American Eel Distribution and Growth in Selected Tributaries of the James River

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Abstract

In July of 1999, a team of researchers from the Virginia Department of Game and Inland Fisheries (VDGIF) and the United States Forest Service (USFS) electrofished a 2-km reach of Shoe Creek, Virginia, and captured 66 American eels. Eels were weighed (g) and measured (mm) and 61 individuals were implanted with Passive Integrated Transponders (PIT). Size distribution of the tagged eels ranged from 174-775 mm total length. The team returned to Shoe Creek in October of 1999 for a recapture survey, but captured only seven eels in the same 2-km reach with no recaptures. This sparked considerable interest among the biologists of VDGIF and USFS. Goals of the biologists included identifying daily movement, seasonal distribution, relative abundance, habitat use, and growth of American eels in Virginia headwater streams. This information was needed for the protection of eel habitat and migration corridors, as well as development of restoration plans for eels.

Seasonal movement of thirty-three American eels *Anguilla rostrata* was monitored from July 2000 through September 2001 via radio telemetry. South Fork Piney River, South Fork Tye River, and Shoe Creek, Virginia were the streams chosen for eel research. Eels exhibited the greatest amount of movement in summer 2000 and the least amount of movement in winter 2000-01. Diel activity was significantly lowest in winter 2000-01 and highest in spring 2001. From late October 2000 through May 2001, eels appeared to be buried within the interstitial spaces of the stream bottom and under stream banks.

Habitat preference (average depth, dominant substrate, and pool vs. riffle) was also determined over multiple seasons via radio telemetry. When a preference was detected, eels always preferred pools and the deepest water available relative to each stream. Eels preferred cobble as the dominant substrate during all seasons in S.F. Tye

River. Eels showed no preference for substrate in S.F. Piney River. Substrate preference varied among seasons in Shoe Creek.

Estimates of 12, 41, and 25 eels/ha were calculated for S.F. Piney River, S.F. Tye River, and Shoe Creek, respectively, in summer 2000. There was a significantly higher density of eels in S.F. Tye River when compared to S.F. Piney River in summer 2000. Estimates of 7, 54, and 15 eels/ha were calculated for S.F. Piney River, S.F. Tye River, and Shoe Creek, respectively, in summer 2001. There was a significantly higher density of eels in S.F. Tye River when compared to both S.F. Piney River and Shoe Creek in summer 2001.

Growth in total length (TL) was determined in S.F. Piney River, S.F. Tye River, and Shoe Creek from summer 2000 to summer 2001. Growth in TL for S.F. Piney River, S.F. Tye River, and Shoe Creek was 18, 23, and 21 mm/year, respectively. Growth in TL for Shoe Creek was also calculated from 1999-2000 (43 mm/year) and 1999-2001 (32 mm/year). There was a significant difference in growth between Shoe Creek 1999-2000 and Shoe Creek 2000-01 as well as Shoe Creek 1999-2000 and S.F. Tye River 2000-01.

Growth in weight was also determined in S.F. Piney River, S.F. Tye River, and Shoe Creek from summer 2000 to summer 2001. Growth in weight for S.F. Piney River, S.F. Tye River, and Shoe Creek was 24, 21, and 27 g/year, respectively. Growth in weight for Shoe Creek was also calculated from 1999-2000 (50 g/year) and 1999-2001 (40 g/year). There was a significant difference in growth between Shoe Creek 1999-2000 and Shoe Creek 2000-01 as well as Shoe Creek 1999-2000 and S.F. Tye River 2000-01.

Our results have contributed to knowledge of the biology and ecology of the American eel in the upper James River drainage, including diel activity, seasonal movements, habitat use, densities, and growth. Eels were more active during spring and summer, particularly at night. They demonstrated very little movement throughout the other seasons of the year. The majority of eels displayed a behavior similar to hibernation, burying in the substrate and under the banks of the stream from mid-fall through mid-spring. Eels showed a trend to use deep pools with large substrate throughout the majority of this study. Eel densities seemed to vary among streams, with higher growth in streams with lower eel densities and a higher average water temperature.

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Table of Contents

Abstract .... **iv**

List of Tables .... **vii**

List of Figures .... **ix**

Appendices .... **x**

Introduction **1**

Chapter 1: Eel Activity and Movement **4**

Introduction 4
Diel Activity 4
Seasonal Movements 4
Home range and homing 7

Methods 8
Study Area and Site Selection 8
Transmitter Description 8
Eel Capture and Implanting Transmitters 9
Diel Tracking 9
Seasonal Movement 10

Data Analysis: Null Hypothesis 1.1 11

Data Analysis: Null Hypothesis 1.2 11

Data Analysis: Null Hypothesis 1.3 11

Data Analysis: Null Hypothesis 1.4 12

Results 12
Diel Activity 12
Seasonal Movement 13

Discussion 14
Diel Activity 14
Seasonal Movement 15

Conclusions **18**

Future Research and Management Recommendations 18

Chapter 2: Habitat preference, eel densities, and growth **28**

Introduction 28
Habitat 28
Eel Densities 28
Growth rates 28

Methods 29
Habitat Availability 29
Habitat Use 30
Population Estimates 31
Growth Rates 32
Data Analysis: Null Hypothesis 2.1 33
Data Analysis: Null Hypothesis 2.2 34
Results 34
Available Habitat 34
Relative Habitat Preference 35
Density Estimates 36
Growth Rates 37
Discussion 38
Relative Habitat Preference 38
Density Estimates 39
Growth Rates 40
Conclusions 43
Future Research and Management Recommendations 43
Summary 64
Appendices 66

List of Tables

Table 1.1 American eels observed for diel activity from summer 2000 through summer 2001. Frequency: number of the transmitter implanted in the eel. Fate: battery - transmitter battery expired, lost - fish was unable to be located, bank - transmitter was found on bank, still on - transmitter is currently working. 23

Table 1.2 Average hourly activity of American eels among seasons. Activity was determined by counting the number of changes in the amplitude of the transmitter for a three-minute interval, every hour. Critical value of Tukey's HSD = 3.883 (seasons with different letters are considered significantly different). Please note (winter (Dec. 23-Mar. 22), spring (Mar. 23- June 22), summer (June 23-Sept. 22), and fall (Sept. 23-Dec. 22)). 24

Table 1.3 P-values for seasonal comparisons of stream distance occupied sizes for American eels. There is a significant difference in SDO size if p-value < 0.05. "*" indicates significant difference between average SDO sizes of seasons compared... 25

Table 1.4 P-values for seasonal comparisons of total distance moved (TDM) for American eels. There is a significant difference in TDM if p-value < 0.05. "*" indicates significant difference between average TDM of seasons compared.......... 25

Table 1.5 SDO size (m) for American eels monitored from summer 2001 through summer 2001. An "*" indicates eels were believed to be in route of the Sargasso Sea and were not considered to have a SDO for this study, thus not included in calculations for average SDO size. "-" indicates transmitter had not yet been implanted. "dead" indicates transmitter found on bank on 10/8/00. 26

Table 1.6 Total distance moved (m) for American eels monitored from summer 2001 through summer 2001. "-" indicates transmitter had not yet been implanted. "dead" indicates that the transmitter was found on the bank on 10/8/00. 27

Table 2.1 Compositional analysis of habitat availability vs. use for average depth. Critical value for MANOVA = 0.05. "Rank" is the ranking of habitats in order of least to most preferred. 52

Table 2.2 Compositional analysis of habitat availability vs. use for habitat type. Critical value for MANOVA = 0.05. "Rank" is the ranking of habitats in order of least to most preferred. 53

Table 2.3 Compositional analysis of habitat availability vs. use for dominant substrate. Critical value for MANOVA = 0.05. "Rank" is the ranking of habitats in order of least to most preferred. 54

Table 2.4 Estimates of number of eels in 1000 m designated reaches of Shoe Creek, S.F. Piney, and S.F. Tye for summer 2000 and summer 2001. "Mark" is total number fish marked on the 1st day. "Capture" is the total number of fish captured on the 2nd day. 56

Table 2.5 Density estimates (per hectare) of American eels in Shoe Creek, S.F. Piney, and S.F. Tye for summer 2000 and summer 2001 57

Table 2.6 Comparison of density estimates among S.F. Tye River, S.F. Piney River, Shoe Creek and S.F. Shenandoah River from Goodwin (1999). 58

Table 2.7 Comparison of yearly growth for eels in S.F. Tye, S.F. Piney, and Shoe Creek to other studies. 59

List of Figures

Figure 1.1 Map of Virginia with enlargement of study streams (Shoe Creek, S.F. Piney River, and S.F. Tye River). 20
Figure 1.2 Seasonal diel activity of American eels. Bars represent the average number of signal fluxes per three-minute interval each hour during each time period. Amplitude fluctuations are indicative of activity........ 21
Figure 1.3 Net upstream/downstream movement among seasons. 22
Figure 2.1 Percentages of dominant substrate for S.F. Tye River, S.F. Piney River, and Shoe Creek. 45
Figure 2.2 Box plots of daily growth in length (mm) (a) and weight (g) (b) for American eels in Shoe Creek, S.F. Piney River, and S.F. Tye River. Line in box represents the median, box represents 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, and the black dots represent outliers. 46
Figure 2.3 Scatter plots of daily growth (mm/day) vs. length at time of original capture in S.F. Tye 2000-01 (a) and Shoe Creek 2000-01 (b). 47
Figure 2.4 Scatter plots of daily growth (mm/day) vs. length at time of original capture in Shoe Creek, 1999-2000 (a) and 1999-2001 (b). 48
Figure 2.5 Scatter plots of daily growth (g/day) vs. weight at time of original capture in S.F. Tye 2000-01 (a) and Shoe Creek 2000-01 (b). 49
Figure 2.6 Scatter plots of daily growth (g/day) vs. weight at time of original capture in Shoe Creek, 1999-2000 (a) and 1999-2001 (b). 50
Figure 2.7 Temperature profiles of each stream from 10/4/00 through 2/8/01. S.F. Tye River was monitored through 8/8/01. Temperature loggers for Shoe Creek and S.F. Piney were stolen after 2/8/01. 51

Appendices

Appendix A. Growth of American eels in S.F. Tye River marked in 2000 and recaptured in 2001 (n = 85). "nt" indicates that the measurement was not taken. 66

Appendix B. Growth of American eels in Shoe Creek marked in 2000 and recaptured in 2001 (n = 28). "nt" indicates that the measurement was not taken. 70

Appendix C. Growth of American eels in S.F. Piney River marked in 2000 and recaptured in 2001 (n = 2). 71

Appendix D. Growth of American eels in Shoe Creek marked in 1999 and recaptured in 2000 (n = 22). 72

Appendix E. Growth of American eels in Shoe Creek marked in 1999 and recaptured in 2001 (n = 14). 73

Appendix F. Stream distance location of eels tracked on S.F. Tye River from summer 2000 through spring 2001. Distances are listed in meters above or below (+ or -) the start of the sampling reach for each stream when determining density estimates (Chapter 2). "unknown" indicates eels were believed to be in route of the Sargasso Sea and were not considered to have a SDO for this study. 74

Appendix G. Stream distance location of eels tracked on Shoe Creek from summer 2000 through spring 2001. Distances are listed in meters above or below (+ or -) the start of the sampling reach for each stream when determining density estimates (Chapter 2). "-" indicates transmitter had not yet been implanted. "unknown" indicates eels were believed to be in route of the Sargasso Sea and were not considered to have a SDO for this study. "x" indicates transmitter was not functioning that particular day. "dead" indicates transmitter was found on the bank on 10/8/00. 76

Appendix H. Stream distance location of eels tracked on S.F. Piney River from fall 2000 through summer 2001. Distances are listed in meters above or below (+ or -) the start of the sampling reach for each stream when determining density estimates (Chapter 2). 78

Appendix I. Stream distance location of eels tracked on Shoe Creek from spring 2001 through summer 2001. Distances are listed in meters above or below (+ or -) the start of the sampling reach for each stream when determining density estimates (Chapter 2). "-" indicates transmitter had not yet been implanted. 80

Appendix J. Stream distance location of eels tracked on Shoe Creek from spring 2001 through summer 2001. Distances are listed in meters above or below (+ or -) the start of the sampling reach for each stream when determining density estimates (Chapter 2). "-" indicates transmitter had not yet been implanted. "nt" indicates that fish was not tracked that day. 81

Introduction

American eels *Anguilla rostrata* are a species of concern in the United States because of their declining population. They are found in watersheds of the Atlantic coast from southern Greenland to South America (Jenkins and Burkhead 1994). Since the mid-1970s, harvest pressure and habitat loss (due to dam construction, channelization, and urbanization) have led to declines in the abundance of American eels (ASMFC 2000). Haro et al. (2000) suggest that contaminants, disease, riverine obstructions, and variation in oceanic conditions have contributed to the decline of the species. Additional factors include slow maturation (7-30 years to attain sexual maturity), cumulative harvest over multiple years on the same year class, and the fact that all mortality is pre-spawning because eels spawn only once then die (ASMFC 2000).

The Atlantic States Marine Fisheries Commission (ASMFC) developed and approved the American Eel Fishery Management Plan (FMP) to: "improve the knowledge of eel habitat utilization at all life stages, to protect and enhance American eels in historic waters, to provide adequate forage for natural predators, as well as support ecosystem health and food chain structure" (ASMFC 2000). The FMP emphasizes the importance of identification and protection of existing eel habitat in freshwater. Barriers such as dams restrict or prevent migration into current or historical habitat, thereby reducing total production. In addition, poorly constructed roads and stream crossings can accumulate erosion and deposition of sediment, resulting in shallow depths and filling of interstitial spaces on the streambed. Identification and protection of historical habitat is critical to the survival of the American eel.

Knowledge of habitat selection by American eels in streams is limited. The ASMFC Fishery Management Plan (2000) acknowledged that eels inhabit rivers, lakes, and streams of the eastern U.S., but did not identify the specific habitat features required by eels. In the South Fork of the Shenandoah River, Virginia, Goodwin (1999) found that eels were associated with leaf packs, root wads, and woody debris. He also found more eels in areas of flowing water as opposed to backwaters and other slack-water areas.

The distribution and abundance of American eels in headwater streams of Virginia are not well understood. Smogor et al. (1995) suggested that in Virginia the American eel declines in abundance, but individuals achieve a greater size, with increasing distance from the ocean. A decrease in American eel density with increasing distance from the ocean has also been reported in the Maritime Provinces of Canada (Smith and Saunders 1955). Historical data suggests that eels decline in abundance with distance from the ocean and the amount of migrational barriers (i.e. dams) (ASMFC 2000).

A 1999 survey of American eel distribution and abundance in a headwater tributary of the James River was conducted by a team from Virginia Tech, the USDA Forest Service, and the Virginia Department of Game and Inland Fisheries. The team electrofished a 2-km reach of Shoe Creek, a second-order tributary of the Tye River sub-drainage in the George Washington National Forest, and captured 66 American eels. Eels were weighed (g) and measured (mm) and 61 individuals were implanted with Passive Integrated Transponders (PIT). Size distribution of the tagged eels ranged from 174-775 mm total length.

The team returned to Shoe Creek in October of 1999 for a recapture survey, but captured only seven eels in the same 2-km reach with no recaptures. Possible explanations for this low capture rate included mortality after the initial sampling, inability to capture eels in October, or emigration from the reach. Sampling methods in October were identical to July and no mortality was observed during or immediately following sampling, which suggested that the eels probably moved out of the study reach. The unexpected summer abundance followed by disappearance in the fall generated considerable interest among both state and federal agencies. Agencies were concerned as to why the eels left and whether or not this was a natural occurrence. A more comprehensive study was planned to investigate the seasonal distribution and relative abundance of American eels in small headwater tributaries.

The goal of this study was to provide new information on the daily movement, seasonal distribution, relative abundance, and habitat use by American eels in Virginia headwater streams. This information was needed for the protection of eel habitat and migration corridors, as well as development of restoration plans for eels.

The ASMFC requires all states along the east coast of the United States, to assess American eel populations within their state (ASMFC 2000). All east coast states are also required to report eel assessments to the American Eel Management Board of the Atlantic

States Marine Fisheries Commission. Research needs of the ASMFC include, but are not limited to, data concerning growth, movement, abundance, and identifying and understanding American eel habitat needs (ASMFC 2000).

To address these needs we developed specific objectives:

1.) Describe activity patterns of eels over multiple seasons
2.) Describe movement of eels over multiple seasons
3.) Describe habitat preference of eels over multiple seasons
4.) Estimate density estimates of eels in three headwater streams
5.) Estimate daily growth of eels in three headwater streams.

Chapter 1: Eel Activity and Movement

Introduction

Diel Activity

Very little is known about the diel activity patterns of American eels in freshwater. Limited research suggests that eels are primarily active at night. Helfman (1986) studied diel activity of American eels in a cave spring in Florida using video cameras in March and July. He found that eel activity was high before sunset, after midnight, and before sunrise, and lowest throughout the day until late afternoon. Dutil et al. (1989) visually observed peak migratory invasions of juvenile eels into freshwater streams of the Gulf of St. Lawrence between 21:00 and 23:00. This was based on eel counts of fish that by-passed the falls at Petite Trinite River (north shore of the Gulf of St. Lawrence) in July of 1982 and 1983. Facey and Helfman (1985) studied reproductive migrations of eels and caught 9 silver eels during 21 nights of trapping, and none during ten days of trapping in a pond in Georgia. Winn et al. (1975) studied natural movements of eels in the fishway of Annaquatucket River, Rhode Island using fyke nets. They observed peak silver eel migrations just after sundown until 23:00 (Winn et al. 1975). Haro et al. (2000) found that eels moved very little during the day, and downstream movements occurred primarily at night in a study on the Connecticut River, MA. However, the study focused on the movement of silver-phase eels. Helfman (1986) is the only known study monitoring non-migratory diel activity for American eels aside from this project. Diel activity patterns for yellow-phase American eels have not been explored using radio telemetry. Diel activity indicates when an eel is moving or feeding. This information is also important to better understand the biology of the American eel.

Seasonal Movements

Several researchers in North America have attempted to follow the seasonal movement of sexually mature eels. Sexually mature American eels move downstream during late summer and fall in eastern Canadian waters (Eales 1968). Ninety-two female silver eels were caught migrating from a Newfoundland pond during August and September (Gray and Andrews 1970). Thirty-six eels that had previously been tagged in Lake Ontario were caught by commercial fisherman in the lower St. Lawrence River from mid-September through late October (Hurley 1972). Large eels were reported to migrate from lakes in the Maritime Provinces of Canada in late August through November (Smith and Saunders 1955). In the U.S., Winn et al. (1975) captured most silver eels leaving Rhode Island waters from September through November. Six male silver eels were captured primarily in August in the Cooper River, South Carolina (Harrell and Loyacano 1980). Silver eels were captured in Cape Charles, Virginia in late November (Wenner and Musick 1974). These studies suggest that sexual metamorphosis takes place sometime over summer and spawning migrations take place during fall. However, these studies have only dealt with sexually mature eels and an intense study of seasonal movements of sexually immature eels has not been done.

