water Quality

The mean (standard error of the mean) width of the study reach was 7.42 (0.38) meters at a discharge of 8.83 cfs\(^{-1}\). The upper study reach of Rolling Rock Creek contained a mix of riffle (50.2% of total surface area), run (39.9% of total surface area), and pool (9.9% of total surface area) habitat. The study reach contained a total of 8 pools, 6 riffles, and 6 runs. Mean length, width, depth, and velocity of each habitat type are given in Table 4-1.

Table 4-1: Mean (standard error of the mean) length, width, depth, and velocity of each habitat type within the 300 meter study reach on Rolling Rock Creek.

<table>
<thead>
<tr>
<th>Habitat Type</th>
<th>Pool</th>
<th>Riffle</th>
<th>Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (m)</td>
<td>4.46 (1.10)</td>
<td>25.87 (8.38)</td>
<td>16.85 (3.68)</td>
</tr>
<tr>
<td>Width (m)</td>
<td>8.41 (0.46)</td>
<td>6.54 (0.52)</td>
<td>6.97 (0.84)</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>0.79 (0.08)</td>
<td>0.14 (0.01)</td>
<td>0.34 (0.02)</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>0.00 (0.02)</td>
<td>0.46 (0.05)</td>
<td>0.14 (0.03)</td>
</tr>
</tbody>
</table>
The mean (± standard error of the mean) pH, acid neutralizing capacity (µEq/L), and total dissolved aluminum (mg/L) during the trapping trials was 7.07 (± 0.1), 274.0 (± 33.91), and 0.015 (± 0.001), respectively. The observed maximum concentration of total dissolved aluminum was 0.023 mg/L and occurred during the maximum discharge observed during the trapping trials.

Descriptive statistics of the discharge during each trapping trial are shown in Table 4-2. Figure 4-3 shows the daily discharge of the upper study reach of Rolling Rock Creek during the three trapping trials. Trial 1 was concluded prior to the high flow event documented in Figure 4-3. Mean discharge in the first trapping trial was greater than the mean discharge in trials two (t = 5.73, p < 0.0001) and three (t = 7.28, p < 0.0001). The difference in mean discharge for trials two and trial three was not statically significant (t = 1.79, p = 0.19). The mean discharge for the study reach from April to October 2007 to 2009 was 17.22 (0.75) cfs\(^{-1}\) with a minimum of 0.94 cfs\(^{-1}\) and a maximum of 140.49 cfs\(^{-1}\).

**Table 4-2:** Descriptive statistics for daily discharge measurements among the three trapping trials. All numbers in the table are in cubic feet per second (cfs\(^{-1}\)).

<table>
<thead>
<tr>
<th>Trial</th>
<th>Mean (SE)</th>
<th>Min</th>
<th>Median</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15.61 (1.54)</td>
<td>11.94</td>
<td>15.64</td>
<td>20.61</td>
</tr>
<tr>
<td>2</td>
<td>10.31 (0.67)</td>
<td>8.34</td>
<td>9.40</td>
<td>17.12</td>
</tr>
<tr>
<td>3</td>
<td>8.58 (0.19)</td>
<td>7.87</td>
<td>8.32</td>
<td>9.95</td>
</tr>
</tbody>
</table>
Figure 4-3: Daily discharge measurements during the three trapping trials. Time 0 indicates the date trout were released into the 300 meter study reach. Electrofishing surveys were conducted on day 14 of each trial. Data collection in trial 1 ended at day 5.

4.4.2 Tagged Trout Data

The mean (±SE) total length (mm), mass (g), Fulton condition factor (K) and statistical comparisons of the hatchery-reared trout used in the three trials of
the study are given in Table 4-3. Rainbow trout were larger than brook trout and brown trout in each of three trials in terms of total length and mass (Table 4-3).

**Table 4-3**: Mean (standard error of the mean) total length (mm), mass (g), and Fulton’s Condition Factor (K) for trout released in Rolling Rock Creek. Superscripted lower case letters denote statistical comparisons among species within each trial. Superscripted upper case letters denote statistical comparisons among trials within each species. Different letters denote statistical significance at $\alpha = 0.05$.