Two preliminary surveys on Shoe Creek, Virginia, a second-order tributary of the Tye River sub-drainage, may provide insight into the seasonal movement of sexually immature eels. In July of 1999, a team of researchers from the Virginia Department of Game and Inland Fisheries (VDGIF) and the United States Forest Service (USFS) electrofished a 2-km reach of Shoe Creek and captured 66 American eels. Eels were weighed and measured and 61 individuals were implanted with Passive Integrated Transponders (PIT). Size range of the tagged eels was 174-775 mm total length. The team returned to Shoe Creek in October of 1999 for a recapture survey, but captured only seven eels in the same 2-km reach with no recaptures. Possible explanations for this low capture rate included mortality after the initial sampling, inability to capture eels in October, or emigration from the reach. Sampling methods in October were identical to July and no mortality was observed during or immediately following sampling, which suggested that the eels probably moved out of the study reach.

Downstream spawning migrations may explain the disappearance of some of the large American eels from Shoe Creek, which may have metamorphosed after tagging in 1999. Goodwin (1999) found sexually mature eels from 346 to 984 mm TL in Virginia waters. Oliveira (1999) found sexually mature female eels from 400 to 867 mm TL in the Annaquatucket River, Rhode Island. Many of the eels captured during the preliminary survey of Shoe Creek in 1999 were in this size range, and could have left the stream to spawn.

American eels are able to recognize and use specific habitats. In his study of Irish rivers, Moriarity (1987) suggested that European eels gradually migrate upstream to regions of decreased population pressure and less risk of competition and cannibalism. Whether eels move to avoid unsuitable environmental conditions or to find forage, it appears that they return to select areas of a stream (Dutil et al. 1988). Dutil et al. (1988) studied tidal influence on eel movement in the estuary of the Calumet River, a tributary of the northern Gulf of St. Lawrence. He found that eels moved upstream or shoreward on the high tide. After the tide went out, eels returned to the same section of river they previously inhabited. Thus, eels have the ability to leave an area and return a short time later. Biologists from VDGIF and USFS assumed eels tagged in Shoe Creek might demonstrate a similar behavior over a longer period of time. Because no marked eels were captured in fall of 1999, agencies thought that eels might have migrated downstream to reside during the fall, winter, and spring (to avoid extremely cold and unfavorable conditions). It was hypothesized that eels may possibly return in summer of 2000 to areas they inhabited during the previous summer. However, no information in literature suggests this type of seasonal movement for any *Anguilla* species.

In contrast, Gunning and Shoop (1962) suggested that eels do not necessarily occupy the same habitat for extended periods. Of 42 eels tagged in Talisheek Creek, Louisiana, 27 were never recaptured. Eleven of fifteen eels were recaptured once within two months of tagging; only two eels were recaptured the following year. However, these two eels were caught only 101-150 meters from original site of capture. Although scars or notches on nine captured eels were clearly visible, it was apparent that a high percentage of the eels no longer inhabited the study area. Of four eels captured and marked in Big Creek, Louisiana, one was recaptured once in the same stream segment. However, two eels were recaptured repeatedly over 10 and 13-month periods and probably maintained home ranges of 300 to 450 linear feet of stream, respectively (Gunning and Shoop 1962).

Recapture success in mark-recapture studies tends to be low. Of 195 eels tagged in the South Fork of the Shenandoah River, Virginia, only 31 were recaptured (16%) (Goodwin 1999). Goodwin (1999) suggested that although sampling efficiency was probably the primary cause of low recaptures, eels may have moved out of the study area. The ability of marked fish to move out of an open study area, and thus evade recapture, is the reason why mark and recapture methods are not well suited to studies of movement (Albanese 2001).

Home range and homing

There have been few studies of home range and homing by American eels. LaBar and Facey (1983) noted very little evidence for homing in a radio telemetry study of 16 eels in Lake Champlain, Vermont. Displacement distances ranged from 0.6 to 4.9 km per fish located in the study area. A mark-recapture study demonstrated that seven eels were recaptured hundreds of km from the study area in Quebec Province; one of these eels had traveled about 400 km in a maximum of 63 days (LaBar and Facey 1983). Research by Oliveira (1997) provided limited evidence for homing by recapturing only 24% of tagged American eels in his study on the Annaquatucket River, Rhode Island. However, Ford and Mercer (1986) used mark-recapture to determine that American eels moved less than 100 m in a Massachusetts salt marsh during the summer of 1979. Biologists of VDGIF and USFS wanted to see if Shoe Creek eels and other eels in the drainage occupy different areas of the drainage during different times of the year.

Mark-recapture has been used to determine home range of eels (Labar and Facey 1983, Oliveira 1997, and Ford and Mercer 1986), but because of low recapture of marked fish, this may not be an appropriate method to assess the home range of eels. Non-quantitative mark-recapture studies can estimate movement over only limited spatial scales because fish can move out of recapture sections (Albanese 2001). Problems with spatial scale can be avoided in a well-designed telemetry study (Roghair 2000). Radio telemetry allows a fish to be located as often as desired. Recapturing a marked fish requires much more effort and the possibility of recapturing the fish is much lower than the possibility of relocating a radio-tagged fish.

Based on the abundance and disappearance of eels in Shoe Creek in 1999 and the lack of information on eel activity and movement, specific objectives were developed to better understand the biology of American eels, specifically within the upper James River drainage.

The specific objectives were to:

1.) Describe what time of day eels were most active

2.) Describe what time of year eels were most active

3.) Estimate size of stream distance occupied by eels among seasons

4.) Estimate total distance moved by eels among seasons.

Methods

Study Area and Site Selection

Three streams in the upper James River watershed (Shoe Creek, South Fork Piney River, and South Fork Tye River) (Figure 1.1) were sampled to investigate a wide range of stream conditions. These streams were chosen because they were known to support American eels, and were accessible within the George Washington National Forest. A distance of 2 km was chosen as the designated reach length on each stream because it was the greatest distance that was available on Forest Service lands and could be effectively sampled in one day. Stream reach characteristics were determined at the beginning of the study. Stream habitat was categorized using a Basinwide Visual Estimation Technique (BVET) (Hankin and Reeves 1988). Shoe Creek lies at an elevation between 533-600 m, and a drainage area of approximately 11.7 km^2. The designated reach for Shoe Creek had a maximum depth of 300 cm and an average stream width of 7.0 m. This is the same reach that was surveyed during preliminary sampling in 1999. South Fork of Piney River lies at an elevation of 667-733 m, and a drainage area of 13.0 km^2. The designated reach for S.F. Piney has a maximum depth of 145 cm and average width of 7.0 m. South Fork of Tye River lies at an elevation of 533-600 meters, and has a drainage area of 33.6 km^2. The designated reach for S.F. Tye had a maximum depth of 125 cm and average width of 8.4 m. Each stream is heavily forested and streamside development is rare. In addition, each stream receives very little fishing pressure based on conversations with local residents, though all have healthy populations of brook trout *Salvelinus fontinalis* (Scott Smith, VDGIF, personal communication). No known angling for American eels exists on any of the streams.

Transmitter Description

Advanced Telemetry Systems (ATS) assembled transmitters for this study. Transmitter size did not exceed 10 g in weight (including battery) and 14 mm in diameter. A Maxell 10-28 battery was used for the transmitters. According to body cavity measurements, a transmitter could be implanted in an eel $\geq$ 500 mm in total length (A. Haro, personal communication). Transmitters were on a duty cycle of two days on, two days off with a rate of 40 pulses per minute. The transmitters hypothetically would last 340 days, which is much longer than other documented studies (Helfman et al. 1983: 6.9 days and Dutil et al. 1988: 10 days).

Eel Capture and Implanting Transmitters

A backpack electroshocker was used to capture all eels during the July and August of 2000 and May of 2001. Once captured, the eel was placed in five-gallon buckets with MS-222 and anesthetized. Once anesthetized for handling efficiency, eels were placed in an eelvise (Goodwin 1999), which hindered eel movement and allowed for quick and efficient surgical procedures. A 2.0 to 2.5 cm vertical slit was cut in the abdomen beneath the anterior origin of the dorsal fin for transmitter implantation (LaBar and Facey 1983). Three to four non-absorbable, monofilament sutures were used to close the incision. The antennae exited the body cavity through a separate incision located approximately 1cm posterior of the primary incision. This was done to prevent the eels from readily ejecting the transmitter from their body before the surgical wound healed. Eels were held 10-15 minutes then released at the site of capture. A total of 10, 10, and 13 eels were implanted with transmitters in S.F. Piney, S.F. Tye, and Shoe creek, respectively.

Diel Tracking

Diel activity was determined by counting amplitude fluctuations hourly, over a three-minute interval. A change in the amplitude of the transmitter pulse indicated a change in the transmitter antenna orientation (Clapp et. al 1990). Such a change in the orientation of the transmitter could result from any discrete movement by the eel that would cause the antenna position to vary. Error rates could be associated with movement of the transmitter antennae without movement by the eel. This could occur if the eel was stationary within the water column. However, eels are a bottom-dwelling species, and movement of the antennae by water currents was probably not an issue. Error associated with or without movement did not occur during preliminary trials with eels in a controlled environment (living stream). When eels did or did not move, amplitude fluctuations were observed, accordingly.

One 24-hour study was conducted for every eel implanted with a transmitter per season (winter, spring, summer, and fall). Two to six fish were monitored per 24-hour period. The average number of amplitude fluctuations, which was indicative of activity, was used to determine if eels were more or less active during certain times of the year or during certain times of the day throughout the year.

Seasonal Movement

The eels equipped with transmitters for the diel movement study were also used to study seasonal movements. All eels were located at least once a week during daylight hours. Based on preliminary trials using unimplanted, hidden transmitters, a transmitter could be located within $1m^2$ of its precise location. Eel location was recorded as distance (in meters) above or below the beginning of the 2-km study reach in each stream. This was determined by distances recorded on tree tags placed sequentially throughout the 2-km study reach. There was a minimum time of 48 hours between observations.

If an eel was missing and suspected of migration, I attempted to locate it by searching both upstream and downstream by foot and automobile. Eels could go upstream no farther than 8 km on any of the three streams, however they could go downstream as far as 300 km to the mouth of the James River. An attempt to locate a missing eel by driving ceased after unsuccessfully searching 8 km upstream and 25 km downstream of the eel's previous location. Distance and direction moved between relocations was recorded for each individual. Amount of movement was described as the change in distance between each eel location. Stream distance occupied was the difference between the most upstream and downstream locations of each fish per season (winter (Dec. 23-Mar. 22), spring (Mar. 23- June 22), summer (June 23-Sept. 22), and fall (Sept. 23-Dec. 22)).

Net upstream/downstream movement of eels was determined seasonally. This was determined for each individual. If an individual was located further downstream at the time last location of a season than it was at the beginning of that season, it was considered to have exhibited downstream movement for that season, and vice versa. If an individual was located in the same location at the end of a season as it was in the beginning of that season, it was considered to have zero net movement. Percentages of eels each season that exhibited net upstream, downstream, or zero movement were used to determine if net movement differed among seasons. Chi-square analysis and chi-square pairwise comparisons were used to determine if and where differences in net movement existed among seasons.

Data Analysis: Null Hypothesis 1.1

Data collected for eels in all three streams were pooled by season for analysis. Data were pooled because the streams selected were similar based on stream morphology and elevation (See Methods, *Study Area and Site Selection)*. In addition, eels from all three streams should be genetically similar since eels are panmictic spawners (E. Hallerman, personal communication) and similar in size (>500 mm). I assumed that eels would not act differently among streams and that data could be pooled for analysis (Bennett Otieno, Dept. of Statistics, Virginia Tech, personal communication). The average number of changes in the amplitude of the pulses for all eels studied each season was plotted to show trends in activity for each season. Data were analyzed by diel quarters to determine the time that eels were most active for each season (One-way ANOVA, $\alpha = 0.05$). If differences in time of activity existed within a season, a Tukey's pairwise comparison was used to determine between which quarters of the day levels of activity differed.

Data Analysis: Null Hypothesis 1.2

Data collected for eels in all three streams were pooled for analysis. Data were analyzed to compare average hourly activity of eels among seasons. Total activity was calculated for each fish over a 24-hour period for each season. This was then divided by 24 to determine average hourly activity, and defined as the average number of changes in amplitude for all fish, each hour, over the course of the day. A two-way analysis of variance (ANOVA) with crossed-structure was used to test if total activity differed among seasons (Hinkelmann and Kempthorne 1994).

Data Analysis: Null Hypothesis 1.3

Data were analyzed to compare individual eel movements over the life of the transmitter. This was used to determine the seasonal stream distance occupied (SDO) for an eel. Seasonal SDO for an individual eel was considered the linear distance of stream that an eel inhabited over each season (distance between furthest upstream location and furthest downstream location each season). A Kruskal-Wallis test was used to determine if SDO differed among seasons. Wilcoxon's two-sample test was used to determine between which seasons SDO varied (Levine et al. 1999). SDO data for eels from all three streams were pooled for this analysis.

Data Analysis: Null Hypothesis 1.4

Data were also analyzed to determine if the total distance eels travel varied among seasons. This was determined by adding all eel movement upstream and downstream for each season from the bi-weekly eel locations. A Kruskal-Wallis test was used to determine if total distance moved (TDM) differed among seasons. Wilcoxon's two-sample test was used to determine between which seasons, differences in TDM existed (Levine et al. 1999). Data for TDM of eels from all three streams were pooled for this analysis.

Results

Diel Activity

Thirty-three eels were monitored over nineteen 24-hour periods from July 2000 to September 2001. Totals of 10, 10, and 13 eels were monitored from S.F. Tye, S. F. Piney, and Shoe Creek respectively (Table 1.1). Eels ranged from 520 to 680 mm in total length (Table 1.1). Diel activity was averaged for all eels in all streams, for each season. Data were plotted to show average activity by diel quarters over a 24-hour period (Figure 1.2).

The time at which eels were most active was significantly different only in summer 2000 ($p = 0.002$). Activity in summer 2000 was highest between 18:00 and 23:59. A difference in time of activity was not detected in fall 2000, winter 2000-2001, spring 2001, and summer 2001 ($p > 0.05$).

The two-way ANOVA on total activity of eels revealed differences between seasons ($p < 0.0001$). Average hourly activity was significantly higher in the spring (Table 1.2). Average hourly activity was not significantly different among summer 2000, fall 2000, winter 2000-01, and summer 2001 (Table 1.2).

All fish remained in the same habitat unit (pool or riffle) as originally located at the beginning of the 24-hour observation, with the exception of two fish in S.F. Tye River. One eel moved downstream about 500 meters between 21:12 and 23:00 on

7/30/00 from a pool to a riffle. Another eel moved downstream approximately 10 meters between 03:50 and 04:24 on 10/27/00 and moved another 20 meters downstream between 11:44 and 12:19 from a pool to another pool. Nonetheless, eels remained in original habitat unit location during 97% of 24-hour observations.

Seasonal Movement

Eels' stream distance occupied (SDO) and total distance moved (TDM) were highly variable among most seasons they were monitored. Eels monitored during the summer of 2000 had significantly greater SDO and TDM than all other seasons of the year including summer 2001 (Tables 1.2 and 1.3). Eels monitored during fall and summer 2001 had significantly larger SDO and TDM than they had in winter (Tables 1.3 and 1.4). Means ± SE for SDO size and TDM during all seasons are listed on the bottom row of Tables 1.4 and 1.5.

Net movement of eels was examined among seasons. There was a significant difference in net upstream/downstream movement among seasons (chi-square, $p<0.001$). Chi-square pairwise comparisons were performed to determine where differences occurred among seasons. A corrected alpha level was calculated using the following formula (new $\alpha = \alpha/(2k)$), where k equals the number of treatments, or in this case five seasons. The alpha level for pairwise comparisons was 0.005. There were significant differences between summer 2000 and winter 2000-01 and between summer 2000 and spring 2001. Ninety-five percent of eels monitored in summer 2000 exhibited net upstream or downstream movement, whereas only 28% and 42 % of eels exhibited net upstream or downstream movement in winter 2000-01 and spring 2001, respectively (Figure 1.3). Downstream movement was more frequent throughout all seasons.

A lack of movement was detected during multiple seasons of the year. Fourteen of nineteen eels monitored throughout the winter of 2000-2001 (Dec. 23-Mar. 22) had a SDO of zero. Ten of those fourteen also had a SDO of zero throughout the spring of 2001 (Mar. 23- June 22)(Table 1.4). However, eight of the fourteen eels that had a SDO of zero in the winter had a SDO greater than zero in the fall of 2000 and 13 of the 14 had a SDO greater than zero in summer of 2000. This suggests that eels are actively moving in the stream only during the warmer months of the year.

Discussion

Diel Activity

Eels are more active in spring than other seasons of the year. Eels started to emerge from the substrate and undercut banks of the stream around the first week of May. Eight of the thirteen fish observed over a 24-hour period in spring 2001 were observed after the first week of May. Higher levels of diel activity in the spring have also been reported for other fish. Bunnell et al. (1998) found brown trout *Salmo trutta* to be more active in the spring when studying their diel movements in the Chattooga River on the South Carolina/Georgia border. Brown trout activity peaked near sunrise and sunset and intermittently throughout the night, and was thought to be correlated with invertebrate drift (Bunnell et al. 1998). Telemetered eels in this study were of considerable size (520 to 680 mm TL), and were not considered to be dependent on small invertebrates. Ogden (1970) suggested that larger eels feed on crayfishes and fishes. Thus, high levels of activity could be due to another factor, possibly the need for the species to rebuild fat reserves that may have been used during winter.

Activity of eels was highest from 18:00 to 23:59 in summer 2000. This contradicts the findings of Helfman (1986) in which activity was high before sunset, after midnight, and before sunrise in March and July of 1983. Peak activity throughout other seasons was difficult to detect. There was no mention of diel activity during other seasons in Helfman (1986) or in any other literature reviewed. Such differences may be due to climatic differences between the geographic locations of this study and that of Helfman (1986) or climatic differences between years of the two studies. A warmer season or year may result in higher eel activity, than would otherwise be observed.

Further basis for the notion that eel activity may vary among years of the same season is exemplified in this study. Eels monitored in summer of 2000 peaked in activity from 18:00 to 23:59. A peak in activity during this time period was not evident during this time period in summer 2001. No activity was observed between 06:00 and 11:59 in summer 2000, yet in summer 2001 activity was observed during this time period.

Differences in time of activity could also be due to variation in activity among individuals. No eel that was monitored in summer 2000 was monitored in summer 2001, due to a limited battery life of transmitters. However, trends of eels were consistent among seasons, thus contradicting the notion that individuals monitored in one season would behave differently than other individuals monitored in the same season.

One bias that could not be avoided when studying the diel activity of American eels was the monitoring of only large individuals. All fish tracked were $\geq$ 520 mm (Table 1.1). This represents only 19%, 20%, and 25% of eels captured during sampling in 2000 and 21%, 19%, and 18% of eels captured during sampling in 2001 of S.F. Piney, S.F. Tye, and Shoe Creek, respectively. Hence, the scope of this analysis is limited to large individuals (>520 mm TL), which probably represent less than ¼ of the total population within each stream. Monitoring of larger eels has also been a bias in other tracking studies (Haro et al. 2000, LaBar and Facey 1983). Smaller eels may not exhibit similar activity patterns to large eels. Smaller eels, which are considered primarily invertebrate feeders (Lookabaugh and Angermeier 1992), may exhibit activity peaking in morning and evening, which is associated with invertebrate drift.

The ability to determine the specific activity of the fish was difficult. Although I was confident that I could determine if a fish was active, I could not always tell if the activity was feeding, movement back and forth across the stream, or interacting with other fishes. This could only be determined through visual observations. Due to the cryptic nature of the species and complexity of the habitat, accurate hourly visual observations were not possible. In addition, fish could not be monitored visually after dark without the use of a flashlight, which may have altered their behavior.