<table>
<thead>
<tr>
<th>Species</th>
<th>Trial 1</th>
<th>Trail 2</th>
<th>Trial 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brook</td>
<td>276.3 (5.3) $^{a; AB}$</td>
<td>302.1 (8.7) $^{a; A}$</td>
<td>250.2 (4.4) $^{a; B}$</td>
</tr>
<tr>
<td>Brown</td>
<td>280.3 (6.2) $^{a; A}$</td>
<td>288.7 (6.1) $^{a; A}$</td>
<td>246.4 (3.8) $^{a; B}$</td>
</tr>
<tr>
<td>Rainbow</td>
<td>334.1 (3.7) $^{b; A}$</td>
<td>300.8 (8.6) $^{a; B}$</td>
<td>318.7 (4.6) $^{b; AB}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Mass (g)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Brook</td>
<td>250.1 (14.3) $^{a; AB}$</td>
<td>308.4 (19.4) $^{a; A}$</td>
<td>184.5 (9.1) $^{a; AB}$</td>
</tr>
<tr>
<td>Brown</td>
<td>284.6 (15.8) $^{a; A}$</td>
<td>294.0 (17.4) $^{a; A}$</td>
<td>198.0 (8.3) $^{a; B}$</td>
</tr>
<tr>
<td>Rainbow</td>
<td>396.9 (13.4) $^{b; A}$</td>
<td>331.4 (23.5) $^{a; A}$</td>
<td>375.2 (15.1) $^{b; A}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>K</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Brook</td>
<td>1.17 (0.03) $^{ab; A}$</td>
<td>1.11 (0.04) $^{a; A}$</td>
<td>1.16 (0.02) $^{a; A}$</td>
</tr>
<tr>
<td>Brown</td>
<td>1.28 (0.02) $^{a; A}$</td>
<td>1.21 (0.04) $^{a; A}$</td>
<td>1.32 (0.03) $^{b; A}$</td>
</tr>
<tr>
<td>Rainbow</td>
<td>1.06 (0.02) $^{b; A}$</td>
<td>1.18 (0.02) $^{a; B}$</td>
<td>1.15 (0.01) $^{a; B}$</td>
</tr>
</tbody>
</table>
4.4.3 Downstream Movement of Trout

A total of 48 of the 180 (27%) individual trout were captured during the three trials. All trout captured appeared healthy at the time of release and there were no indications of involuntary dispersal of these trout. No mortality was observed in the trap, either by stress induced in the trap itself or by deceased fish entering the trap. Table 4-4 shows the number of trout that were captured during each trial of the study. A total of 13 brook trout (22%), 20 brown trout (33%), and 15 rainbow trout (25%) were captured during the three trials (Table 4-4). A greater number of brown trout moved downstream during the first trial than brook trout or rainbow trout (Table 4-4). In trial 2, more rainbow trout were captured than brook trout or brown trout and the number of each species trapped during the third trial were approximately equal (Table 4-4).

The downstream movement of individual trout began within 24 hours of release in each trial and continued throughout the duration of the study (Figure 4-4). The majority (87.5%; 42 of 48 total trout) of downstream movements of released trout occurred within the first eight days of release (Figure 4-4). Single-pass electrofishing surveys conducted at day 14 of each trapping trail provided an efficiency estimate of the trap. Of the 60 trout released for each trial, 30, 39, and 34 trout were recaptured via electrofishing surveys 14 days after release for trials 1, 2, and 3, respectively. A total of 29 out of 180 (16%) trout released were unaccounted for by either trapping or electrofishing surveys.

The time of day that downstream movement occurred is provided in Table 4-5. The majority of downstream movements (85.4%; 41 of the 48 trout
captured) occurred nocturnally between 2200 and 0600 hrs (Eastern Standard Time, EST) (Table 5). No trout were captured during the mid-day hours between 1000 and 1800 hrs (EST). The remainder of the observed movements (7 of the 48 trout captured) were crepuscular, occurring in the morning and evening hours of the day (Table 4-5).

All three species of trout demonstrated a tendency to move downstream during discharges that were greater than the mean discharge of each particular trapping trial. Of the 48 total trout captured, 34 of the downstream movements (70.8%) occurred when the discharge was greater than the mean discharge for each trial. Figure 4-5 shows the discharge during each trapping trial along with the number of brook trout, brown trout, and rainbow trout captured throughout the study periods. The mean (± S.E.) discharge at the time of capture for brook trout, brown trout, and rainbow trout was 10.9 (± 0.9), 13.9 (± 0.86), and 13.31 (± 0.82) cfs⁻¹, respectively. Brown trout dispersed during periods with a mean discharge greater than brook trout (t = -2.42; p = 0.022). Rainbow trout movements occurred at discharges greater than those for brook trout at an α-level of 0.1 (t = -1.96; p = 0.061). There were no statistically significant differences between the mean discharge during movements of brown trout and rainbow trout (t = 0.53; p = 0.602). The stream discharge, pH and total dissolved aluminum concentrations during the three trials are given in Figure 4-6.

A statistically significant negative relationship existed between the number of hours trout remained within the study reach prior to downstream movement into the trap and the deviance from the standard W r of 100 (r² = 0.226, p =
0.001). The fitted linear regression line and scatter plot of the data are shown in Figure 4-7. Downstream movement of trout with a relative weight further from the standard \( W_r \) of 100 (either higher or lower than 100) occurred more rapidly after release than trout with a relative weight near the standard \( W_r \).

**Table 4-4:** Number of trout captured in each trapping trial by species.

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brook</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>Brown</td>
<td>13</td>
<td>1</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>Rainbow</td>
<td>1</td>
<td>10</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>13</td>
<td>16</td>
<td>48</td>
</tr>
</tbody>
</table>
Figure 4-4: The total (cumulative) number of trout captured over time (days) by the downstream trap in each of the three trials. No data were available for days 8 – 14 in trial 1.
Table 4-5: Timing of downstream movements of brook trout, brown trout, and rainbow trout. Data from each trapping trial are combined.

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Number of Trout Captured</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Brook</td>
<td>Brown</td>
<td>Rainbow</td>
<td>Total</td>
</tr>
<tr>
<td>Morning Low light</td>
<td>0600 - 1000 hrs</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Mid Day</td>
<td>1000 - 1400 hrs</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1400 - 1800 hrs</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Evening Low Light</td>
<td>1800-2200 hrs</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Nocturnal</td>
<td>2200- 0200 hrs</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>0200 - 0600 hrs</td>
<td>7</td>
<td>9</td>
<td>8</td>
<td>24</td>
</tr>
</tbody>
</table>
Figure 4-5: Number of brook, brown, and rainbow trout captured on each day of the three trapping trials. Daily discharge measurements are given along with the mean discharge of each trapping trial.
**Figure 4-6:** Discharge (cfs⁻¹), pH, and total dissolved aluminum (mg Al/l) concentrations during each of the three trapping trials.
Figure 4-7: Scatter plot (with fitted linear regression line) of the number of hours trout were in the study reach prior to being trapped and the absolute value of the relative weight (Wr) subtracted from the standard Wr of 100 for trout that were trapped during the three trapping trials. The equation of the fitted regression line was $y = 4.52 - 0.0463x$ (n = 48, $r^2 = 0.226$, $p = 0.001$).
4.5 DISCUSSION

Post stocking mortality of hatchery-reared trout has been shown to be high compared to the mortality of wild salmonids (Weiss and Schmutz 1999). Post-stockling mortality of salmonids has been attributed to nutritional deprivation (Ersbak and Haase 1983), transportation stress (Schreck et al. 1989), inadequate stream water temperatures (Lee and Rinne 1980), high concentrations of total dissolved aluminum (Gagen et al. 1993), and angler induced stress (Dotson 1982; Schister and Bergersen 1996). However, the results of the present study indicated that the loss of hatchery-reared trout may be largely attributed to the dispersal of trout beyond the area of initial release. All trout that were captured during the study appeared healthy and in good condition. No mortality or loss of equilibrium was observed in the trap and all trout that were captured were capable of swimming independently when released into the stream. Therefore, it appeared that that trout were actively dispersing downstream rather than dispersing due to mortality or excessive stress due to stocking or environmental conditions.

The present study confirmed that 27% of the tagged trout released into the study reach had dispersed downstream within the first two weeks of release. Electrofishing surveys at day 14 of each trapping trial revealed that approximately 50% of the trout remained within the 300 meter study reach where the trout were initially released. This value is within the 95% confidence interval of the two week survival rate of 52.4% estimated in Chapter 2. Sixteen percent of the trout initially released into the stream remained unaccounted for by
trapping and subsequent electrofishing surveys. These trout may have been unaccounted for due to a variety of reasons, such as inefficiency of the trap or electrofishing gear, upstream dispersal from the study reach, loss due to angler harvest, or mortality due to predation. The trap was capable of containing the majority of the stream discharge of Rolling Rock Creek during low flow conditions; however, during periods of higher stream discharge, trout may have been able to avoid the trap. Upstream movements of trout were observed in previous studies (see previous chapters) and may account for a portion of the trout that were not accounted for. Single-pass electrofishing surveys in small streams such as Rolling Rock Creek have been reported to provide accurate estimates of trout abundance (Kruse et al. 1998). However, inefficiency of the electrofishing gear may account for the tagged trout that were not located. The loss of trout due to angler harvest was not likely a factor on Rolling Rock Creek because the stream is a privately managed fishing club and anglers must report all harvested trout. No tagged trout from this study were reported to be harvested during the three trapping trials. Predation may account for a large portion of the 16% of the tagged trout that remained unaccounted for in the study. Great blue herons (*Ardea herodias*) were commonly observed throughout the Rolling Rock Creek watershed and have a significant role in the post-stockling loss of hatchery-reared trout (see Chapter 5).

The majority of downstream movements observed occurred nocturnally, with a portion of the movements occurring during the twilight hours of the day. Previous authors have suggested that brown trout are largely nocturnal (Regal
1992; Hudson 1993; Young et al. 1997; Young 1999). Nocturnal activity in juvenile salmonids has been attributed to be a predator avoidance mechanism because most predators of trout depend on light to forage (Heggenes et al. 1993; Fraser and Metcalfe 1997). Another possible mechanism to explain the nocturnal activity of trout is related to foraging behavior because many invertebrates become more active at night (Allan 1995). Young (1999) reported small diel home ranges of brown trout (within 10 m) and longer movements occurring at night (mean of 141 m). No trout captured in the present study were subsequently recaptured following release at the trap site, suggesting that trout did not return to their original diel home range. However, the low discharge that occurred during the study along with the installation of the trap may have inhibited the upstream movement of trout over the 1.5 meter high jack-dam. Future research should be directed toward understanding the mechanisms driving the nocturnal behavior of brook trout, brown trout, and rainbow trout. Understanding the underlying mechanisms involved in nocturnal activity may lead to a better understanding of the ecology of fluvial trout populations.