The possibility exists that eels do not act differently among different seasons. Sample sizes were always at or below ten eels for each stream and in some cases were as low as two eels for a particular stream. If all eels do not act the same in a particular stream, then as few as one or two individuals could lead to misinterpretation of their "true" activity. A greater sample size may have provided a more accurate representation of overall eel activity.

Seasonal Movement

Eels did not migrate downstream to over-winter in deeper pools of larger rivers as expected. This was the suspected eel behavior after the disappearance of eels from Shoe Creek from July to October 1999. Eels also did not die after tagging. Eels began to bury in the interstitial spaces on the stream bottom and under the banks (hyporheic zone) of the stream beginning in October of 2000. I attempted to locate eels by excavating stream banks and bottoms in October 2000 and January 2002. Only one of nine eels in October 2000, and one of eight eels in January 2002 was located visually. All other eels could not be located due to burying. This behavior is similar to that of eels observed on the Nottaway River, Virginia, where eels were observed buried tail first into sand substrate in December of 1999 (Amanda Rosenberger, personal communication). This is why fourteen of nineteen eels monitored throughout the winter of 2000-2001 (Dec. 23-Mar. 22) had a SDO of zero and ten of those fourteen also had a SDO of zero throughout the spring of 2001 (Mar. 23- June 22)(Table 1.5). Most eels were not actively moving in the stream until May of 2001. This explains why there was not a significant difference in TDM and SDO size comparing winter and spring. Eel burying may also explain why very few eels were captured during fall sampling in October of 1999. The seasonal movement data suggest that the eels may have been present, but were not susceptible to capture.

Eels had a larger TDM in summer 2000 than other seasons of the year. The majority of eels did not move greater than 500 meters, yet two eels had a TDM > 2000 meters during summer of 2000 (Table 1.6). Two eels in 2000 began migrating in late summer for possible spawning migration. One eel was identified as a silver eel upon transmitter implantation, and the other was not. The eel that was identified as a silver eel, was located in Shoe Creek and was implanted with a transmitter on 8/16/00. It remained at the location of capture through 8/28/00. The eel exhibited a downstream movement pattern beginning on 9/1/00, moving downstream ~ 2,617 meters from the original site of capture, but was never relocated. The other eel was located in S.F. Tye River and did not show a downstream movement pattern, remaining at the same location over multiple observations for a 20-day period. This eel also was not relocated after 9/1/00. This timing of migration is similar to the timing of silver eel migrations in other studies (e.g., Winn et al. (1975), Eales (1968), Gray and Andrews (1970), Hurley (1972), and Smith and Saunders (1955)). Although the S.F. Tye River eel was not identified as a silver eel, its transmitter was implanted early in the summer and metamorphosis may not have yet taken place. Because these eels were believed to be in route to the Sargasso Sea, they were not considered to have a true stream distance occupied, and were not used for analysis to test for differences among seasons. In addition, an eel began to exhibit downstream movement patterns in S.F. Piney River on 9/24/01, after "official" data collection for this project had concluded. The eel had previously been found at the same location for six consecutive weeks. From 9/24/01 to 10/11/01 the eel had moved downstream ~ 2 km, but was never relocated again. This eel was also suspected of spawning migration.

Analysis of net movement of eels among seasons revealed no obvious trends for eels moving either upstream or downstream. Net upstream movement ranged from 6% to 40%, whereas net downstream movement ranged from 22% to 63% of eels monitored among seasons (Figure 1.3). However, eels did show a tendency to not move at all in winter. Seventy-three percent of individuals monitored showed no net upstream or downstream movement during winter 2000-01 (Figure 1.3). In contrast, 95% of eels monitored in summer 2000 exhibited a net upstream or downstream movement. This correlates with the diel activity data, which shows that eels are less active in the colder months and more active during warmer months.

All eels monitored in summer 2000 with the exception of one had a value greater than zero for their stream distance occupied, whereas seven in fall, fourteen in winter, ten in spring, and four in summer 2001 did not have a value greater than zero for their SDO. This suggests that eels do not act the same from season to season or from year to year.

SDO and TDM values were very similar (Tables 1.4 and 1.5) in this study due to the behavior of the eels. Eels typically did not move up and down the stream and occupy what would be considered a SDO or territory. Many eels occupied a single pool or riffle for the majority of the study. The remainder of eels moved to another habitat unit and occupied it usually for several consecutive weeks, not relocating back and forth between locations. Many eels occupied a particular area of a habitat unit for several consecutive weeks and did not move. Thus SDO size and TDM values of individual eels differed slightly, therefore p-values also differed slightly when comparing differences of SDO size and TDM among seasons (Tables 1.2 and 1.3).

It is possible that eels may have had a larger TDM and SDO than reported for this study. Eels in this study were tracked only bi-weekly. Eels may have moved during the period between trackings, but this is unlikely considering eels were often found in the same habitat unit, in fact the same spot in that unit, for five consecutive months. Eels could have been tracked daily, but this would have limited the life of the transmitter battery. The transmitters were on a duty cycle so eels could be tracked over the course of a year. If not on a duty cycle, these results could not have been reported for all seasons of the year.

Conclusions

Based on what I found:

1.) Eels were more active in the spring than other seasons
2.) Peak activity was between 18:00 and 23:59 during summer 2000
3.) Peak activity during other seasons was difficult to detect
4.) Eel SDO size and TDM was greatest in summer 2000 and smallest in winter 2000-01
5.) Eels buried under stream banks and within interstitial spaces of the stream bottom from October 2000 – May 2001

Future Research and Management Recommendations

Determining accurate diel activity and seasonal movement patterns for small fish over the course of a year is logistically difficult because a smaller transmitter is needed. This results in a smaller battery and shorter battery life. For example, a transmitter half the size of the ones used this project may be suitable for eels as small as 300-350 mm. Based on sampling in 2000 this would represent 64%, 69%, and 65% and in 2001 56%, 70%, and 60% of eels captured in S.F. Piney, S.F. Tye, and Shoe Creek, respectively. However, the battery life may be only 90-110 days. If the transmitters were placed on a duty cycle two days on, four days off, this would triple the life of the transmitter, making monitoring of smaller eels for nearly a year a possibility. This would result in a greater risk of not relocating fish because of a greater time between trackings and the fishes' ability to move a great distance downstream. However, based on the results of this study, showing that eels did not move often, smaller transmitters (with a more risky duty cycle) could probably be used with a high success of relocation.

Techniques such as mark-recapture or the use of weirs may be less effective methods of monitoring movement. Both techniques rely on capturing individuals multiple times. These methods would be ineffective if a lack of movement persists. Investigators would be unable to interpret if eels are present in sampling areas, moved out of the areas, or are dead. Weirs may also be ineffective due to the species' ability to maneuver around obstacles (e.g. dams). If eels can get around dams, they can also probably go around, over, or through weirs without being captured.

Caution is also advised towards activities that lead to erosion and deposition of sediment, resulting in filling of interstitial spaces on the streambed and the hyporheic zone. These spaces are important to the biology of the eels in these streams, particularly during the colder months of the year when eels bury within the substrate and under the banks of the stream.

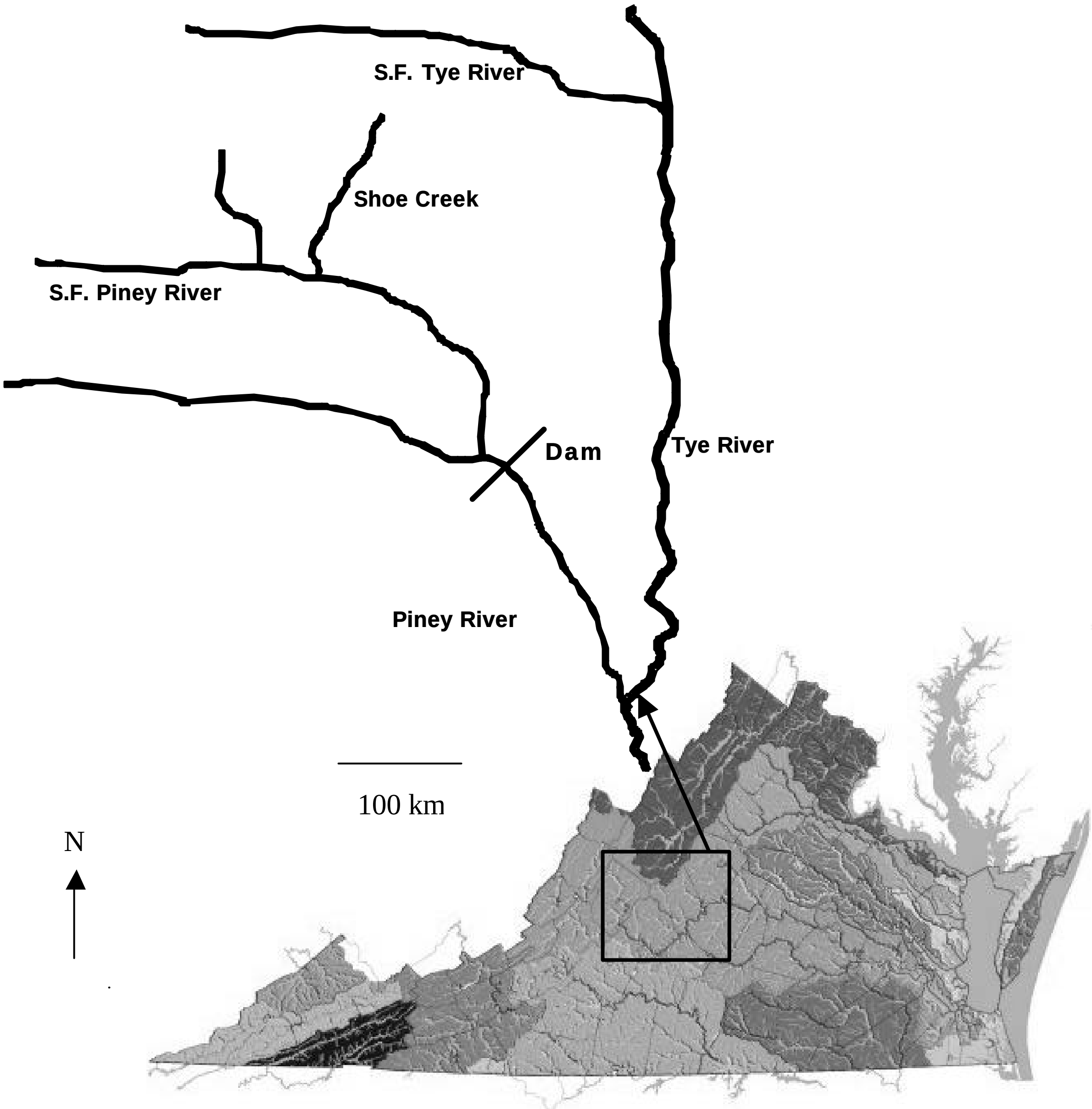


Figure 1.1 Map of Virginia with enlargement of study streams (Shoe Creek, S.F. Piney River, and S.F. Tye River).

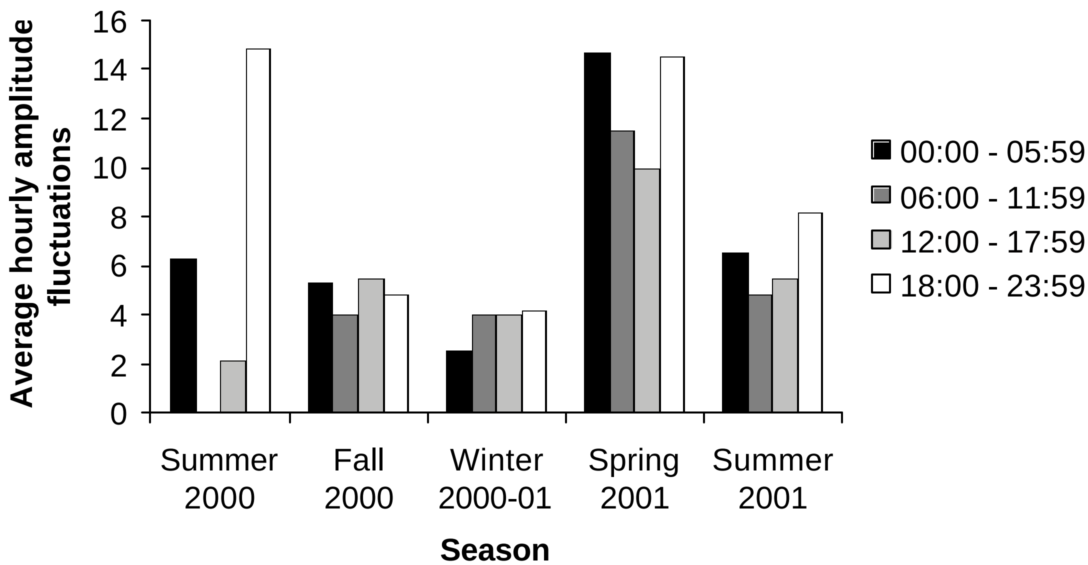


Figure 1.2 Seasonal diel activity of American eels. Bars represent the average number of signal fluxes per three-minute interval each hour during each time period. Amplitude fluctuations are indicative of activity.

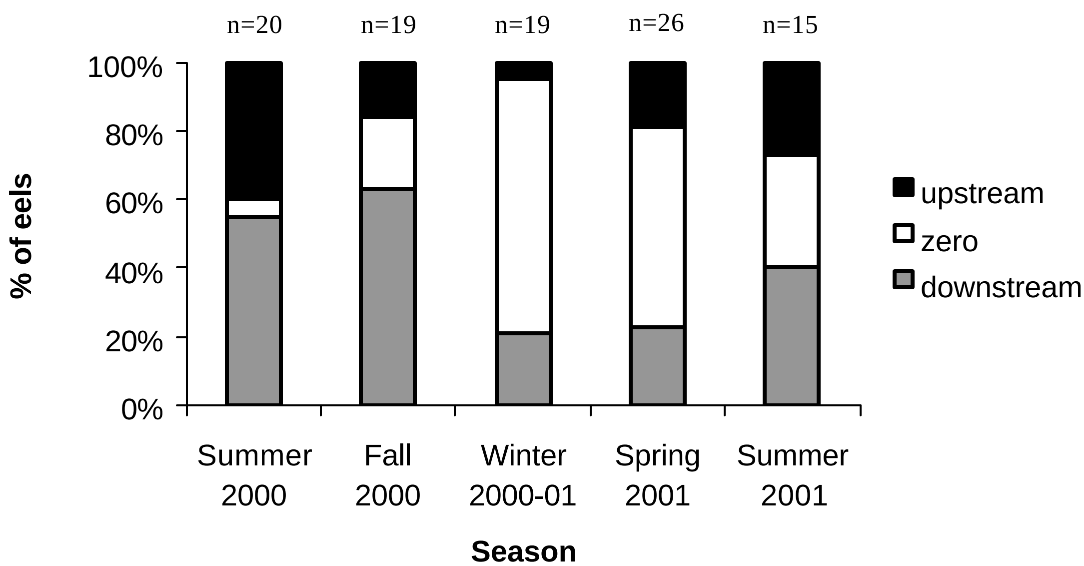


Figure 1.3 Net upstream/downstream movement among seasons.

Table 1.1 Diel activity of American eels from summer 2000 through summer 2001. Frequency: number of the transmitter implanted in the eel. Fate: battery - transmitter battery expired, lost - fish could not be located, bank - transmitter was found on bank, still on - transmitter currently working.

Stream	Frequency	Date Implanted	Length (mm)	Weight (g)	Fate	Last Date Observed
S.F. Tye	14	7/6/00	582	425	battery	4/5/01
S.F. Tye	34	7/6/00	520	242	battery	5/14/01
S.F. Tye	56	7/6/00	580	453	battery	5/14/01
S.F. Tye	76	7/6/00	607	408	battery	5/19/01
S.F. Tye	93	7/6/00	620	474	battery	4/13/01
S.F. Tye	115	7/6/00	560	299	battery	5/19/01
S.F. Tye	134	7/6/00	628	520	battery	5/19/01
S.F. Tye	153	7/6/00	596	547	lost	9/1/00
S.F. Tye	174	7/10/00	640	445	battery	5/19/01
S.F. Tye	196	7/6/00	670	685	battery	4/1/01
Shoe Creek	225	8/8/00	596	412	battery	4/13/01
Shoe Creek	244	8/8/00	620	431	battery	5/19/01
Shoe Creek	262	8/8/00	661	669	battery	5/19/01
Shoe Creek	284	8/8/00	549	300	battery	5/19/01
Shoe Creek	306	8/8/00	661	683	battery	5/7/01
Shoe Creek	324a	8/16/00	625	486	bank	10/3/01
Shoe Creek	344	8/16/00	551	282	battery	5/19/01
Shoe Creek	364	8/8/00	679	603	lost	9/1/01
Shoe Creek	385	8/16/00	596	441	battery	4/13/01
Shoe Creek	404	8/16/00	521	271	battery	5/7/01
Shoe Creek	596	6/8/01	578	424	still on	9/24/01
Shoe Creek	654	6/5/01	540	not taken	still on	9/24/01
Shoe Creek	685	6/5/01	657	not taken	still on	9/24/01
S.F. Piney	494	9/29/00	590	337	battery	7/18/01
S.F. Piney	513	9/29/00	680	573	battery	8/11/01
S.F. Piney	435	5/15/01	602	423	still on	9/24/01
S.F. Piney	455	5/15/01	543	265	still on	9/24/01
S.F. Piney	473	5/15/01	605	356	lost	10/11/01
S.F. Piney	533	6/6/01	591	not taken	still on	9/24/01
S.F. Piney	556	6/6/01	534	not taken	still on	9/24/01
S.F. Piney	625	6/6/01	668	not taken	still on	9/24/01
S.F. Piney	575	6/8/01	528	237	still on	9/24/01
S.F. Piney	324b	7/14/01	565	324	still on	9/24/01

Table 1.2 Average hourly activity of American eels among seasons. Activity was determined by counting the number of changes in the amplitude of the transmitter for a three-minute interval, every hour. Critical value of Tukey's HSD = 3.883 (seasons with different letters are considered significantly different). Winter = Dec. 23-Mar. 22, spring = Mar. 23- June 22, summer = June 23-Sept. 22, and fall = Sept. 23-Dec. 22.

Season			Avg. Activity ± SE
Summer 2000	A		6.48 ± 2.58
Fall 2000	A		4.89 ± 2.83
Winter 2000-01	A		2.72 ± 1.78
Spring 2000		B	13.19 ± 8.23
Summer 2001	A		6.89 ± 4.33

Table 1.3 P-values for seasonal comparisons of stream distance occupied for American eels. There is a significant difference in SDO size if $p < 0.05$ (Wilcoxon's two-sample test). "*" indicates significant difference between mean SDO sizes among seasons compared.

	Summer 2000	Fall	Winter	Spring	Summer 2001
Summer 2000					
Fall	0.0042*				
Winter	<0.0001*	0.042*			
Spring	0.0001*	0.2348	0.22		
Summer 2001	0.011*	0.7241	0.0179*	0.1411	

Table 1.4 P-values for seasonal comparisons of total distance moved (TDM) for American eels. There is a significant difference in TDM if $p < 0.05$ (Wilcoxon's two-sample test). "*" indicates significant difference between mean TDM among seasons compared.