Following the initial release of the tagged trout, downstream movements were observed within the first 24 hours. Dispersal continued throughout the 14 day trapping trials, although the number of trout captured each day declined over time. Behavioral observations on hatchery-reared trout indicated that a population of trout reared at the same hatchery facility contains some individuals that are predisposed to disperse and others that may be considered resident trout, not leaving the stream reach where they were initially released (see
Chapter 3). Although not directly tested in this study, individuals that display behaviors more characteristic for dispersing individuals may be among the first to leave the area of release. Examining the relationship between behavioral characteristics and the amount of time a trout remains within the area of initial release prior to downstream dispersal is a possible direction for future studies of trout dispersal.

Stream discharge also appeared to have a role in the dispersal of hatchery-reared trout. All three species of trout used in the present study demonstrated a tendency to disperse during periods of discharge that were greater than the mean discharge for the particular trapping trial. Previous authors have documented movements of trout in relation to stream discharge (Erman and Leidy 1975; Heggenes 1988; Clapp et al. 1990). During periods of high discharge the concentration of total dissolved aluminum was also at its peak in Rolling Rock Creek. Increased concentrations of inorganic monomeric aluminum from acid episodes during periods of high discharge has been shown to cause mortality in brook trout (Gagen et al. 1993; Baker et al. 1996; Baldigo and Murdoch 1997). Baker (1982) determined the threshold concentration of total dissolved aluminum for brook trout to be 0.2 mg/L and Baker et al. (1996) observed net downstream movements of brook trout caused by poor water quality (decreased pH and increased total dissolved aluminum concentrations) during acid episodes. Although concentrations of total dissolved aluminum observed in the present study were not greater than the tolerance level of 0.2 mg/L, it is possible that downstream movements of brook trout, brown trout, and
rainbow trout were induced at lower concentrations of total dissolved aluminum due to increased physiological stress associated with acid waters (Wood et al. 1988 a & b).

The condition of an individual trout was also an important factor determining the length of time an individual trout remained within the study reach. Individual trout that deviated further from a relative weight of 100 were observed to move downstream in a shorter period of time after initial release. Hatchery-reared trout are typically raised at high densities and in conditions with little water velocity. In addition, trout exhibiting high growth rates are often selected for in the hatchery, possibly leading to trout with relative weights further from the predicted value of 100. Trout with higher growth rates have been shown to exhibit decreased aerobic swimming performance (Gregory and Wood 1999). The swimming performance of hatchery-reared trout has also been shown to be lower compared to that of wild trout (Duthie 1987). Decreased swimming performance could affect the ability of hatchery-reared trout to maintain favorable stream positions after release into flowing waters and lead to downstream movements due to a lack of fitness.

Fisheries managers may be able to select for fish with relative weights closer to the optimal condition for a particular species by adjusting food rations. Raising trout with relative weights closer to the published values for the wild counterpart of a given species may increase the swimming performance of individuals and possibly decrease post-stocking dispersal of hatchery-reared trout. Based on the results of this study fisheries managers utilizing hatchery-
reared trout primarily for recreational angling opportunities should release trout as closely to the time of harvest as possible. This technique would maximize the return rate of hatchery-reared trout to the angler’s creel, increasing angler satisfaction. An increase in harvest rates of hatchery-reared trout will also limit dispersal from stream reaches open to angling and decrease possible negative ecological interactions with wild trout and other native fish species.
4.6 LITERATURE CITED


Skaala, Ø., K.E. Jørnstad, R. Borgstrøm. 1996. Genetic impact on two wild brown trout (Salmo trutta) populations after release of non-indigenous hatchery spawners. Canadian Journal of Fisheries and Aquatic Sciences 53:2027-2035.


Chapter 5

Minimum Predation Rates of Hatchery-reared Trout Released into Sinking Creek (Centre County, Pennsylvania) by Great Blue Heron (*Ardea herodias*)

5.1 ABSTRACT

A portion of the post-stocking loss of hatchery-reared trout may be attributed to active dispersal away from the point of release. However, predation also is a likely contributor. Salmonids have many natural predators in the wild, but one of the most wide-spread predators of adult trout is the great blue heron (*Ardea herodias*). Previous studies have examined the predation of trout by great blue herons within hatchery facilities; however, the predation rate in the wild has not been quantified. The purpose of this study was to provide a preliminary analysis of the predation rate of recently released hatchery-reared trout in the wild. Trout were tagged and released into Sinking Creek, Centre County, Pennsylvania in close proximity to a great blue heron rookery. The forest floor surrounding the rookery and active nests were searched to located tags from fish that had presumably been consumed at the nesting site. A mean great blue heron predation rate of 8% of adult trout released into the stream was observed over a two year period. An understanding of the number of adult trout predated after release may aid fisheries managers utilizing hatchery-reared trout for their management objectives.
5.2 INTRODUCTION