	Summer 2000	Fall	Winter	Spring	Summer 2001
Summer 2000					
Fall	0.0025*				
Winter	<0.0001*	0.0471*			
Spring	<0.0001*	0.3381	0.2201		
Summer 2001	0.008*	0.6977	0.0218*	0.193	

Table 1.5 SDO size (m) for American eels monitored from summer 2001 through summer 2001. An "*" indicates eels were believed to be migrating and were not considered to have a SDO for this study, thus not included in calculations for average SDO size. "-" indicates transmitter had not yet been implanted. "dead" indicates transmitter found on bank on 10/8/00. Mean SDO ± standard error are at bottom of table.

Transmitter #	Summer 2000	Fall 2000	Winter 2001	Spring 2001	Summer 2001
494	-	55	0	10	0
513	-	11	0	11	9
14	71	0	0	0	off
34	59	14	0	0	off
56	462	0	0	0	off
76	572	65	0	0	off
93	20	6817	410	6960	off
115	84	9	0	0	off
134	25	24	0	0	off
156	2161*	gone	gone	gone	gone
174	456	4	1	8	off
196	2148	0	0	0	off
364	2617*	gone	gone	gone	gone
306	2	2	0	0	off
284	2	7	0	22	off
262	7	0	0	0	off
244	51	31	0	0	off
225	90	1	87	0	off
324	0	dead	dead	dead	dead
344	25	9	4	13	off
385	30	60	29	0	off
404	2	7	0	11	off
435	-	-	-	0	3
473	-	-	-	0	368
455	-	-	-	9	11
533	-	-	-	111	3
556	-	-	-	7	7
625	-	-	-	5	0
575	-	-	-	2	86
324	-	-	-	-	0
682	-	-	-	-	3
653	-	-	-	-	0
596	-	-	-	-	17
654	-	-	-	-	19
685	-	-	-	-	8
	mean = 228 ± 114	mean = 375 ± 358	mean = 28 ± 22	mean = 276 ± 267	mean = 36 ± 24

Table 1.6 Total distance moved (m) for American eels monitored from summer 2000 through summer 2001. "-" indicates transmitter had not yet been implanted. "dead" indicates that the transmitter was found on the bank on 10/8/00. Mean TDM ± standard error are at bottom of table.

	Summer 2000	**Fall 2000**	**Winter 2001**	**Spring 2001**	**Summer 2001**
Transmitter #					
494	55	0	0	16	0
513	0	11	0	11	9
14	113	0	0	0	off
34	67	14	0	0	off
56	462	0	0	0	off
76	614	65	0	0	off
93	27	6833	410	6960	off
115	136	15	0	0	off
134	53	48	0	0	off
156	2189	gone	gone	gone	gone
174	456	8	1	16	off
196	2155	0	0	0	off
364	2617	gone	gone	gone	gone
306	2	2	0	0	off
284	2	12	0	24	off
262	7	0	0	0	off
244	51	61	0	0	off
225	90	1	87	0	off
324	0	dead	dead	dead	dead
344	30	27	4	13	off
385	90	0	29	0	off
404	9	0	0	11	off
435	-	-	-	0	3
473	-	-	-	0	368
455	-	-	-	9	16
533	-	-	-	111	3
556	-	-	-	7	14
625	-	-	-	5	0
575	-	-	-	2	86
324	-	-	-	-	0
682	-	-	-	-	3
653	-	-	-	-	0
596	-	-	-	-	31
654	-	-	-	-	42
685	-	-	-	-	8
	mean = 459 ± 185	mean = 376 ± 359	mean = 28 ± 22	mean = 276 ± 267	mean = 39 ± 24

Chapter 2: Habitat preference, eel densities, and growth

Introduction

Habitat

Little is known about habitat use by American eels in Virginia waters. Goodwin (1999) had greater capture success in flowing areas as opposed to backwaters and other slack-water areas on the South Fork of the Shenandoah River, Virginia. However, in their study of distribution and abundance in Virginia streams, Smogor et al. (1995) found that eel occurrence was not consistently or strongly-related to stream habitat features. Hence, I had no expectations that eels would use a particular depth or substrate more often than others throughout this study. However, individuals may show patterns in habitat use when monitored frequently over time. This information is important to gain a better understanding of the biology of eels and the habitat they use daily throughout multiple seasons.

Eel Densities

Density of American eels in mountain streams could be influenced by such factors as the number of migration barriers, distance from the ocean, habitat availability, food abundance, and abundance of other fish species (ASMFC 2000). The distance from the ocean and amount of available habitat were very similar for Shoe Creek, S.F. Piney River, and S.F. Tye River. Fish located on S.F. Piney River and Shoe Creek had one additional barrier to overcome. Piney River had a man-made dam ~ 1.5 m high, which was downstream of the mouths of Shoe Creek and S.F. Piney River. Although this was a minor barrier, I expected that S.F. Tye River would have a higher density of eels than S.F. Piney and Shoe Creek. Historical data suggests that eels decline in abundance with increasing distance from the ocean and the number of migration barriers (i.e. dams) (ASMFC 2000).

Growth rates

Growth is a measure of body size between two points in time (DeVries and Frie 1996). DeVries and Frie (1996) did not mention how short an interval is appropriate to monitor growth, but mentioned that direct observation is the least variable technique for quantifying growth, with the only variation being caused by human error when measuring fish. Variation in growth among individuals will exist, but for the purposes of this study, inferences are being made with regards to the population in a particular stream.

Growth is influenced by a number of factors including water temperature, water chemistry, interspecific competition, intraspecific competition, and food availability. It is unknown whether a stream with a higher or lower average water temperature would be expected to have a higher or lower growth rate than other streams because an optimum temperature for growth of American eels has not been documented. Water temperature was monitored throughout this study and will be discussed later (see Discussion). Streams with greater food availability, less competition, and higher productivity would be expected to have higher growth rates. However, these factors were outside the realm of this study. Growth information for these streams could be compared to eel growth data from other waters throughout Virginia and North America.

Growth of American eels has been well documented throughout waters of the eastern United States. Growth of eels is believed to decrease with increasing distance inland and more northern latitudes (Helfman et al. 1984a; Helfman et al. 1987). However, Oliveira (1999) found no correlation between distance upriver and growth in his study of the Annaquatucket River, RI. He suggested that sex ratio of eels (males grew faster than females) and length of growing season (latitude) were important factors influencing growth rate (Oliveira 1997). Oliveira (1999) also found no correlation between eel density and growth. Based on this, growth rates of eels among the study streams should be similar.

The specific objectives were to:

1.) Describe habitat preference of eels in the tributaries

2.) Estimate density of eels in the tributaries

3.) Estimate growth rate of eels in the tributaries

Methods

Habitat Availability

Available habitat for the three streams studied in this project was determined by a basinwide visual estimation technique (BVET) (Hankin and Reeves 1988). Average depth, area, and dominant substrate were recorded for each habitat unit (pool or riffle) throughout 2-km reaches in each stream. Labeled tags were nailed to trees every 25 meters, beginning at the downstream end, throughout the 2-km reach of each stream. These tags were later used to determine eel locations when determining habitat use.

Average depth was calculated by taking the average of a series of 10-15 random measurements using a depth rod labeled with measured increments of 5 cm.
Habitat unit area was calculated by visually estimating the average width of each pool or riffle and multiplying by the measured length in meters. Dominant substrate also was determined visually, and recorded as the substrate type that was in greatest abundance in each particular habitat unit. Substrate was classified into nine categories: clay, silt, sand, small gravel, large gravel, cobble, boulder, bedrock, or organic matter (Hankin and Reeves 1988).

An attempt to measure cover within the study reaches of each stream was made. However, woody debris and undercut banks were sparse throughout the study reaches of the streams. Thus, cover available to eels within these streams was quantified through a combination of depth and large substrate (cobble and boulder). A habitat unit with a maximum depth $\geq$ 100 cm and dominant substrate of either cobble or boulder was considered to have "good" cover. A habitat unit with either a maximum depth $\geq$ 100 cm or dominant substrate of either cobble or boulder was considered to have "fair" cover. A habitat unit with a maximum depth < 100 cm and a dominant substrate other than cobble or boulder was considered to have "poor" cover.

Habitat Use

All transmitter-equipped eels were located twice a week throughout the study, by triangulation from the streambank. Location was recorded as distance (m) above or below the beginning of the study reach. Times of locating eels were not pre-determined throughout the study. Eels were located during a variety of daylight hours; all weather conditions, lunar phases, and water conditions throughout the year were included in sampling. After each eel was located and its stream location was recorded: average depth, dominant substrate, and habitat unit where the eel was residing (pool or riffle) was determined by observation of recorded available habitat data. Locating eels twice a week using radio-telemetry equipment likely did not affect their location. Young (1996) found that many fish were located in the same position for several consecutive observations during twice-weekly locations of Colorado River cutthroat trout (*Oncorhynchus clarki*).

Thus, it was assumed that bi-weekly observations of a more cryptic species, such as the American eel, would have no effect on their locations.

Population Estimates

Eel populations were estimated by mark and recapture methods in June and July of 2000 and 2001. This was determined in a 1000-m reach that was electroshocked in Shoe Creek, S.F. Piney River, and S.F. Tye River on Forest Service property. The same number of crew members sampled the study reaches of each stream and were instructed to exert the same effort each day to capture eels. All eels captured were anesthetized and measured for total length (mm), weighed (g), and injected with a PIT-tag before being returned to the point of capture. Insertion was made ventrally approximately 25 mm anterior of the anus. All eels also received a small pectoral fin clip to make marked individuals readily identifiable. Mortality was assumed to be zero based on these simple procedures and the hardy nature of the species. The day following each stream's sampling, the 1000-m reach, as well as 500 meters above and 500 meters below each reach were sampled. Only the fish in the designated 1000-m reach were used estimate eel density in each stream.

Mark-recapture methods have four basic assumptions: 1) no emigration, immigration, recruitment or mortality; 2) constant effort is being used; 3) probability of capture and recapture is the same for all individuals and remains constant over time; 4) marked individuals are easily and reliably identifiable (Ricker 1975). I judged that these assumptions were not seriously violated in this study.

The effect of fish moving in or out of the sample reach between days of sampling has been discussed in Pollack et al. (1990). If deletions after the first sample occurred randomly from the population with respect to marked and unmarked animals (i.e. eels leave the sample area), then the Petersen estimator was valid for population size at the time of the first sample (Pollock et. al 1990). It is not certain that if fish move out of the marked reach that it occurred randomly with respect to marked and unmarked individuals, but no literature was found to suggest otherwise. If additions occurred after the first sample (i.e. eels come into the sample area), then they were always unmarked, and the Petersen estimator was valid for population size at the time of the second sample (Pollock et al. 1990). If deletions occurred, there is a chance of capturing a marked individual when sampling 500 meters above and below the marked reach on the second day of sampling. There was no way of knowing whether eels were coming into the marked reach. Thus, the density of eels was documented for the date of the second sample.

If both additions and deletions occurred, then this would have resulted in a greater number of unmarked individuals in the sample reach than would be otherwise, and cause an overestimate of the density of eels. Conversely, if capturing an eel in the first sample had a positive effect on the ability to recapture it; this would have caused an underestimate of the density of eels. To account for this, eels were marked one day and recaptured the following day. This was intended to minimize the effects of shocking and capture as well as minimize the opportunity for immigration and emigration. However, the time between marking and recapturing was less than 24 hours and if any additions and/or deletions to or from the marked reach occurred, they would likely be minimal.

The probability of capture/recapture was assumed to be the same for all individuals and remain constant with time, but this may not hold true. Larger eels may have been more efficient at avoiding the electrical field or smaller eels may have been more difficult to see, yet spotters observed very few eels elude capture regardless of size. Population size estimates were calculated for all eels and also separately by the following size classes: 0-200 mm, 201-400 mm, and 401 mm and greater. In addition, I assumed that capturing an animal in the first sample has neither a positive nor negative effect on recapturing that animal. If capturing an eel in the first sample has a negative effect on the ability to recapture it, this may cause an overestimate of the density of eels.

Growth Rates

Lengths to the nearest millimeter and weights to the nearest gram were taken for all eels during the population estimate sampling in 2000 and 2001. Any untagged eels were tagged with PIT-tags, weighed, and measured. All eels previously tagged were also weighed and measured. Recapture of eels marked with PIT-tags provided an estimate of growth for the interval between the time the eels were marked and the time they were recaptured. Growth was expressed in terms of absolute increase in length (l_2-l_1) and weight (w_2-w_1). The recapture event for each stream was planned approximately one year after tagging. Since all eels were marked and recaptured during the same weeks, comparisons of average eel growth among streams were possible.

One Stowaway Tidbit temperature logger was placed in each stream in a well-shaded area at the bottom of each marked sample reach. The loggers recorded the water temperature once an hour every day from 10/18/00 to 2/8/01. Temperature differences among streams may provide an explanation for differences in growth.

Data Analysis: Null Hypothesis 2.1

Statistical tests were performed to determine differences between habitat composition within the study reaches of S.F. Tye River, S.F. Piney River, and Shoe Creek. A one-way ANOVA was used to test differences in average depth among streams. Chi-square analyses were performed to assess differences among pool/riffle area ratios, dominant substrate composition, and cover availability.

Data were analyzed to determine relative habitat preference for all eels within a stream each season. Compositional analysis was used to determine if proportions of habitat available varied from proportional habitat use among seasons (Aebischer et al. 1993). Compositional analysis is a statistical method to determine relative preference based on proportions of availability and use. Proportions of habitat available for each stream were determined by calculating percentages of available habitat relative to the entire 2-km reach for each stream. Proportional habitat use was calculated for individual fish based on the number of observations of each fish per season and the percentage of observations that each fish was located in a particular habitat. Habitat descriptors included habitat unit type (pool or riffle), depth (three categories: shallow, medium, and deep relative to the particular stream), and dominant substrate. The sample size for the data used was the number of individuals tracked in each stream per season and not the number of times each fish was located.

Log-ratios of the proportions of habitat type used by each individual and habitat available (relative to the stream the individual occupied) were compared by compositional analysis, which includes all MANOVA/MANCOVA-type linear models (Aebischer et al. 1993). To determine relative habitat preference I used a Statistical Analysis Software (SAS) program by Peter Ott and Fred Hovey (1997) (http://nhsbig.inhs.uiuc.edu/wes/habitat.html). This program determined if differences existed between habitat available and habitat used. If differences did exist between availability and use, the program would also rank the habitat types in order from least to most preferred. The critical value for all compositional analysis tests was 0.05.

Data Analysis: Null Hypothesis 2.2

I used Bailey's modification of the Petersen method (Ricker 1975) to estimate population densities of eels by size classes in each stream. The formula was as follows:

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

"N" is the estimation of the population size, "M" is the number of fish marked and released (1st sample), "C" is the number of fish collected and examined for marks (2nd sample), and "R" is the number of recaptures.

The estimate for variance was as follows:

$$V(N) = \frac{M^2 (C + 1)(C - R)}{(R + 1)^2 (R+2)}$$

A 95% confidence interval was calculated for each stream as follows:

$$N = \pm 1.96(\text{var } N)^{0.5}$$

Population estimates were significantly different when confidence intervals did not overlap.

Results

Available Habitat

Average depth and pool/riffle area ratios were similar, but dominant substrate composition and cover availability varied among the three streams. There was not a statistical difference in average depth among the three streams (p=0.440); 36 cm, 35 cm, and 33 cm for S.F. Tye River, S.F. Piney River, and Shoe Creek, respectively. There was not a significant difference in pool/riffle area ratios among the three streams (chi-square; p=0.300); 1:1.63, 1:2.70, and 1:2.13 for S.F. Tye River, S.F. Piney River, and Shoe Creek, respectively. Although cobble was the dominant substrate in all three streams, percentages of dominant substrate differed among streams (chi-square; $p<0.001$). Multiple comparisons were performed to detect which streams differed. An adjusted alpha level was calculated using the following formula $\alpha = \alpha /(2k)$, where k equals the number of treatments, or in this case the number of streams. Thus, instead of $\alpha = 0.05$, $\alpha = 0.008$. Dominant substrate composition differed between S.F. Tye River and S.F. Piney River ($p<0.001$) and S.F. Tye River and Shoe Creek ($p<0.001$), but not between S.F. Piney River and Shoe Creek ($p = 0.652$). S.F. Tye River has more small substrate (small gravel, large gravel, and cobble, collectively), but less large substrate (boulder and bedrock, collectively), than S.F. Piney and Shoe Creek (Figure 2.1). There was a significant difference in cover availability among the three streams (chi-square, $p = 0.000$). Based on pairwise comparisons, there was significantly less cover in S.F. Tye versus S.F. Piney ($p = 0.000$) and S.F. Tye versus Shoe Creek ($p = 0.000$), but no difference in available cover between Shoe Creek and S.F. Piney ($p = .0785$).

Relative Habitat Preference

Relative habitat preference was determined for eels in S.F. Tye, S.F. Piney, and Shoe Creek over multiple seasons. Percentages of available habitat and habitat used by eels in all three streams are listed in Tables 2.1 – 2.3. Percentages of available habitat were compared to percentages of habitat used by eels in each stream to determine relative preference.

Stream depth was categorized as shallow, medium, and deep, relative to each stream. This resulted in similar proportions of each category among streams. Eels showed a depth preference in only two seasons throughout the study based on compositional analysis. The deepest habitat available (31-125 mm) was most preferred in Shoe Creek during fall of 2000. A depth range of 21-30 mm ranked second in relative preference during fall of 2000. A depth range of 0-20 mm was least preferred in Shoe Creek during fall of 2000. The deepest habitat available (41-100 mm) was most preferred in S.F. Piney during spring of 2001. A depth range of 26-40 mm ranked second in relative preference in S.F. Piney during spring of 2001. A depth range of 0-25 mm was least preferred in S.F. Piney during spring of 2001. There was not a significant difference between average depth available and average depth used for all other seasons monitored (Table 2.1). However, eels usually used the deepest water proportionally more, and the shallowest water proportionally less the percentage available (Table 2.1). This was the case in every stream during every season except S.F. Tye River in summer 2000, when eels used the shallowest depth range (0-25 mm) 45% of the time, when it was available in only 33% of the reach (Table 2.1).

Eels preferred pools over riffles during all seasons they were monitored in Shoe Creek (summer, fall, winter, and spring) and S.F. Piney (spring and summer) (Table 2.2). Eels showed no statistical preference for pools or riffles during any season in S.F. Tye River (p-value always exceeded 0.05) (Table 2.2). However, eels used pools 55%-72% of the time monitored throughout the study (summer, fall, winter, and spring), although pools were available in only 32%-38% of the area of the study reaches. Thus, in every stream during every season eels used pools a greater percentage of the time than the percentage available and used riffles a lower percentage of the time than the percentage available.

Cobble was the most preferred substrate for eels in S.F. Tye River during all seasons monitored (summer, fall, winter, and spring) ($p<0.001$) (Table 2.3). Eels exhibited no preference for substrate during either spring or summer in S.F. Piney River ($p > 0.05$). Unlike eels in S.F. Tye and S.F. Piney, eels in Shoe Creek substrate preference seemed to vary depending on season. Eels in Shoe Creek preferred cobble, small gravel, and bedrock during fall ($p = 0.0001$), winter ($p = 0.001$), and spring ($p = 0.040$), respectively. Eels exhibited no preference for substrate during summer in Shoe Creek ($p = 0.396$).

Overall, eels preferred the deepest water available and pools. Eels in S.F. Tye River preferred cobble as the dominant substrate during all seasons. Eels in Shoe Creek varied in preference for dominant substrate among seasons, but eels in S.F. Piney River showed no preference for dominant substrate.

Density Estimates

Numbers of eels were calculated for each stream's 1-km reach in summer of 2000 and summer 2001 by size classes: 0-200 mm, 201-400 mm, and 401 mm and greater, and all eels combined (Table 2.4). Density estimates (eels per hectare) were calculated by dividing the area of each stream's designated 1-km reach by the number of eels estimated to be in that reach. In addition, 95% confidence intervals for density estimates were also calculated for all three streams in each of the three size classes and for all eels combined (Table 2.5).

There was a significant difference in the density of eels for all sizes combined, as well as density of eels 200-400 mm and 401 mm and greater between S.F. Piney and S.F. Tye in both 2000 and 2001 (Table 2.5). There was also a significant difference in the density of eels of all sizes combined and eels 401 mm and greater between Shoe Creek and S.F. Tye River in 2001 (Table 2.5). There were no significant differences between densities of eels of all size classes between Shoe Creek and S.F. Piney (Table 2.5). In general, S.F. Tye River had the highest eel density of the three streams.

Growth Rates

Eighty-five, two, and 28 fish were tagged in 2000 and recaptured in 2001 in S.F. Tye River, S.F. Piney River, and Shoe Creek, respectively (Figure 2.2 a). Growth rates were 0.063 mm/day for S.F. Tye, 0.050 mm/day for S.F. Piney, and 0.056 mm/day for Shoe Creek. This converts to 23 mm/year for S.F. Tye, 18 mm/year for S.F. Piney, and 20 mm/year for Shoe Creek.

Growth rates were also calculated for Shoe Creek from 1999 through 2000 and 2001. Sixty-eight eels were tagged in summer and early fall of 1999. Twenty-two eels were recaptured in the summer of 2000 and 14 were recaptured in the summer of 2001. Growth rates from 1999 through 2000 were 0.118 mm/day (Figure 2.2 a) or 43 mm/year. Growth rates from 1999 through 2001 were 0.878 mm/day (Figure 2.2 a) or 32 mm/year.

Statistical differences in growth rate (mm/day) were detected among years based on a one-way ANOVA ($p<0.001$). There was a significant difference in growth rates between Shoe Creek 1999-2000 and Shoe Creek 2000-01 as well as Shoe Creek 1999-2000 and S.F. Tye River 2000-01 based on Turkey's pairwise comparisons (Figure 2.2 a).

Eighty, two, and 26 fish were marked in 2000 and recaptured in 2001 in S.F. Tye River, S.F. Piney River, and Shoe Creek, respectively (Figure 2.2 b). Growth rates were 0.056 g/day for S.F. Tye, 0.065 g/day for S.F. Piney, and 0.073 g/day for Shoe Creek. This converts to 20 g/year for S.F. Tye, 24 g/year for S.F. Piney, and 27 g/year for Shoe Creek.

Growth rates relative to weight were also calculated for Shoe Creek from 1999 through 2000 and 2001. Growth rates from 1999 through 2000 were 0.136 g/day or 50 g/year based on 14 recaptures (Figure 2.2 b). Growth rates from 1999 through 2001 were 0.110 g/day or 40 g/year based on 11 recaptures (Figure 2.2 b). Sample sizes on Shoe Creek were smaller for weights than lengths because we were unable to weigh some of the larger eels at the time of marking in summer and fall of 1999.

Statistical differences in growth rates (g/day) were detected among seasons based on a one-way ANOVA ($p = 0.001$). There was a significant difference in growth rates between Shoe Creek 1999-2000 and Shoe Creek 2000-01 as well as Shoe Creek 1999-2000 and S.F. Tye River 2000-01 based on Tukey's pairwise comparisons (Figure 2.2 b). These patterns are consistent with length growth differences among streams and years.

There was a statistical difference in the temperature profiles for each of the three streams based on a one-way ANOVA ($p< 0.001$). Shoe Creek had a significantly higher average temperature than S.F. Piney and S.F. Tye based on Tukey's Studentized Range test.

Larger eels showed decreased growth in length (Figures 2.3 and 2.4 a and b) and increased growth in weight (Figures 2.5 and 2.6 a and b). This was expected because typical growth of fishes is rapid in length at early ages and growth of fishes in weight is rapid during the latter stages of life (Van Den Avyle and Hayward 1999). Because growth was determined for each stream and movement data was pooled across streams, no inferences between growth and movement were made in this study. Individual growth versus movement was also not compared because growth information was obtained for only one telemetry eel.

Discussion

Relative Habitat Preference

Eels monitored in each stream had different habitat preferences. Although pool use was always greater than pool availability (Table 2.2), eels in S.F. Tye River had no preference for depth or habitat type (pool or riffle) during any season, yet cobble was ranked first in order of relative preference for substrate among all seasons. Eels in S.F. Piney had no preference for a particular substrate during any season, but preferred pools during both spring and summer and also had a preference for the deepest habitat available during spring. Eels in Shoe Creek preferred pools during all seasons (summer, fall, winter, and spring), yet had differences in the dominant substrate preferred during fall, winter, and spring (cobble, small gravel, and bedrock, respectively). Eels in Shoe Creek showed a preference for depth only during fall (31-125mm). These inconsistent results make interpretation of overall habitat preference of eels for all seasons difficult. Relative habitat preference of eels varied among streams, even within the same watershed.

The one consistent trend throughout the study was the preference for pools over riffles. Eels used pools 55% -97 % of time when located on a weekly basis (summer 2000 - summer 2001) (Table 2.2). In contrast, 62%, 68%, and 73% of the area surveyed in the 2km designated reaches of S.F. Tye, Shoe Creek, and S.F. Piney respectively, consisted of riffles. Even though riffle area was greater in abundance for each stream, eels showed a relative preference for pools (Table 2.2). Eels were always found in a higher frequency in pools over riffles, although a statistical significance was only found for all seasons in Shoe Creek and S.F. Piney.

These findings are contrary to previous studies that suggested that eels preferred flowing water. Goodwin (1999) had greater capture success in flowing areas as opposed to backwaters and other slack-water areas on the South Fork of the Shenandoah River, Virginia. However, pools and flowing areas in streams of this study were quite different from pools and flowing areas in the S.F. Shenandoah River. Pools in S.F. Shenandoah River are often several meters deeper than pools of streams studied in this project and depth in flowing areas of the S.F. Shenandoah River are generally greater than the deepest flowing areas of streams studied in this project (Daniel Lafoon, VDGIF, personal communication). Thus, habitat use comparisons are difficult to make with such great differences on a spatial scale. Furthermore, eels may not have general habitat preferences, but exhibit habitat preferences on a stream to stream basis, depending on habitat availability.

Density Estimates

S.F. Tye River had a higher density of eels than Shoe Creek or S.F. Piney. However, only S.F. Piney was significantly different from S.F. Tye River in both years. The difference may be due to the additional barrier (1.5 meter dam on Piney River) that fish must overcome when migrating upstream on Piney River. Historical information suggests that eels decline in abundance with increasing distance from the ocean and the number of migration barriers (i.e. dams) (ASMFC 2000).

I also expected that Shoe Creek would have a significantly lower eel density than S.F. Tye, due to the additional migration barrier, but this was not the case in either year of sampling. S.F. Tye had a higher density of eels than Shoe Creek in 2001, but only for individuals $\geq$ 401 mm and all sizes combined. However, densities were higher in S.F. Tye than the other two streams for both years and all sizes. Eels were present throughout S.F. Tye, yet in Shoe Creek and S.F. Piney the sampling crew would sometimes go 100-200 meters without seeing an eel.

Density estimates of S.F. Tye River, S.F. Piney River, and Shoe Creek can be compared to others waters in Virginia. In his study of American eels on the South Fork of the Shenandoah River (SFSR), Virginia, Goodwin (1999) estimated a density of 14 eels/ha. This is similar to estimates in S.F. Piney River and Shoe Creek in both 2000 and 2001 (Table 2.6). However, density estimates of eels in S.F. Tye River in 2000 were nearly three times greater than SFSR and nearly four times greater for S.F. Tye River in 2001 than SFSR (Table 2.6).

Only one marked eel was captured outside the 1-km designated reach in both years of sampling the three streams. A marked eel was captured seven meters below the start of the marked reach on the recapture day of sampling in S.F. Tye River in 2001. The eel was originally captured within the first meter of the marking reach. Considering this was the only marked eel captured outside the marking reach throughout the entire mark/recapture study for all three streams, little emigration was suspected to occur between the time of the first and second sample. I have no reason to suspect that eels may have moved out of the marked reach; thus the density estimate for S.F. Tye River was valid for the time of the first sample or the day of marking (Pollock et al. 1990).

Growth Rates

Growth rates by length were similar for all three streams in 2000-2001. However, annual growth rates in length for fish in Shoe Creek were much higher from 1999-2000 than any stream's growth rates from 2000-2001. There was a significant difference between growth rates (mm/day) in the streams between years (ANOVA $p<0.001$). There were significant differences between Shoe Creek from 1999-2000 and Shoe Creek 2000-

01, as well as Shoe Creek 1999-2000 and S.F. Tye River 2000-01. Annual growth rates for length of fish marked in 1999 and recaptured in 2001 also were higher than growth rates from all streams from 2000-01.

Growth rates by length (mm/year) were lower than those of other published studies. Gunning and Shoop (1962) had a growth rate of 232 mm/year in their study in Talisheek Creek, LA. Helfman et al. (1984b) had a growth rate of 62 mm/year in their study of Fridaycap Creek, GA. Goodwin (1999) had a growth rate of 43 mm/year in his study of the Shenandoah River drainage, which is more similar to the growth rates of this study (Figure 2.7). Such differences in growth could be attributed to differences in latitude between studies or seasonal growth conditions from year to year (Oliveira 1997)

Growth rates by weight (g/day) were higher in Shoe Creek, throughout all years monitored, than in S.F. Tye and S.F. Piney. Growth rates by weight for Shoe Creek from 1999-2000 were more than twice that of eels in S.F. Tye and S.F. Piney from 2000-2001. Significant differences in growth rates (g/day) were detected between Shoe Creek 1999-2000 and Shoe Creek 2000-2001, as well as Shoe Creek 1999-2000 and S.F. Tye 2000-2001. Comparable growth data in weight for eels were not found in the literature.

Water temperature was higher in Shoe Creek than in S.F. Tye and S.F. Piney (Figure 2.7). Because water temperature is a correlate of growth, this may have been a factor in why growth rates were higher in Shoe Creek than in S.F. Tye and S.F. Piney. Average water temperature in Shoe Creek may have been more similar to the optimum temperature for growth of eels.

The differences in growth rates (g/day) could also be due to higher densities of eels in S.F. Tye. Densities of 41 and 54 eels/ha were estimated in S.F. Tye for 2000 and 2001. Densities of 25 and 15 eels/ha were estimated for Shoe Creek in 2000 and 2001. Shoe Creek had higher growth rates than S.F. Tye from 2000-2001 (0.073 g/day vs. 0.056 g/day). Shoe Creek had even higher growth rates in 1999-2000 (0.136 g/day) and 1999-2001 (0.110 g/day). The higher density of eels in S.F. Tye may result in greater intraspecific competition, and a lower rate of growth. This has been documented in other fish species. Novinger and Legler (1979) found that bluegill in higher densities in small impoundments grew slower than bluegill in lower densities. However, Oliveira (1999) reported that mean growth rates did not appear to be correlated with density in a study of

American eels on the Annaquatucket River, RI. Thus, differences in growth may be attributed to others factors outside the realm of this study.

An estimate of eel biomass in the study reaches was calculated to determine if slower growth was compensated by higher density. Biomass estimates of eels of the three streams were calculated using the average weight and density of eels of the following size classes: 0-200 mm, 201-400 mm, and ≥ 401 mm. Estimates for biomass of eels in the study reaches was 982, 2661, and 3985 g/ha in 2000 for S.F. Piney, Shoe Creek, and S.F. Tye, respectively. Estimates in 2001 were 711, 1433, and 6095 g/ha for S.F. Piney, Shoe Creek, and S.F. Tye, respectively. This was not expected because eels in S.F. Tye River had less available cover than eels of S.F. Piney and Shoe Creek. This suggests that eel biomass is not related to available cover or that my estimate of cover is inadequate. Further investigation beyond the scope of this study is needed to determine other possible explanations.

Conclusions

Through the use of radio telemetry and mark and recapture techniques, I was able to determine information on habitat preference, density, and growth of eels in S.F. Tye River, S.F. Piney River, and Shoe Creek.

Based on what I found:

1.) Eels preferred the deepest water, pools, and predominately larger substrate when differences were detected
2.) Density for eels of all sizes was significantly higher for S.F. Tye River than for S.F. Piney in 2000 and higher in S.F. Tye than for Shoe Creek and S.F. Piney in 2001
3.) Density of eels 0-200 mm and $\geq$ 401 mm was higher for S.F. Tye than for S.F. Piney in both 2000 and 2001
4.) Density of eels $\geq$ 401 mm was higher for S.F. Tye than for Shoe Creek
5.) Eels grew an average of 20 mm and 24 g from July 2000 – July 2001.
6.) Daily growth was higher for length and weight from 1999-2000 for Shoe Creek than all streams monitored from 2000-2001.

Future Research and Management Recommendations

When statistical differences were detected, it appeared that eels preferred pools, relatively deep water, and large substrate. These habitat characteristics are endangered by activities such as logging and land development that can lead to habitat degradation (FISRWG 1998). Habitat degradation is exemplified by a variety of factors including shallow water depths and embedding of stream sediments (FISRWG 1998). Such activities must be avoided to protect the habitat of the eel within the streams of this watershed.

Eel sampling via electrofishing should be conducted during the warmer months of the year. Based on estimates of numbers of eels in the designated reaches, 16% to 42% of eels were captured during the first day of sampling on each stream in 2000 and 2001 (Table 2.4). This range of capture would be significantly lower if streams were sampled during colder months due to a change in the eel's behavior. I recommend that eel sampling in these streams be restricted to June, July, and August to ensure greatest capture success.

Marking eels with PIT-tags was effective in determining growth of eels in these streams. Based on the results of this study, eels can be recaptured year after year, and growth of individuals can be monitored as long as eels do not leave a designated study reach. Of 31 individuals that were successfully monitored weekly via radio telemetry in this study, only 6 left the study reach (19%) (Chapter 1, Tables 1.7-1.11). Two of the six were suspected to be sexually mature. One was identified before transmitter implantation and the other was not. Based on this, PIT-tags are a useful tool to estimate growth of sexually immature eels.

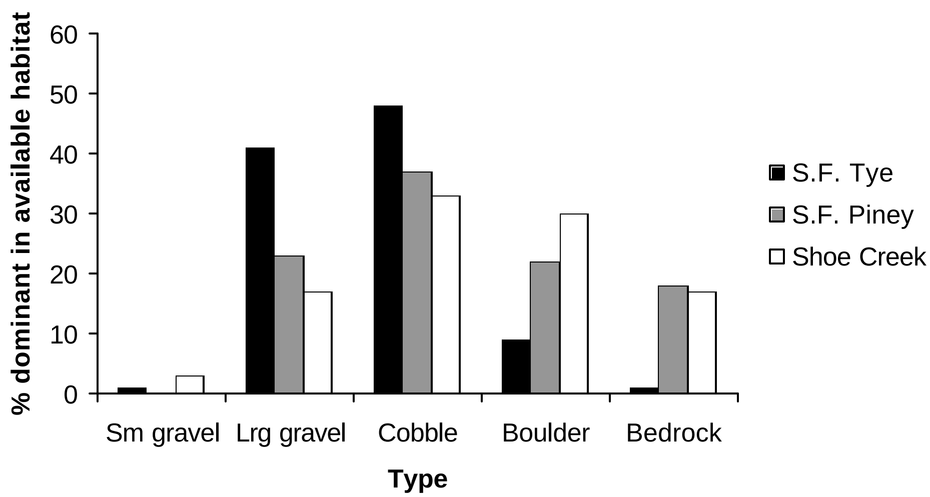


Figure 2.1 Percentages of dominant substrate for S.F. Tye River, S.F. Piney River, and Shoe Creek.

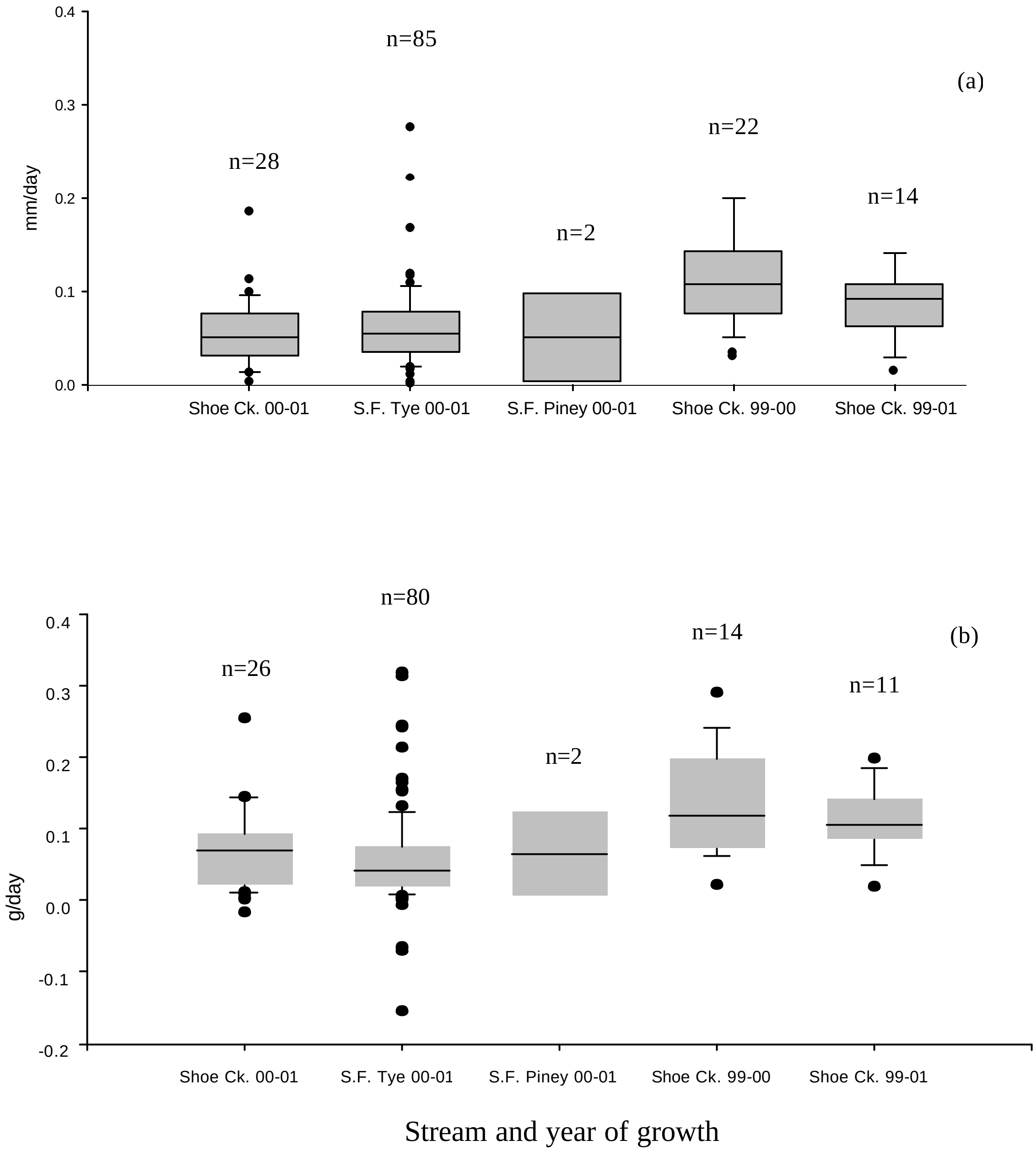
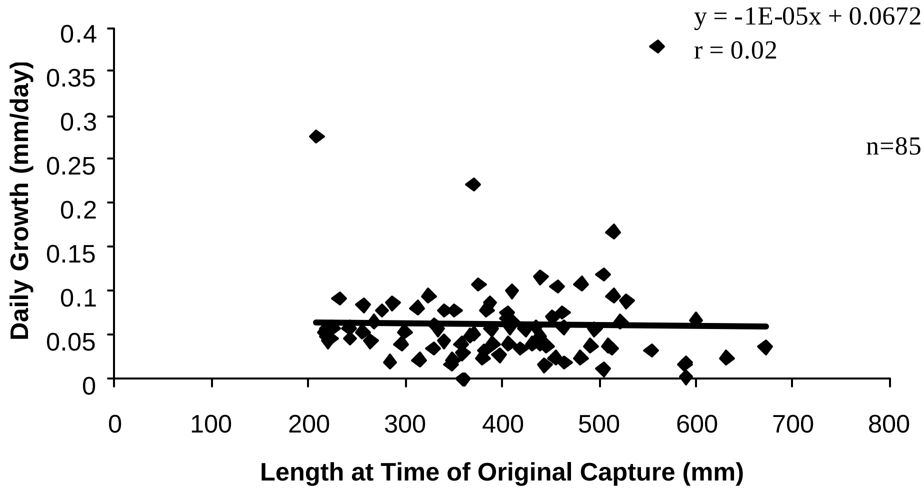


Figure 2.2 Box plots of daily growth in length (mm) (a) and weight (g) (b) for American eels in Shoe Creek, S.F. Piney River, and S.F. Tye River. Line in box represents the median, box represents 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, and the black dots represent outliers.