The loss of hatchery-reared trout from the area of release has become a concern among fishery managers and biologists (Cobb 1933; Cresswell 1981; Cresswell and Williams 1982; Riley et al. 1992; Gowan and Fausch 1996; Bettinger and Bettoli 2002; Weber and Fausch 2003; Aarestrup et al. 2005; Wnuk 2005; Pierce et al. 2006; Runge et al. 2008). While a large portion of the loss is due to active dispersal from the point of initial release (see previous chapters and for a review see Cresswell 1981), a portion of the loss is suspected to be a result of predation. Trout have a number of natural predators in the wild. Common predators of trout in fish hatcheries in the northeastern United States, as reported by Parkhurst (1992), include the belted kingfisher (Ceryle alcyon), common grackle (Quiscalus quiscula), American crow (Corvus brachyrhynchos), osprey (Pandion haliaetus), green-backed heron (Butorides striatus), great blue heron (Ardea herodias), mallard (Anas platyrhynchos), ring-billed gull (Larus delawarensis), muskrat (Ondatra zibethicus), domestic cat (Felis catus), and northern water snake (Nerodia sipedon). In addition, mink (Mustela vison), bald eagle (Haliaeetus leucocephalus), common merganser (Mergus merganser), chain pickerel (Esox niger), and snapping turtle (Chelydra serpentina) are also common fish predators that have been observed within the Sinking Creek watershed.

Several studies have examined the loss of hatchery-reared trout due to predation (Parkhurst 1992; USDA 1995; Modde et al. 1996; Pitt and Conover 1996; Glahn et al. 1999; Dieperink et al. 2001). However, these studies have
been conducted within hatchery facilities and have primarily focused on the economic loss to hatchery managers associated with fish predation. Few studies have evaluated the post-stocking loss of hatchery-trout due to predation in a natural stream environment. Most studies conducted in a natural environment (Collis et al. 2001; Ryan et al. 2003) have focused on juvenile rather than adult salmonids.

The great blue heron is the most common predator of salmonids in the northeastern United States (Tobin et al. 1997). An individual great blue heron has been reported to take between three and six trout per day in the hatchery environment (Butler 1991; Bennett 1993). With populations of great blue herons increasing throughout Pennsylvania (Brauning and Siefken 2003), the impact of great blue herons on salmonid populations will also likely increase. Although the success rate of great blue herons capturing salmonids may decrease in the wild compared to the hatchery environment, it was hypothesized that a portion of the post-stocking loss of hatchery-reared trout was due to great blue heron predation. The purpose of this study was to obtain a minimum estimate of heron predation on hatchery-reared trout released into Sinking Creek, Centre County, Pennsylvania.
5.3 METHODS

The Sinking Creek watershed is located in Centre County, Pennsylvania (Figure 5-1). Sinking Creek flows approximately 31 km from its origin in Bear Meadows Bog in Rothrock State Forest (Lat: 40.729489; Long: -77.761658) to its confluence with Penn's Creek in Spring Mills, Pennsylvania (Lat: 40.85474; Long: -77.57293). Land use is mixed throughout the watershed, consisting of forested, agricultural, and developed tracts of land. The watershed consists of both privately and publicly owned lands. Reaches of Sinking Creek that are open to the public are annually stocked by the Pennsylvania Fish and Boat Commission (PFBC) beginning in early March. The PFBC releases approximately 3000 brown trout (Salmo trutta) and rainbow trout (Oncorhynchus mykiss) into Sinking Creek each year. The mean (standard deviation) width and depth of the study reaches on Sinking Creek was 10.7 (± 2.18) meters and 1.4 (± 0.8) meters, respectively.
**Figure 5-1:**  
**a)** Location of the Sinking Creek watershed in Pennsylvania.  
**b)** Detail of Sinking Creek watershed.
Upper (Lat: 40.82633; Long: -77.62535) and lower (Lat: 40.83677; Long: -77.61828) study reaches were established within Sinking Creek (Figure 1). Both study reaches were 300 meters in length. In each study reach, 60 age-1+ hatchery-reared trout were stocked on two separate occasions in 2007, 2008, and 2009 (120 total trout stocked in each study reach per year). The hatchery-reared trout were an even mix of brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Oncorhynchus mykiss*) (20 individuals of each species). The hatchery-reared trout were reared at the Elk Creek (rainbow trout) and Cedar Springs (brook trout and brown trout) fish hatcheries located in Rebersburg and Mill Hall, Pennsylvania, Respectively. These hatcheries were approximately 25 kilometers from the study reaches. Each individual trout was weighed to the nearest gram and the total length was measured to the nearest millimeter. Fulton’s condition factor (K) was then calculated for each individual trout using Equation 1. Individual trout were tagged with an external FLOY® t-bar anchor tag (FLOY® Tag and Mfg. Inc., item #: FD-94) below the dorsal fin (Dell 1968) (Figure 5-2). Each tag had a unique number for individual identification. Tags were color coded based on the location and time of release (Table 5-1).