(a)



(b)

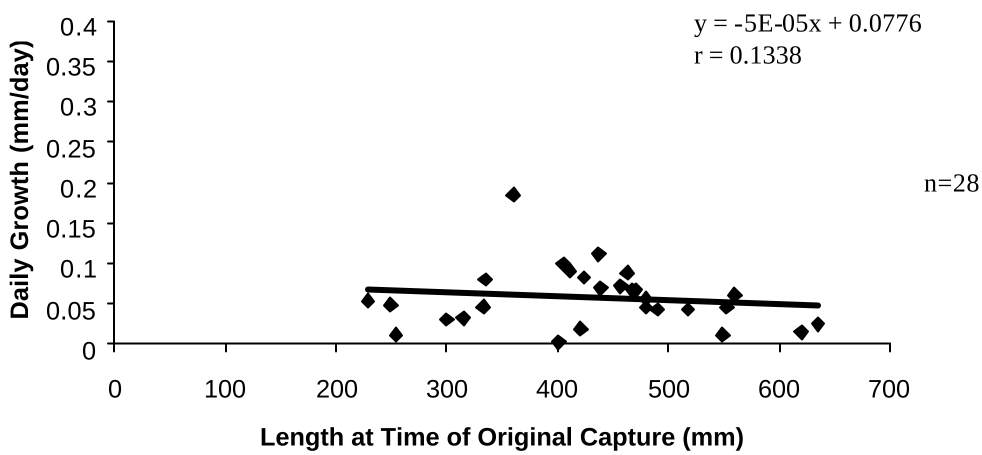
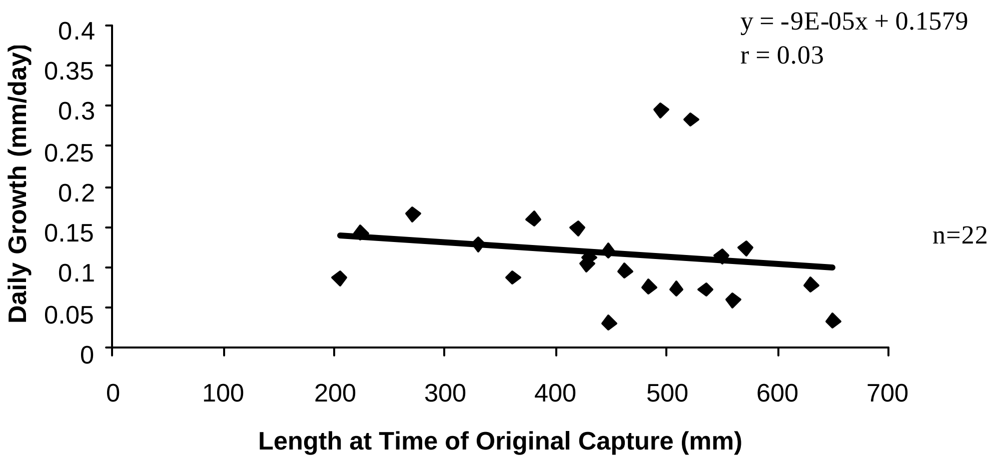


Figure 2.3 Scatter plots of daily growth (mm/day) vs. length at time of original capture in S.F. Tye 2000-01 (a) and Shoe Creek 2000-01 (b).

(a)



(b)

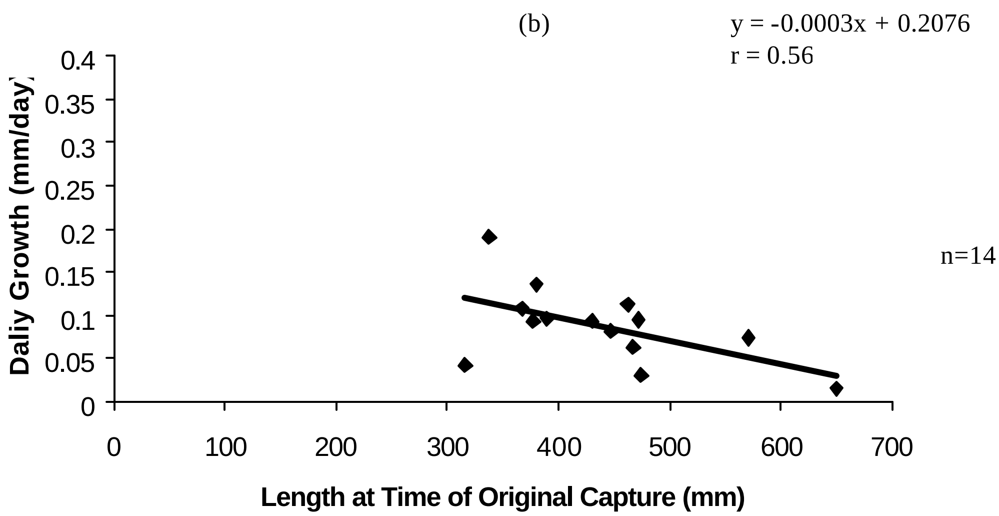
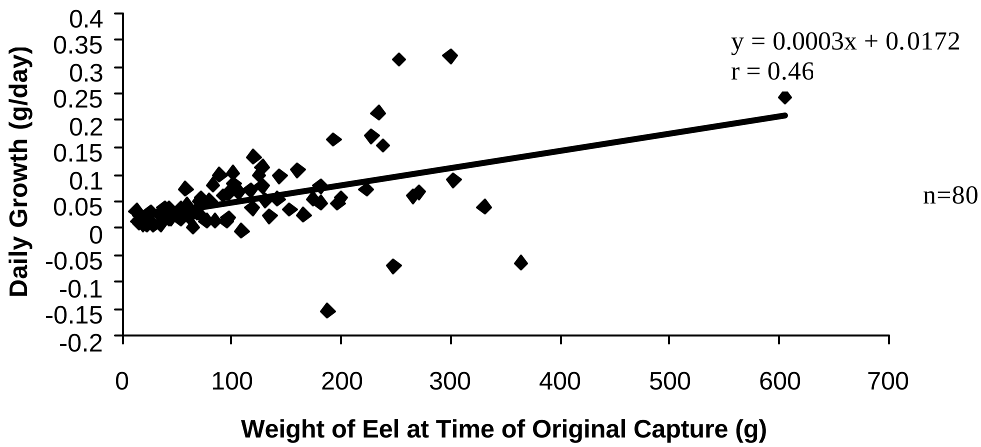


Figure 2.4 Scatter plots of daily growth (mm/day) vs. length at time of original capture in Shoe Creek, 1999-2000 (a) and 1999-2001 (b).

(a)



(b)

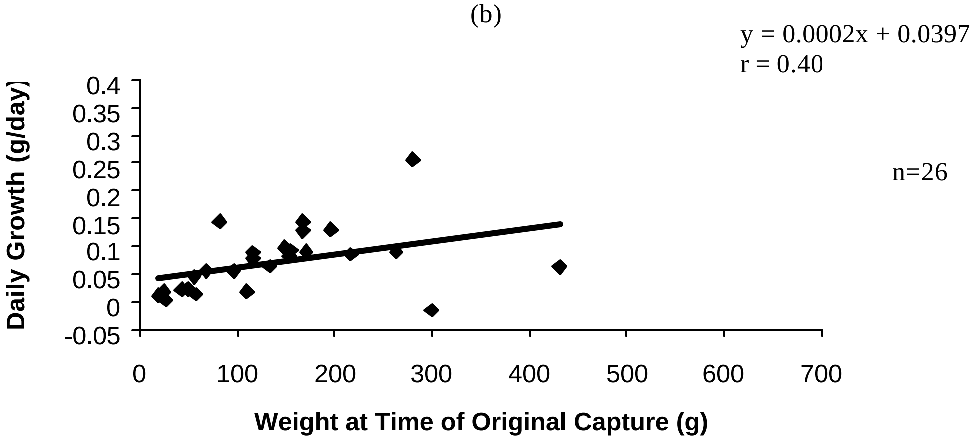
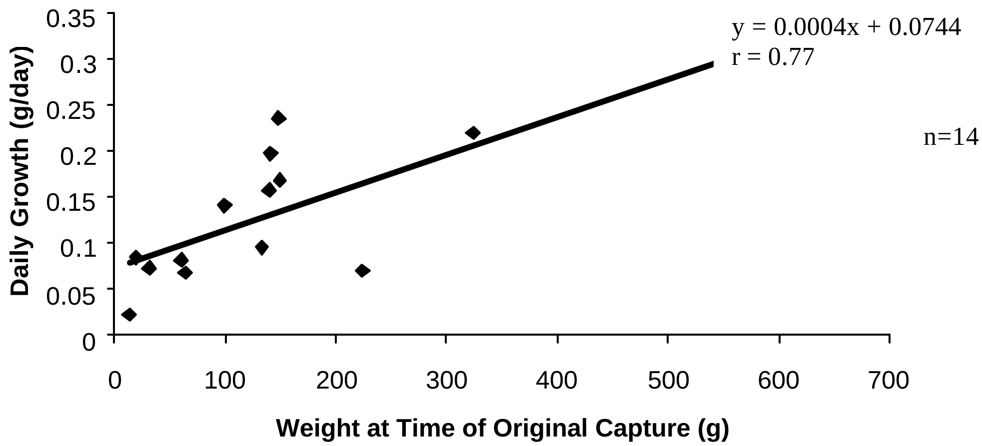


Figure 2.5 Scatter plots of daily growth (g/day) vs. weight at time of original capture in S.F. Tye 2000-01 (a) and Shoe Creek 2000-01 (b).

(a)



(b)

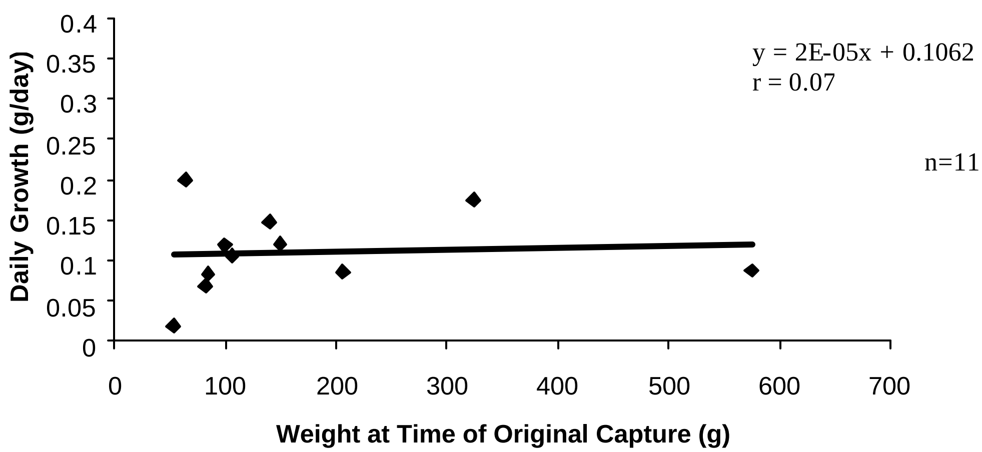


Figure 2.6 Scatter plots of daily growth (g/day) vs. weight at time of original capture in Shoe Creek, 1999-2000 (a) and 1999-2001 (b).

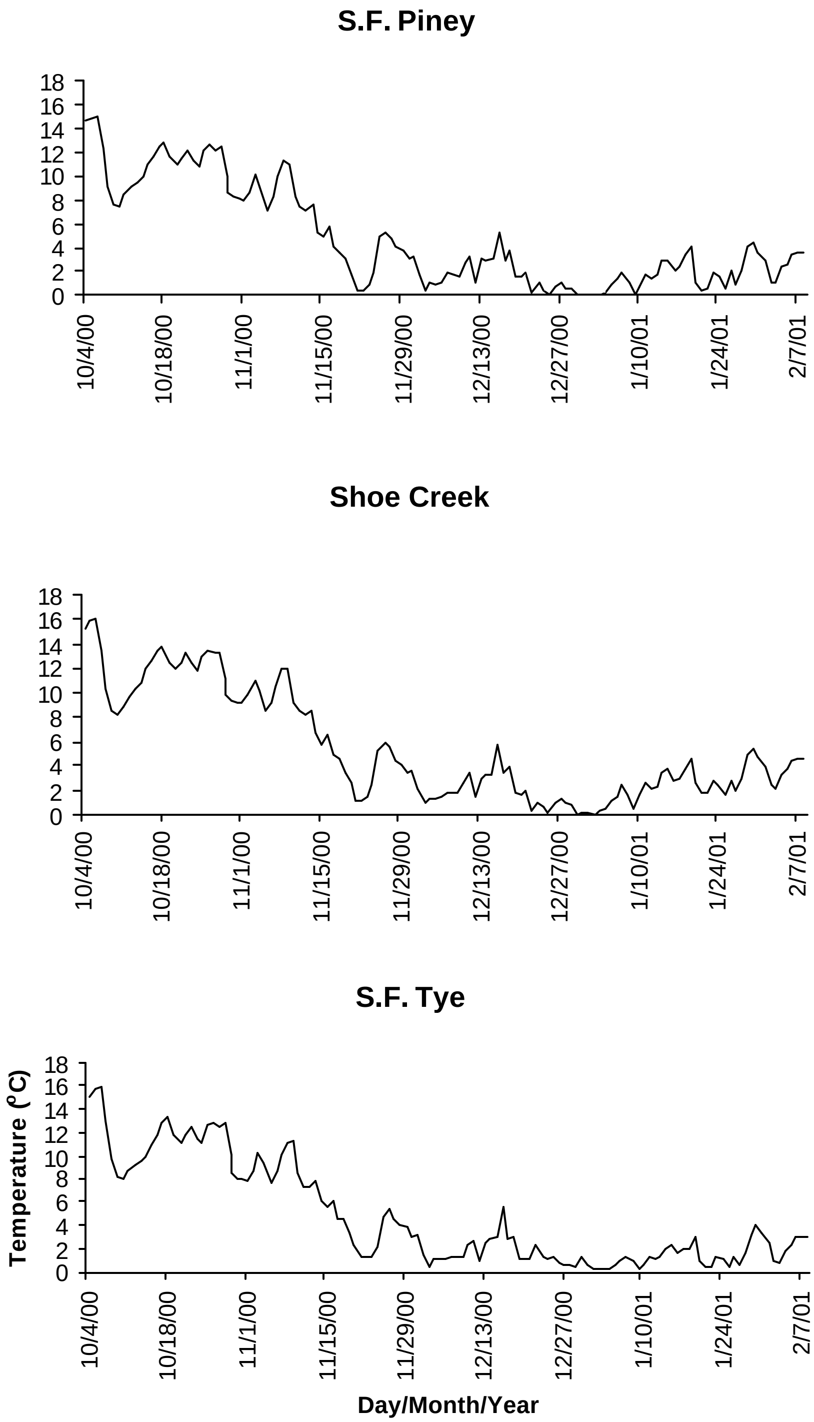


Figure 2.7 Temperature profiles of each stream from 10/4/00 through 2/8/01.

Table 2.1 Compositional analyses for habitat availability vs. use for average depth. Critical value for MANOVA = 0.05. "Rank" is the ranking of habitats in order of least to most preferred.

	# observations	Range (mm)	% Avail.	% Used	Rank	p value
			S.F. Tye			
Summer 2000	144	0-25	0.33	0.45		
n=10		26-40	0.35	0.19		
		41-65	0.32	0.36		0.6158
Fall 2000	99	0-25	0.33	0.27		
n=6		26-40	0.35	0.30		
		41-65	0.32	0.43		0.9398
Winter 2000-01	90	0-25	0.33	0.14		
n=5		26-40	0.35	0.26		
		41-65	0.32	0.60		0.6699
Spring 2001	77	0-25	0.33	0.20		
n=5		26-40	0.35	0.20		
		41-65	0.32	0.60		0.6699
			S.F. Piney			
Spring 2001	95	0-25	0.39	0.04	3	
n=9		26-40	0.34	0.26	2	
		41-100	0.27	0.70	1	0.0029
Summer 2001	146	0-25	0.39	0.23		
n=10		26-40	0.34	0.14		
		41-100	0.27	0.63		0.1417
			Shoe Creek			
Summer 2000	47	0-20	0.31	0.11		
n=10		21-30	0.32	0.33		
		31-125	0.37	0.56		0.1897
Fall 2000	129	0-20	0.31	0.06	3	
n=9		21-30	0.32	0.20	2	
		31-125	0.37	0.74	1	0.049
Winter 2000-01	113	0-20	0.31	0		
n=8		21-30	0.32	0.22		
		31-125	0.37	0.78		0.3119
Spring 2001	67	0-20	0.31	0.14		
n=11		21-30	0.32	0.17		
		31-125	0.37	0.69		0.2746

Table 2.2 Compositional analyses for habitat availability vs. use for habitat type. Critical value for MANOVA = 0.05. "Rank" is the ranking of habitats in order of least to most preferred.