\[ \text{Equation 5-1:} \quad K = \frac{(10^5 \times W)}{L^3} \]

where K is Fulton’s condition factor, W is the fish’s weight in grams, and L is the total length in millimeters (Ricker 1975).
Figure 5-2: Example of a hatchery-reared rainbow trout with FLOY® T-Bar anchor tag inserted below dorsal fin. Each tag was color coded for the location of release and was printed with a unique number for identification of individual trout.
Table 5-1: Tagging scheme used for trout released in Sinking Creek in 2007, 2008 and 2009. Each tag was labeled with a unique number to enable identification of individuals when the tag was found.

<table>
<thead>
<tr>
<th>Site</th>
<th>Release</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>1</td>
<td>Orange</td>
<td>Blue</td>
<td>Blue</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Blue/Pink</td>
<td>White</td>
<td>White</td>
</tr>
<tr>
<td>Lower</td>
<td>1</td>
<td>Green</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Chartreuse</td>
<td>Green</td>
<td>Green</td>
</tr>
</tbody>
</table>

One half of the trout released in the lower study reach (30 trout; 10 of each species) in 2009 were tagged as described above and also implanted with Destron Fearing TX1211SST 12.5 mm passive integrated transponder (PIT) tags. The tags were implanted into the peritoneal cavity using MK7 implanters from BioMark® (Boise, Idaho), via the ventral surface of the trout, between the posterior tips of the pectoral fins, with the caudal fin oriented away from the researcher, as specified in the instructions provided by BioMark®. This procedure ensured that the PIT tag implantation process did not cause damage to sensitive internal organs. To maximize PIT tag retention, the needle was held at a 60° angle, and initially inserted into the peritoneal cavity bevel-side up. The needle was then rotated 180° as the tag was inserted and the needle withdrawn,
permitting the tag to be positioned as far away as possible from the insertion point.

A great blue heron rookery was located upstream of the upper study reach on Sinking Creek (Lat: 40.81819; Long: -77.62521) (Figure 5-1). Visual observations of the rookery were conducted periodically throughout the breeding season (March – June) to determine the number of birds regularly using the nesting site. It was determined that a total of 5 active nests were located in two different white pine (Pinus strobus) trees. Each year, an area of 900 m² under the nesting area was searched between mid-August to the beginning of September by hand for FLOY tags from hatchery-reared trout presumably predated by the herons using the rookery (Figure 5-3). A 30 by 30 meter area was plotted at the nest site, with the trees housing great blue heron nests located at the center of the plot. The entire area of the plot was searched on several occasions each year to locate FLOY tags. In each of the three years 25 – 30 total hours of effort were invested searching the 900 m² search area by several different researchers. In addition to searching the area beneath the rookery, an arborist from the Pennsylvania State University was employed each year of the study to climb the two trees containing nests to search for tags located in nests and to verify the number of active nests in the rookery.

In 2009, in addition to the procedures described above, a portable antenna system from BioMark® was used to scan the 900 m² area for PIT tags. The objective was to compare the hand-searching method previously described with an electronic scanning method.
Minimum predation rates in the field are given based on the number of t-bar anchor tags found during rookery searches per the total number of tagged hatchery-reared trout released into the study reaches. Only a minimum estimate could be calculated due to variability in the probability of locating a tag and the inability to estimate the number of tagged trout consumed at locations other than the nesting site. This study did not attempt to account for predation by other predators present in the watershed. Other predators observed included osprey, bald eagle, northern water snake, mink, muskrat, belted kingfisher, snapping turtle, chain pickerel, and larger trout. Observed predation rates were compared with previous predation estimates from the scientific literature.
Figure 5-3: A FLOY ® T-Bar anchor tag in leaf litter below great blue heron nesting location. Red arrow indicates location of tag in photograph.
5.4 RESULTS

The mean (standard error) mass (g), total, length (mm), and Fulton’s condition factor (K) of brook, brown, and rainbow trout used for the study in 2007, 2008, and 2009 are given in Table 5-2. FLOY tags were located below the great blue heron nesting location in 2007 and 2008. However, in 2009, great blue herons appeared to have vacated the rookery. This was verified by the arborist in August of 2009. Several attempts were made to locate the new nesting site from August to October of 2009, however we were unable to locate the new nesting site. Therefore, data were only available for 2007 and 2008.

The maximum number of great blue herons observed at the rookery at one time was 13, in May 2007. This included both juvenile and adult herons. Five active nests were identified in the rookery in 2007 and 2008 by the arborist. Therefore, it was assumed that 10 adult great blue herons were using the rookery in 2007 and 2008. Tags that were located at the nesting site were clean of fecal material in all cases except one, suggesting that the tags were removed from the fish prior to ingestion. The one tag with fecal material had a white coating that was difficult to remove, indicating that clean tags were not made so by contact with rainfall.

A total of 22 of 240 possible tags (9.2%) from trout released in 2007 were located below the nesting location during searches and a total of 15 of 240 possible tags (6.3%) were located from trout released in 2008, yielding a total of 37 of 480 possible tags (7.7%) for both 2007 and 2008 releases. A greater number of tags from trout released into the upper study reach were found below
the great blue heron nesting location (14 from 2007, 8 from 2008; 22 total) than trout released into the lower study reach (8 from 2007, 7 from 2008; 15 total). Approximately equal numbers of tags were located from the two release dates each year (18 total tags from the first release and 19 total tags from the second release).

**Table 5-2**: Mean (standard error) mass (g), total, length (mm), and Fulton’s condition factor (K) of brook, brown, and rainbow trout from the Elk Creek and Cedar Springs fish hatcheries in 2007, 2008, and 2009.

<table>
<thead>
<tr>
<th></th>
<th>Year</th>
<th>Brook</th>
<th>Brown</th>
<th>Rainbow</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass (g)</strong></td>
<td>2007</td>
<td>163.8 (3.4)</td>
<td>190.8 (7.3)</td>
<td>261.5 (3.2)</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>215.8 (4.0)</td>
<td>164.1 (5.4)</td>
<td>238.9 (2.6)</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>261.8 (2.7)</td>
<td>250.0 (1.7)</td>
<td>273.9 (1.7)</td>
</tr>
<tr>
<td><strong>Total Length (mm)</strong></td>
<td>2007</td>
<td>248.0 (1.5)</td>
<td>252.7 (2.5)</td>
<td>277.5 (0.9)</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>257.8 (1.1)</td>
<td>236.1 (2.8)</td>
<td>267.0 (1.0)</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>201.4 (6.2)</td>
<td>184.7 (4.4)</td>
<td>238.1 (4.3)</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>2007</td>
<td>1.07 (0.02)</td>
<td>1.14 (0.01)</td>
<td>1.21 (0.02)</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>1.25 (0.01)</td>
<td>1.22 (0.01)</td>
<td>1.26 (0.01)</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>4.54 (0.40)</td>
<td>5.22 (0.52)</td>
<td>2.32 (0.12)</td>
</tr>
</tbody>
</table>
The number of tags located below the nesting location in 2007 and 2008 for brook, brown, and rainbow trout are given in Table 3. No linear correlations were detected between the number of brook, brown, and rainbow trout predated and the mean total length ($r = -0.36; p = 0.49$) or mass ($r = -0.03; p = 0.96$) of predated trout. The relatively small sample size may have precluded statistical significance.

Table 5-3: Number of tags located below great blue heron nesting location from brook, brown, and rainbow trout 2007 – 2009. * No tags were located in 2009 due to abandonment of the nesting location by great blue herons.

<table>
<thead>
<tr>
<th>Species</th>
<th>Brook</th>
<th>Brown</th>
<th>Rainbow</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>11</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>2008</td>
<td>4</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>2009*</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>8</td>
<td>14</td>
</tr>
</tbody>
</table>

As previously discussed, no tags (t-bar anchor or PIT) were located from trout released in 2009 due to the abandonment of the nesting location by great blue herons. Therefore, a comparison of hand-searches for t-bar anchor tags and scanning the area for PIT tags was not possible. We hypothesize that the nesting site was abandoned due to the presence of great horned owls (Bubo
Great horned owl excrement was found in one of the abandoned nests during the August 2009 nest search. In addition, one brown trout was observed to have been predated by a northern water snake following angler release during an angling survey on the lower study reach of Sinking Creek in 2008.

5.5 DISCUSSION

The results of this study indicate that great blue herons removed an average of about 8% of the tagged trout released into Sinking Creek in 2007 and 2008. This estimate does not include tags that were unable to be located during the visual search or trout that may have been consumed away from the nesting location; consequently, it represents a minimum estimate of great blue heron predation. The predation rate for our study falls within the range of values previously reported in the literature. We are unaware of any previous studies of great blue heron predation on catchable size adult trout in the wild. Therefore, the previous studies that have primarily examined predation in hatchery facilities were used to provide reference to the predation numbers observed in this study, even though their relevance to this study may be limited. Previous studies have estimated trout loss due to predation in hatchery facilities to be between 0 – 40% (USDA 1995; Pitt and Conover 1996; Glahn et al. 1999). Predation rates of smolt and fingerling fish has been estimated as high as 65% (Dieperink et al.
Double crested cormorants (*Phalacrocorax auritus*) and western grebes (*Aechmophorus occidentalis*) were reported to have removed 31.3% and 8.8% of planted fingerlings, respectively, within two weeks of release into the wild (Modde et al. 1996).