	# observations	Habitat type	% Avail.	% Used	Rank	p value
			S.F. Tye			
Summer 2000	144	Pool	0.38	0.55		
n=10		Riffle	0.62	0.45		0.4501
Fall 2000	99	Pool	0.38	0.61		
n=6		Riffle	0.62	0.39		0.3573
Winter 2000-01	90	Pool	0.38	0.72		
n=5		Riffle	0.62	0.28		0.6334
Spring 2001	77	Pool	0.38	0.67		
n=5		Riffle	0.62	0.33		0.6334
			S.F. Piney			
Spring 2001	95	Pool	0.27	0.83	1	
n=9		Riffle	0.73	0.17	2	0.0025
Summer 2001	146	Pool	0.27	0.81	1	
n=10		Riffle	0.73	0.19	2	0.0063
			Shoe Creek			
Summer 2000	47	Pool	0.32	0.89	1	
n=10		Riffle	0.68	0.11	2	0.0004
Fall 2000	129	Pool	0.32	0.87	1	
n=9		Riffle	0.68	0.13	2	0.0014
Winter 2000-01	113	Pool	0.32	0.97	1	
n=8		Riffle	0.68	0.03	2	< .0001
Spring 2001	67	Pool	0.32	0.78	1	
n=11		Riffle	0.68	0.22	2	0.0428

Table 2.3 Compositional analyses for habitat availability vs. use for dominant substrate. Critical value for MANOVA = 0.05. "Rank" is the ranking of habitats in order of least to most preferred.

	# observations	Substrate Type	% Avail.	% Used	Rank	p value
			S.F. Tye			
Summer 2000 n=10	144	Sm. gravel	0.01	0	4	
		Lrg. gravel	0.41	0.16	2	
		Cobble	0.48	0.78	1	
		Boulder	0.09	0.01	5	
		Bedrock	0.01	0.05	3	< .0001
Fall 2000 n=6	99	Sm. gravel	0.01	0	2	
		Lrg. gravel	0.41	0.18	4	
		Cobble	0.48	0.82	1	
		Boulder	0.09	0	5	
		Bedrock	0.01	0	2	< .0001
Winter 2000-01 n=5	90	Sm. gravel	0.01	0	2	
		Lrg. gravel	0.41	0.2	4	
		Cobble	0.48	0.8	1	
		Boulder	0.09	0	5	
		Bedrock	0.01	0	2	< .0001
Spring 2001 n=5	77	Sm. gravel	0.01	0	2	
		Lrg. gravel	0.41	0.2	4	
		Cobble	0.48	0.8	1	
		Boulder	0.09	0	5	
		Bedrock	0.01	0	2	< .0001
			S.F. Piney			
Spring 2001 n=9	95	Lrg. gravel	0.23	0		
		Cobble	0.37	0.51		
		Boulder	0.22	0.29		
		Bedrock	0.18	0.20		0.0616
Summer 2001 n=10	146	Lrg. gravel	0.23	0.28		
		Cobble	0.37	0.46		
		Boulder	0.22	0.26		
		Bedrock	0.18	0		0.0831
			Shoe Creek			
Summer 2000 n=10	47	Sm. Gravel	0.03	0.10		
		Lrg. Gravel	0.17	0.20		
		Cobble	0.33	0.32		
		Boulder	0.30	0.08		
		Bedrock	0.17	0.30		0.3955

Table 2.3 (cont.)

	# observations	Substrate Type	% Avail.	% Used	Rank	p value
Shoe Creek						
Fall 2000	129	Sm. gravel	0.03	0.06	4	
n=9		Lrg. gravel	0.17	0.30	3	
		Cobble	0.33	0.31	1	
		Boulder	0.30	0	5	
		Bedrock	0.17	0.33	2	0.0005
Winter 2000-01	113	Sm. gravel	0.03	0.22	1	
n=8		Lrg. gravel	0.17	0.16	3	
		Cobble	0.33	0.25	4	
		Boulder	0.30	0	5	
		Bedrock	0.17	0.37	2	0.0011
Spring 2001	67	Sm. gravel	0.03	0.15	2	
n=11		Lrg. gravel	0.17	0.14	4	
		Cobble	0.33	0.26	3	
		Boulder	0.30	0.01	5	
		Bedrock	0.17	0.44	1	0.0401

Table 2.4 Estimated number of eels in 1000-m designated reaches of Shoe Creek, S.F. Piney, and S.F. Tye for summer 2000 and summer 2001. "Mark" is total number of fish marked on the 1st day. "Capture" is the total number of fish captured on the 2nd day.

	All sizes	0-200 mm	201-400 mm	≥ 401
		Shoe 2000		
Mark	43	5	23	15
Capture	37	4	15	18
Recapture	8	0	4	4
Estimate	186	30	77	61
C.I.	91-284	9-61	34-126	29-100
		Shoe 2001		
Mark	45	8	20	17
Capture	21	4	7	10
Recapture	8	2	1	5
Estimate	107	15	84	33
C.I.	58-159	10-23	26-162	22-49
		Piney 2000		
Mark	14	3	5	6
Capture	11	4	5	2
Recapture	1	0	1	0
Estimate	90	20	18	21
C.I.	24-177	7-39	9-32	8-41
		Piney 2001		
Mark	14	3	6	5
Capture	10	3	5	2
Recapture	2	1	1	0
Estimate	55	16	21	18
C.I.	22-98	11-21	10-38	7-35
		Tye 2000		
Mark	105	9	55	41
Capture	77	7	38	32
Recapture	24	1	11	12
Estimate	331	40	182	107
C.I.	227-435	15-75	101-263	65-149
		Tye 2001		
Mark	124	7	66	51
Capture	102	6	44	52
Recapture	29	0	13	16
Estimate	425	56	215	162
C.I.	299-556	13-119	129-301	101-223

Table 2.5 Density estimates (per hectare) of American eels in Shoe Creek, S.F. Piney, and S.F. Tye for summer 2000 and summer 2001

	All sizes	0-200 mm	201-400 mm	$\geq$ 401
		Shoe 2000		
Estimate	25	4	10	8
C.I.	12-38	1-8	4-17	3-13
		Shoe 2001		
Estimate	15	2	11	4
C.I.	7-22	1-3	3-22	3-6
		S.F. Piney 2000		
Estimate	12	2	2	3
C.I.	3-25	1-5	1-4	1-5
		S.F. Piney 2001		
Estimate	7	1	3	2
C.I.	3-13	0-1	1-5	1-4
		S.F. Tye 2000		
Estimate	41	5	22	13
C.I.	28-54	1-9	12-33	8-18
		S.F. Tye 2001		
Estimate	54	7	27	20
C.I.	38-70	1-14	15-38	12-28

Table 2.6 Comparison of density estimates among S.F. Tye River, S.F. Piney River, Shoe Creek and S.F. Shenandoah River from Goodwin (1999).

Stream	year	eels/ha
S.F. Piney	2000	12
S.F. Piney	2001	7
Shoe Creek	2000	25
Shoe Creek	2001	15
S.F. Tye	2000	41
S.F. Tye	2001	54
S.F. Shenandoah	1996-97	14

Table 2.7 Comparison of yearly growth for eels in S.F. Tye, S.F. Piney, and Shoe Creek to other studies.

Stream	n	mm/year
Shoe 2000-01	28	21
S.F. Tye 2000-01	85	23
S.F. Piney 2000-01	2	18
Shoe 1999-2000	14	43
Shoe 1999-2001	11	32
Shenandoah R. drainage, VA (Goodwin 1999)	24	43
Talisheek Ck. LA (Gunning and Shoop 1962)	2	232
Fridaycap Ck., GA (Helfman et al. 1984b)	7	62

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Summary

A comprehensive study was planned to investigate the seasonal distribution, habitat preference, density, and growth of American eels in small headwater tributaries of the James River, with a goal of gaining a better understanding of the biology and ecology of the species.

Several questions arose about the eels in the streams of that area:

1.) What time of day and year are the eels most active?

2.) Where did the eels go between summer and fall of 1999?

3.) What type of habitat do the eels use/prefer?

4.) How many eels are in these streams?

5.) How fast are these eels growing?

I attempted to answer these questions by using radio telemetry techniques (diel activity, seasonal movement, and habitat preference) and PIT-tags (density estimates and growth rates).

1.) I found that eels were more active in spring than others seasons of the year. Eels were most active just after sunset in spring of 2000 and summer of 2000 and 2001. Eels were most active at 12:00 in fall of 2000 and 09:00 in winter of 2000-01.

2.) I found that eels did not leave the streams during the colder water months. Eels began to bury in the interstitial spaces of the stream bottom or under the banks of the stream in October of 2000. Most eels were not actively moving in the stream until May of 2001. This behavior was probably the cause of low capture rates of eels in fall of 1999.

3.) A depth preference was detected only in fall of 2000 for Shoe Creek and in spring of 2001 for S.F. Piney. In both cases, eels preferred the deepest habitat available. Eels preferred pools during all seasons monitored in Shoe Creek and S.F. Piney, but no statistical preference was detected during any season in S.F. Tye. However, eels used pools 55% - 72% of the time in S.F. Tye, although pools were available in only 38% of the area in the study reach. Cobble was the most preferred substrate for eels in S.F. Tye River during all seasons monitored. Eels exhibited no preference for substrate during either spring or summer in S.F. Piney River. Unlike eels in S.F. Tye and S.F. Piney, eels

in Shoe Creek seemed to vary in substrate preference depending on season (fall-cobble, winter-small gravel, spring-bedrock, and summer-no preference).

4.) S.F. Tye had a significantly greater density of eels for all sizes combined, as well as density of eels 200-400 mm and 401 mm and greater than S.F. Piney in both 2000 and 2001. S.F. Tye River also had a significantly greater density of eels of all sizes combined and eels 401 mm and greater than Shoe Creek in 2001. There were no significant differences between densities of eels of any and all size classes between Shoe Creek and S.F. Piney.

5.) Growth in length and weight was greater for eels of Shoe Creek than the other streams of this study. This may be a result of higher temperature in Shoe Creek that may have been closer to the optimum growth temperature of eels. Lower densities of eels in Shoe Creek compared to S.F. Tye may have resulted in reduced interspecific competition in Shoe Creek and increased rate of growth.

My results have contributed to the understanding of the biology and ecology of the American eel in the upper James River drainage, including diel activity, seasonal movements, habitat use, densities, and growth. Eels seem to be more active during spring and summer, particularly at night. They demonstrate very little movement throughout the other seasons of the year. The majority of eels displayed a behavior similar to hibernation, burying in the substrate and under the banks of the stream from mid-fall through mid-spring. Eels showed a trend to use deep pools with large substrate throughout the majority of this study. Eel densities seemed to vary among streams, with higher growth in streams with lower eel densities and a higher average water temperature. I recommend developing a long-term study and monitoring program to determine if eel populations are increasing, decreasing, or stable. Future research should investigate other variables that impact eel densities and growth in these streams such as diet composition, interspecific competition, and water chemistry. The results may improve our understanding of the American eel in these waters and help us to ensure their future viability.

Appendices

Appendix A. Growth of American eels marked in S.F. Tye River in 2000 and recaptured in 2001 (n = 85). "nt" indicates that the measurement was not taken.

Date Marked	Date Recap	Days	Mark Len. (mm)	Recap Len. (mm)	Growth (mm)	Mark Weight (g)	Recap Weight (g)	Growth (g)	PIT #
7/5/2000	7/11/2001	370	389	410	21	101	139	38	42371A0124
7/5/2000	7/11/2001	370	452	478	26	160	200	40	42394E5020
7/5/2000	7/11/2001	370	276	305	29	35	38	3	42396A295A
7/5/2000	7/11/2001	370	554	566	12	331	346	15	4235677B70
7/5/2000	7/11/2001	371	376	416	40	89	126	37	50314C140A
7/6/2000	7/11/2001	369	287	319	32	43	56	13	42357C7D16
7/6/2000	7/12/2001	371	324	359	35	59	75	16	422E2F786E
7/6/2000	7/11/2001	370	397	407	10	109	107	-2	422E334256
7/6/2000	7/11/2001	370	600	625	25	nt	476	na	422E335B4D
7/6/2000	7/11/2001	370	358	373	15	85	90	5	422E336D1E
7/6/2000	7/11/2001	370	515	550	35	253	369	116	422E35765A
7/6/2000	7/12/2001	371	232	266	34	17	26	9	422E455760
7/6/2000	7/11/2001	370	243	260	17	22	24	2	422E46713E
7/6/2000	7/11/2001	370	510	524	14	248	222	-26	422E472414
7/6/2000	7/12/2001	371	444	450	6	135	143	8	422E5F261B
7/6/2000	7/12/2001	371	405	431	26	106	131	25	422E632D6A
7/6/2000	7/12/2001	371	528	561	33	266	288	22	422E662700
7/6/2000	7/11/2001	369	590	597	7	nt	386	na	423B7B1A3F
7/6/2000	7/11/2001	369	312	342	30	53	65	12	423C097B54
7/6/2000	7/11/2001	369	384	413	29	97	121	24	423C14681E
7/18/2000	7/11/2001	357	672	685	13	605	692	87	422E6F7453
7/18/2000	7/11/2001	357	225	246	21	19	23	4	423B7A1754
7/18/2000	7/11/2001	357	242	263	21	22	28	6	423C183127
7/5/2000	7/12/2001	371	481	490	9	188	131	-57	4235751050
7/5/2000	7/12/2001	371	407	422	15	119	133	14	4239464704

Appendix A. (cont.)

Date Marked	Date Recap	Days	Mark Len. (mm)	Recap Len. (mm)	Growth (mm)	Mark Weight (g)	Recap Weight (g)	Growth (g)	PIT #
7/5/2000	7/12/2001	371	296	311	15	42	49	7	4239534770
7/5/2000	7/12/2001	371	268	292	24	34	44	10	4239633002
7/5/2000	7/12/2001	371	457	496	39	193	254	61	423713103A
7/5/2000	7/12/2001	371	256	276	20	29	31	2	423713320D
7/5/2000	7/12/2001	371	491	505	14	200	221	21	42371E665F
7/5/2000	7/12/2001	371	522	546	24	271	296	25	4237291D0E
7/5/2000	7/12/2001	371	590	591	1	364	340	-24	423832307F
7/5/2000	7/12/2001	371	264	280	16	28	31	3	423A0F045B
7/5/2000	7/12/2001	371	410	447	37	102	130	28	502E1C7709
7/5/2000	7/12/2001	371	351	380	29	71	90	19	502E29322A
7/5/2000	7/12/2001	371	341	370	29	58	85	27	42357A6545
7/5/2000	7/12/2001	371	371	390	19	80	99	19	42360B713C
7/5/2000	7/12/2001	371	463	485	22	181	210	29	502F040819
7/5/2000	7/12/2001	371	405	433	28	96	120	24	502F05535B
7/6/2000	7/12/2001	370	446	460	14	131	150	19	422D5B6936
7/6/2000	7/12/2001	370	370	452	82	120	169	49	422D600830
7/6/2000	7/12/2001	370	330	353	23	61	68	7	422D6C6B06
7/6/2000	7/12/2001	370	462	490	28	174	194	20	422D770768
7/6/2000	7/12/2001	370	435	457	22	144	180	36	422E253255
7/6/2000	7/12/2001	370	495	516	21	238	295	57	422E2C3C7E
7/6/2000	7/12/2001	370	380	389	9	97	104	7	422E2D6E59
7/6/2000	7/12/2001	370	411	435	24	117	143	26	422E360237
7/6/2000	7/12/2001	370	217	237	20	19	22	3	422E366079
7/6/2000	7/12/2001	370	329	342	13	45	55	10	422E3F1A4C
7/6/2000	7/12/2001	370	440	483	43	128	170	42	422E414631
7/6/2000	7/12/2001	370	349	357	8	70	80	10	422E444629
7/6/2000	7/12/2001	370	360	360	0	68	79	11	422E452E01
7/6/2000	7/12/2001	370	424	445	21	128	157	29	422E453A65
7/6/2000	7/12/2001	370	340	356	16	65	66	1	422E500A6C

Appendix A. (cont.)

Date Marked	Date Recap	Days	Mark Len. (mm)	Recap Len. (mm)	Growth (mm)	Mark Weight (g)	Recap Weight (g)	Growth (g)	PIT #
7/6/2000	7/12/2001	370	439	457	18	166	175	9	422E587740
7/6/2000	7/12/2001	370	515	577	62	300	418	118	422E6A6E47
7/6/2000	7/12/2001	370	632	641	9	nt	453	na	422E71585C
7/6/2000	7/12/2001	370	299	319	20	44	51	7	422E782564
7/6/2000	7/12/2001	370	504	548	44	228	291	63	42323A0F63
7/6/2000	7/12/2001	370	513	526	13	197	214	17	423533051D
7/6/2000	7/12/2001	370	223	240	17	17	23	6	4236145A2A
7/6/2000	7/12/2001	370	382	394	12	95	100	5	423678100C
7/6/2000	7/12/2001	370	482	522	40	234	313	79	4238280A2C
7/6/2000	7/12/2001	370	347	353	6	70	85	15	423840441C
7/6/2000	7/12/2001	370	440	455	15	142	162	20	423A061545
7/6/2000	7/12/2001	370	218	239	21	13	25	12	423A122A13
7/6/2000	7/12/2001	370	218	236	18	16	20	4	423A16706A
7/6/2000	7/12/2001	370	257	288	31	26	37	11	423B757128
7/6/2000	7/12/2001	370	208	310	102	39	53	14	423B796723
7/6/2000	7/12/2001	370	419	432	13	104	131	27	423B797050
7/6/2000	7/12/2001	370	464	471	7	181	199	18	423B7D7E34
7/6/2000	7/12/2001	370	408	430	22	102	132	30	423C014601
7/6/2000	7/12/2001	370	504	508	4	223	250	27	423C025A50
7/6/2000	7/12/2001	370	588	594	6	303	336	33	423C031809
7/6/2000	7/12/2001	370	431	446	15	125	161	36	423C040E26
7/6/2000	7/12/2001	370	314	322	8	53	59	6	423C0A3621
7/6/2000	7/12/2001	370	390	405	15	92	114	22	423C145863
7/6/2000	7/12/2001	370	560	700	140	nt	584	na	423C172F19
7/6/2000	7/12/2001	370	359	370	11	77	82	5	423C1B4073
7/6/2000	7/12/2001	370	367	385	18	72	93	21	423C1C5365
7/6/2000	7/12/2001	370	334	355	21	53	66	13	423C1F6B2D
7/6/2000	7/12/2001	370	220	236	16	15	20	5	423C213042
7/6/2000	7/12/2001	370	455	464	9	153	166	13	422E347254

Appendix A. (cont.)

Date Marked	Date Recap	Days	Mark Len. (mm)	Recap Len. (mm)	Growth (mm)	Mark Weight (g)	Recap Weight (g)	Growth (g)	PIT #
7/18/2000	7/12/2001	358	284	291	7	nt	36	na	4232304255
7/18/2000	7/12/2001	358	387	418	31	83	112	29	422E321914

Appendix B. Growth of American eels marked in Shoe Creek in 2000 and recaptured in 2001 (n = 28). "nt" indicates that the measurement was not taken.

Date Marked	Date Recap	Days	Mark Len. (mm)	Recap Len. (mm)	Growth (mm)	Mark Weight (g)	Recap Weight (g)	Growth (g)	PIT #
6/28/2000	7/9/2001	375	468	493	25	167	215	48	4238346304
6/29/2000	7/10/2001	375	439	465	26	154	185	31	4238382508
6/29/2000	7/9/2001	374	480	497	17	167	221	54	4239773478
6/28/2000	7/10/2001	376	437	479	42	149	186	37	407E38035E
6/28/2000	7/9/2001	375	470	495	25	196	245	49	407E445F44
6/29/2000	7/9/2001	375	490	506	16	232	237	5	407E475B2D
8/8/2000	7/10/2001	335	620	625	5	431	452	21	407E517541
6/28/2000	7/9/2001	375	411	445	34	116	145	29	407E592511
8/8/2000	8/14/2001	370	249	267	18	24	31	7	422D642774
8/16/2000	8/14/2001	362	300	311	11	43	51	8	422E2C517B
8/8/2000	8/14/2001	370	421	428	7	110	117	7	422E2E5611
8/8/2000	7/10/2001	335	549	553	4	300	295	-5	422E604E74
8/8/2000	7/10/2001	335	254	258	4	26	27	1	422E74124F
6/29/2000	7/10/2001	375	553	570	17	263	297	34	4238174B25
6/29/2000	7/9/2001	374	518	534	16	217	249	32	42381F226D
6/29/2000	7/9/2001	374	315	327	12	49	58	9	42381F6337
6/29/2000	7/10/2001	375	457	484	27	171	205	34	42382B7029
6/29/2000	7/10/2001	375	424	455	31	133	157	24	4239743F5A
6/29/2000	7/9/2001	374	360	429	69	82	136	54	4239751F4D
6/29/2000	7/9/2001	374	405	442	37	116	149	33	423A016B56
6/29/2000	7/9/2001	374	401	402	1	96	117	21	423A073C37
6/29/2000	7/9/2001	374	229	249	20	19	23	4	423A0A1609
6/28/2000	8/14/2001	411	333	352	19	68	91	23	423A0D2C79
6/29/2000	8/14/2001	410	635	645	10	nt	503	na	423A131B59
6/28/2000	7/9/2001	375	335	365	30	56	73	17	423A1A3E20
6/29/2000	7/10/2001	375	560	583	23	280	376	96	502E32286E
6/29/2000	8/14/2001	410	480	503	23	nt	304	na	50314E5A7C
6/29/2000	7/10/2001	375	463	496	33	155	190	35	503157251C

Appendix C. Growth of American eels marked in S.F. Piney River in 2000 and recaptured in 2001 (n = 2).

Date Marked	Date Recap	Days	Mark Len. (mm)	Recap Len. (mm)	Growth (mm)	Mark Weight (g)	Recap Weight (g)	Growth (g)	PIT #
6/28/2000	7/13/2001	379	245	246	1	24	26	2	502E194061
6/29/2001	7/14/2001	379	528	565	37	277	324	47	502E2E085A

Appendix D. Growth of American eels marked in Shoe Creek in 1999 and recaptured in 2000 (n = 22).

Date Marked	Date Recap	Days	Mark Len. (mm)	Recap Len. (mm)	Growth (mm)	Mark Weight (g)	Recap Weight (g)	Growth (g)	PIT #
7/6/1999	6/29/2000	357	522	623	101	224	249	25	407E424523
7/6/1999	8/8/2000	397	571	620	49	324	411	87	407E517541
7/6/1999	6/29/2000	357	428	465	37	149	209	60	407E316D0F
7/6/1999	6/29/2000	357	495	600	105	nt	247	na	407E5E0A55
7/6/1999	8/8/2000	397	630	661	31	nt	683	na	407E386F78
7/6/1999	6/29/2000	357	205	236	31	13	21	8	407E367548
7/6/1999	6/29/2000	357	462	496	34	nt	261	na	407E371A6D
7/6/1999	8/8/2000	397	509	538	29	nt	290	na	407E40336E
7/6/1999	6/29/2000	357	484	511	27	nt	261	na	407E57425A
7/6/1999	6/29/2000	357	535	561	26	nt	251	na	407E4D673C
7/6/1999	6/28/2000	356	380	437	57	99	149	50	407E38035E
7/6/1999	8/16/2000	405	550	596	46	nt	441	na	407E4C5D27
7/6/1999	6/28/2000	356	430	470	40	140	196	56	407E445F44
7/6/1999	6/28/2000	356	448	459	11	133	167	34	407E49245E
7/6/1999	6/28/2000	356	361	392	31	64	88	24	407E3C120F
7/6/1999	8/8/2000	397	420	479	59	141	219	78	407E446B23
7/6/1999	6/29/2000	357	560	581	21	nt	437	na	407E4A0D4B
7/6/1999	8/16/2000	405	330	382	52	60	93	33	407E4B060E
7/6/1999	6/29/2000	357	224	275	51	19	49	30	407E3E0335
7/6/1999	6/29/2000	357	447	490	43	148	232	84	407E475B2D
7/6/1999	6/29/2000	357	271	330	59	31	57	26	407E46782D
10/18/1999	8/8/2000	323	650	661	11	575	669	94	502E18712B

Appendix E. Growth of American eels marked in Shoe Creek in 1999 and recaptured in 2001 (n = 14).

Date Marked	Date Recap	Days	Mark Len. (mm)	Recap Len. (mm)	Growth (mm)	Mark Weight (g)	Recap Weight (g)	Growth (g)	PIT #
7/6/1999	7/10/2001	732	571	625	54	324	452	128	407E517541
7/6/1999	7/10/2001	732	390	460	70	106	183	77	407E595C1C
7/6/1999	8/14/2001	767	467	515	48	206	272	66	407E536376
7/6/1999	7/10/2001	732	474	496	22	nt	184	na	407E54485B
7/6/1999	6/5/2001	697	462	540	78	nt	nt	na	407E371A6D
7/6/1999	7/10/2001	732	380	479	99	99	186	87	407E38035E
7/6/1999	7/9/2001	731	472	541	69	nt	309	na	407E541E0A
7/6/1999	8/14/2001	767	430	501	71	140	253	113	407E445F44
7/6/1999	7/9/2001	731	377	445	68	84	145	61	407E592511
7/6/1999	7/10/2001	732	447	506	59	149	237	88	407E475B2D
7/6/1999	7/10/2001	732	367	446	79	82	132	50	407E572303
7/6/1999	7/10/2001	732	338	477	139	64	210	146	407E5B5F00
10/18/1999	7/10/2001	689	316	345	29	53	66	13	502E272672
10/18/1999	7/10/2001	689	650	660	10	575	635	60	502E18712B

Appendix F. Location of eels tracked on S.F. Tye River from summer 2000 through spring 2001. Distances are listed in meters above or below (+ or -) the downstream end of the designated sampling reach (Chapter 2). "Unknown" indicates eels were believed to be migrating and were not considered to have a SDO for this study.

Date	# 14	# 34	# 56	# 76	# 93	# 115	# 134	#153	# 174	# 196
7/6/00	10	94	150	230	200	200	230	230	-	564
7/10/00	10	100	154	220	200	217	228	228	524	565
7/18/00	13	100	414	86	220	224	239	163	524	569
7/22/00	12	100	612	39	217	248	239	100	524	569
7/26/00	10	100	612	46	220	229	239	114	524	571
7/31/00	46	100	612	-312	220	222	245	-672	524	69
8/3/00	46	100	612	-286	220	222	241	-966	524	-1094
8/8/00	46	100	612	-286	220	222	241	-1931	147	-1094
8/12/00	20	100	612	-286	219	224	255	-1931	147	-1175
8/16/00	20	100	612	-293	219	224	255	-1931	147	-1175
8/28/00	20	102	612	-342	219	224	255	-1931	147	-1577
9/1/00	20	102	612	-342	219	224	255	-1931	147	-1577
9/5/00	20	102	612	-342	219	224	255	unknown	147	-1577
9/14/00	20	102	612	-342	219	224	255	unknown	147	-1577
9/17/00	-25	43	612	-342	219	284	239	unknown	68	-1577
9/25/00	-25	43	612	-342	219	284	239	unknown	68	-1577
10/11/00	-25	31	612	-407	227	290	263	unknown	68	-1577
10/23/00	-25	29	612	-407	74	281	239	unknown	72	-1577
11/8/00	-25	29	612	-407	74	281	239	unknown	72	-1577
11/13/00	-25	29	612	-407	-6598	281	239	unknown	72	-1577
11/16/00	-25	29	612	-407	-6598	281	239	unknown	72	-1577
11/19/00	-25	29	612	-407	-6598	281	239	unknown	72	-1577
11/28/00	-25	29	612	-407	-6598	281	239	unknown	68	-1577
12/2/00	-25	29	612	-407	-6598	281	239	unknown	68	-1577
12/17/00	-25	29	612	-407	-6598	281	239	unknown	68	-1577
12/22/00	-25	29	612	-407	-6598	281	239	unknown	68	-1577
12/30/00	-25	29	612	-407	-6598	281	239	unknown	68	-1577
1/11/01	-25	29	612	-407	-6598	281	239	unknown	68	-1577
1/15/01	-25	29	612	-407	-6598	281	239	unknown	68	-1577
2/8/01	-25	29	612	-407	-7008	281	239	unknown	67	-1577
2/16/01	-25	29	612	-407	-7008	281	239	unknown	67	-1577
2/20/01	-25	29	612	-407	-7008	281	239	unknown	67	-1577
3/4/01	-25	29	612	-407	-7008	281	239	unknown	67	-1577
3/8/01	-25	29	612	-407	-7008	281	239	unknown	67	-1577
3/12/01	-25	29	612	-407	-7008	281	239	unknown	67	-1577
3/20/01	-25	29	612	-407	-7008	281	239	unknown	67	-1577

Appendix F. (cont.) Stream distance location of eels tracked on S.F. Tye River from Summer 2000 through Spring 2001. Distances are listed in meters above or below (+ or -) the downstream end of the designated sampling reach (Chapter 2). "Unknown" indicates eels were believed to be migrating and were not considered to have a SDO for this study. "Off" indicates transmitter battery had expired.

Date	# 14	# 34	# 56	# 76	# 93	# 115	# 134	#153	# 174	# 196
3/24/01	-25	29	612	-407	-7008	281	239	unknown	67	-1577
3/28/01	-25	29	612	-407	-7008	281	239	unknown	67	-1577
4/1/01	-25	29	612	-407	-7008	281	239	unknown	67	off
4/5/01	-25	29	612	-407	-7008	281	239	unknown	67	off
4/9/01	off	29	612	-407	-7008	281	239	unknown	67	off
4/13/01	off	29	612	-407	-13968	281	239	unknown	67	off
4/20/01	off	29	612	-407	off	281	239	unknown	67	off
4/25/01	off	29	612	-407	off	281	239	unknown	67	off
5/7/01	off	29	612	-407	off	281	239	unknown	67	off
5/14/01	off	29	612	-407	off	281	239	unknown	75	off
5/19/01	off	off	off	-407	off	281	239	unknown	67	off
5/30/01	off	off	off	off	off	off	off	unknown	off	off

Appendix G. Location of eels tracked on Shoe Creek from summer 2000 through spring 2001. Distances are listed in meters above or below (+ or -) the downstream end of the designated sampling reach (Chapter 2). "-" indicates transmitter had not yet been implanted. "Unknown" indicates eels were believed to be migrating and were not considered to have a SDO for this study. "x" indicates transmitter was not functioning that particular day. "Dead" indicates transmitter was found on the bank on 10/8/00.

Date	# 364	# 306	# 284	# 262	# 244	# 225	# 324	# 344	# 385	# 404
8/16/00	617	310	310	202	127	76	-	-	-	-
8/28/00	617	310	310	202	127	76	5	500	570	873
9/1/00	-2100	310	310	202	127	76	5	500	570	873
9/5/00	unknown	310	310	202	127	76	5	500	570	873
9/14/00	unknown	x	310	202	127	76	5	500	570	873
9/17/00	unknown	308	308	209	76	160	5	525	540	875
9/25/00	unknown	308	308	209	76	160	5	525	540	875
9/29/00	unknown	308	308	209	76	160	5	525	540	875
10/3/00	unknown	308	308	209	76	160	5	525	540	875
10/8/00	unknown	308	308	209	76	160	dead	525	540	875
10/11/00	unknown	308	308	209	76	166	dead	525	494	882
10/20/00	unknown	x	308	209	76	160	dead	520	480	882
10/23/00	unknown	308	308	209	76	160	dead	520	480	882
11/1/00	unknown	x	308	209	76	x	dead	520	480	882
11/5/00	unknown	x	303	209	107	159	dead	511	480	882
11/8/00	unknown	310	310	209	76	159	dead	520	480	882
11/13/00	unknown	x	310	209	76	159	dead	511	480	882
11/16/00	unknown	310	310	209	76	159	dead	511	480	882
11/28/00	unknown	310	310	209	76	159	dead	511	480	882
12/2/00	unknown	310	310	209	76	159	dead	511	480	882
12/7/00	unknown	x	310	209	76	x	dead	511	480	882
12/13/00	unknown	310	310	209	76	159	dead	511	480	882
12/22/00	unknown	310	310	209	76	159	dead	511	480	882
12/30/00	unknown	310	310	209	76	159	dead	511	480	882
1/5/01	unknown	x	310	209	76	x	dead	511	480	882
1/11/01	unknown	310	310	209	76	159	dead	511	480	882
1/15/01	unknown	310	310	209	76	159	dead	511	480	882
1/20/01	unknown	x	310	209	76	x	dead	507	507	882
1/24/01	unknown	x	310	209	76	x	dead	507	507	882
1/27/01	unknown	310	310	209	76	76	dead	507	507	882
2/4/01	unknown	310	310	209	76	76	dead	507	507	882
2/8/01	unknown	310	310	209	76	76	dead	507	509	882
2/20/01	unknown	310	310	209	76	76	dead	507	509	882
3/1/01	unknown	x	310	209	76	76	dead	507	509	882
3/4/01	unknown	310	310	209	76	76	dead	507	509	882

Appendix G. (cont.) Location of eels tracked on Shoe Creek from summer 2000 through spring 2001. Distances are listed in meters above or below (+ or -) the downstream end of the designated sampling reach (Chapter 2). "Unknown" indicates eels were believed to be migrating and were not considered to have a SDO for this study. "Dead" indicates transmitter was found on the bank on 10/8/00. "Off" indicates transmitter battery had expired

Date	# 364	# 306	# 284	# 262	# 244	# 225	# 324	# 344	# 385	# 404
3/8/01	unknown	310	310	209	76	72	dead	507	509	882
3/12/01	unknown	310	310	209	76	72	dead	507	509	882
3/20/01	unknown	310	310	209	76	72	dead	507	509	882
3/24/01	unknown	310	310	209	76	72	dead	507	509	882
3/28/01	unknown	310	310	209	76	72	dead	507	509	882
4/1/01	unknown	310	310	209	76	72	dead	507	509	882
4/5/01	unknown	310	310	209	76	72	dead	507	509	882
4/13/01	unknown	310	310	209	76	72	dead	507	509	882
4/30/01	unknown	310	310	209	76	off	dead	507	off	882
5/7/01	unknown	off	308	209	76	off	dead	520	off	903
5/15/01	unknown	off	288	209	76	off	dead	520	off	off
5/19/01	unknown	off	300	off	off	off	dead	520	off	off
6/5/01	unknown	off	off	off	off	off	dead	off	off	off

Appendix H. Location of eels tracked on S.F. Piney River from fall 2000 through summer 2001. Distances are listed in meters above or below (+ or -) the downstream end of the designated sampling reach (Chapter 2).

Date	# 494	# 513
10/3/00	415	560
10/11/00	360	560
10/20/00	360	560
10/23/00	360	560
11/1/00	360	560
11/5/00	360	560
11/8/00	360	549
11/13/00	360	549
11/16/00	360	549
11/28/00	360	549
12/2/00	360	549
12/7/00	360	549
12/13/00	360	549
12/22/00	360	549
12/30/00	360	549
1/5/01	360	549
1/11/01	360	549
1/15/01	360	549
1/20/01	360	549
1/24/01	360	549
1/27/01	360	549
2/4/01	360	549
2/8/01	360	549
2/20/01	360	549
3/1/01	360	549
3/4/01	360	549
3/8/01	360	549
3/12/01	360	549
3/20/01	360	549
3/24/01	360	549
3/28/01	360	549
4/1/01	360	549
4/5/01	360	549
4/13/01	360	549
4/30/01	360	549
5/7/01	360	549
5/15/01	356	549
5/19/01	351	549

Appendix H. (cont.) Location of eels tracked on S.F. Piney River from Fall 2000 through Summer 2001. Distances are listed in meters above or below (+ or -) the downstream end of the designated sampling reach(Chapter 2). "Off" indicates that the transmitter battery had expired.

Date	# 494	# 513
6/5/01	354	549
6/8/01	354	549
6/13/01	354	549
6/17/01	350	560
6/21/01	350	560
6/28/00	350	560
7/10/01	350	560
7/14/01	350	551
7/18/01	350	551
7/23/01	off	551
7/27/01	off	551
7/31/01	off	551
8/7/01	off	551
8/11/01	off	551
8/20/01	off	off

Appendix I. Location of eels tracked on Shoe Creek from spring 2001 through summer 2001. Distances are listed in meters above or below (+ or -) the downstream end of the designated sampling reach (Chapter 2). "-" indicates transmitter had not yet been implanted.

Date	# 596	# 654	# 685
6/5/01	-	308	308
6/8/01	85	308	308
6/13/01	85	308	308
6/17/01	68	310	310
6/21/01	68	310	310
6/28/01	76	310	310
7/10/01	76	310	310
7/14/01	76	308	310
7/18/01	76	308	310
7/23/01	78	303	310
7/27/01	78	303	310
7/31/01	78	308	310
8/7/01	78	308	313
8/11/01	78	308	313
8/20/01	78	310	313
8/28/01	78	310	313
8/31/01	78	310	313
9/4/01	78	303	313
9/12/01	78	310	313
9/16/01	76	322	313
9/20/01	78	322	316

Appendix J. Location of eels tracked on Shoe Creek from spring 2001 through summer 2001. Distances are listed in meters above or below (+ or -) the downstream end of the designated sampling reach (Chapter 2). "-" indicates transmitter had not yet been implanted. "nt" indicates that fish was not tracked that day.

Date	# 435	# 473	# 455	# 533	# 556	# 625	# 575
5/15/01	435	500	641	-	-	-	-
5/19/01	435	500	647	-	-	-	-
6/5/01	435	500	647	-	-	-	-
6/6/01	nt	nt	nt	260	300	295	-
6/8/01	435	500	647	260	300	295	1782
6/13/01	435	500	647	260	300	295	1782
6/17/01	435	500	650	151	293	300	1780
6/21/01	435	500	650	151	293	300	1780
6/28/01	432	500	642	151	300	300	1780
7/10/01	432	500	642	151	300	300	1780
7/14/01	432	500	636	154	300	300	1780
7/18/01	432	500	636	154	300	300	1780
7/23/01	432	500	636	154	300	300	1727
7/27/01	432	500	636	154	300	300	1702
7/31/01	432	500	636	154	300	300	1702
8/7/01	432	426	631	154	293	300	1699
8/11/01	432	132	631	154	295	300	1699
8/20/01	435	132	631	154	297	300	1694
8/28/01	435	132	631	154	297	300	1694
8/31/01	435	132	631	154	297	300	1694
9/4/01	435	132	631	154	297	300	1694
9/12/01	435	132	631	154	297	300	1694
9/16/01	435	132	636	154	300	300	1694
9/20/01	435	132	636	154	300	300	1694

Vita

Patrick Andrew Strickland was born to Richard and Linda Strickland on June 15, 1977. He was raised in Elkview, West Virginia and graduated from Herbert Hoover High School in 1995. He earned a Bachelor of Science degree in Biology from West Virginia State College in 1999. He began graduate work in August of 1999 toward a Master of Science degree in Fisheries and Wildlife Sciences at Virginia Tech, ultimately earning his degree in December of 2002.