Several studies have investigated the energy requirements of the great blue heron at different stages of their life history. Bennet (1993) determined that the maintenance energy ($E_{\text{MAIN}}$), defined as the energy required to maintain the structure and function required for life, of adult great blue herons was approximately 1,434 kilojoules per day (kJ/d). Free-ranging adult herons typically require an energy input of 1.5 times the $E_{\text{MAIN}}$ value (Schramm et al. 1987). Therefore it may be estimated that the energy requirement of free-ranging adult herons is approximately 2,151 kJ/d (1.5 x 1,434 kJ/d). Adults that are actively feeding small chicks require a greater amount of energy per day. This energy requirement has been reported to be 4,264 kJ/d (Butler 1991). Bennet (1993) also estimated the energy value of an individual rainbow trout to be 7.31 kJ/g. Based on the mean mass of the trout used in the present study (224.5 g), the reported energy content of trout (7.31 kJ/g), and the energy requirements of great blue heron reported above, the maximum number of trout required by great blue herons per day was estimated ($((224.5 \text{ g} \times 7.31 \text{ kJ/g})/\text{heron energy requirement})$) at 1.3 trout/d for an individual adult and 2.6 trout/d for an individual adult feeding small chicks. At this rate of predation, ten individual great blue herons could theoretically account for a maximum loss of 546 – 1092 trout of the size used in this study in a six week period. Of course, great blue heron diets will
almost certainly include other food items. Great blue herons eat a wide variety of prey including crayfish, non-salmonid fishes, amphibians, salamanders, etc., all of which were present in the Sinking Creek watershed.

The period of highest energy demand for great blue herons (the period of rearing young chicks) coincides with the release of the majority of hatchery-reared trout for recreational angling opportunities in Pennsylvania (March – May). A significant portion of these trout may be predated by great blue herons, thus reducing the number of trout returned to the angler’s creel. Therefore, predation estimates should be incorporated into the overall management of cold water fisheries.

The interaction of hatchery-reared trout with native and wild (stream-bred) fishes has interested researchers and managers since the release of hatchery-reared trout has been popularized (White et al. 1995). With respect to predation, the release of hatchery-reared trout may increase or decrease the impacts on wild fish (Pearsons 2008). Predators have been shown to move to areas of high prey abundance and to shift their diet to the most abundant prey (Collis et al 1995; Shively et al 1996(a) & (b); Major et al 2005). In areas where a large number of hatchery-reared trout have been released, predators such as the great blue heron may target these trout rather than native fish species, reducing the impact of predation on native populations. However, the attraction of predators to areas where hatchery-reared trout have been released may also increase the predation rates on native fish populations. Predators may target hatchery-reared trout rather than native or wild fishes due to their reported lack of predator
avoidance behavior compared to native or wild fish populations (Alvarez and Nicieza 2003). The actual effect that the release of hatchery-reared trout has on the predation rates of native or wild fish populations has not been extensively studied and is a topic for future research.

In summary, predation by great blue herons accounts for a significant portion of post-stocking loss of hatchery-reared trout. This loss should be accounted for in any management objectives that involve the release of hatchery-reared trout. Further research is needed to obtain more accurate estimates of salmonid predation in the wild by great blue herons, as well as other species known to predate salmonids. Technological developments such as PIT tags may enhance the researcher’s ability to accurately estimate losses due to predation (see Collis et al. 2001; Ryan et al. 2003). In addition, further research is needed to evaluate how the release of hatchery-reared trout influences predation rates on native and wild salmonids.
5.6 LITERATURE CITED


Vita

Shawn Michael Rummel

EDUCATION:
Ph.D. 2010, Ecology, The Pennsylvania State University, University Park, PA
M.S. 2006, Ecology, The Pennsylvania State University, University Park, PA
B.S. 2003, Biology, Grove City College, Grove City, PA

RESEARCH EXPERIENCE:
Graduate Research Assistant 2006-2010, School of Forest Resources, The Pennsylvania State University
Research Assistant, 2006-2007, Penn State Cooperative Extension, Master Well Owner Network
Graduate Research Assistant 2003-2006, Penn State Institutes of Energy and the Environment
Research Technician 2002, Pennsylvania Cooperative Fish and Wildlife Unit, PA
Undergraduate Research Assistant 2001-2003, Grove City College & Slippery Rock Watershed Coalition

TEACHING EXPERIENCE:
Instructor, FOR 475, Management of Forest Soils, The Pennsylvania State University, PA, Spring 2010
Teaching Assistant, FOR 475, Management of Forest Soils. The Pennsylvania State University, PA 2007-2009
Teaching Assistant, General Ecology, Grove City College, 2002-2003

PUBLICATIONS:

HONORS & AWARDS:
Penn State School of Forest Resources Outstanding Graduate Teaching Assistant Award, 2010.
Northeast Fish and Wildlife Conference, 2009, Best Student Poster Award; “Biotic and abiotic influences on the dispersal of three species of hatchery raised trout”