ABSTRACT

USE OF FIRST-ORDER TRIBUTARIES BY BROWN TROUT (*SALMO TRUTTA)* AS NURSERY HABITAT IN A CENTRAL WISCONSIN COLDWATER STREAM NETWORK

By Michael J. Louison

Many studies have examined the importance of suitable in-stream habitat and flow regime to salmonid fishes. However, few studies have examined the use of small (< 5 L/s discharge) headwater streams within a larger stream network by trout. The purpose of this study was to evaluate the use of headwater streams by juvenile brown trout *Salmo trutta* in the Emmons Creek stream network in Wisconsin, USA, and to determine if abundance and body size of trout are related to habitat and food supply in these streams. Fishes in nine spring-fed first-order streams were sampled during a seven month period using a DC backpack electroshocker, identified, and measured for total length. Habitat and biological variables assessed included stream discharge, water velocity, sediment composition, abundance of cover items (woody debris and macrophytes), and benthic macroinvertebrate density. Monthly densities of YOY trout ranged from 0 to 1 per m^2 and differed among streams. Regression analyses revealed negative relationships between fish density and discharge and positive association between fish density and % fine sediment among 1st-order streams in the spring (April and May) but not in the summer (July and August), reflecting the results of previous studies of the habitat preferences of trout in larger streams. There was divergence in mean fish length among 1st-order streams as the study period progressed, and in August mean YOY lengths by stream were negatively associated with density. My work demonstrates the viability of small first-order streams as nursery habitat for trout, and supports the inclusion of headwater streams in future conservation and stream restoration efforts.

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by

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CHAPTER I

INTRODUCTION

While not often listed on maps or included within habitat restoration efforts, so-called "headwater streams" are a major component of stream and river networks. Headwater streams, defined as the streams arising from springs or other water sources which eventually combine together to form a larger stream or river, are noted as major sites of nutrient processing within streams (Craig et al. 2008, Alexander et al. 2007). While often less than a few meters wide, the combined length of all headwater streams often composes over two thirds of the total length of stream within a drainage (Freeman et al. 2007, Fayram et al. 2005, Richardson & Danehy 2007). The health of these headwater streams has been examined frequently within the context of water quality and nutrient processing, but not often within the context of fish habitat. Studies have been done examining the contributions of headwater streams to the larger stream network, which include the input of invertebrates (which serve as prey for fish in the main channel) as well as dissolved organic matter which forms the basis of many aquatic food webs (Wipfli et al. 2007).

The use of headwater streams by aquatic organisms besides fish has been summarized previously in a review by Meyer et al. (2007). Because headwater streams sometimes lack fishes, they are often hot spots for invertebrate abundance, and may contain novel invertebrate communities in comparison to those found in the main reach of a stream. In addition, headwater streams serve as breeding grounds for several other types of organisms, including amphibians which often lay their eggs in their relatively predator-free waters.

Headwater streams have long been considered non-ideal for fish due to their variability, as with less water these streams are more subject to fluctuations in temperature, dissolved oxygen, and depth (Miltner & Rankin 1998, Whiteside & McNatt 1972). The few studies that have been done on fish presence in headwater streams have largely focused on them within the context of fish species assemblage (i.e. what species are present in a given area) by stream order. Stream order refers to a system developed by Strahler (1957) in which first-order streams are defined as streams which have no tributaries and are flowing directly from a source, such as a spring or wetland. When two first order streams combine, they form a second order stream, and higher orders of stream are named at the point of confluence of a stream with another stream of equal or greater order. In these types of studies, first order (headwater) streams are often cited as being very low in fish abundance and diversity (Grenouillet et al. 2004, Beecher et al. 1988, Meador & Matthews 1992).

Despite the fact that their small size makes them unlikely to hold diverse fish communities, it is possible that the shallow waters present in first-order streams may provide habitat for young fishes. In particular, salmonid fishes (trout and salmon) which often dominate coldwater stream systems, often prefer shallow, slow-flowing water during their first months of life (Maki-Petays et al. 1997, Armstrong et al. 2003, Bagliniere et al. 1989). Studies of the habitat choice of young fishes have often focused on their presence along the margins of streams, which are often slower flowing and rich in potential cover items (Cunjak & Power 1986, Armstrong & Nislow 2006). The suitability of small, first order tributary streams for fish (trout in particular) has been rarely studied.

Emmons Creek in Portage County, Wisconsin is a small, coldwater stream network. The main stem of Emmons Creek eventually flows west into the Waupaca Chain of Lakes in Waupaca County, and the fish community of this stream system is dominated by the brown trout *Salmo trutta.* Brown trout are native to Europe and Western Asia (MacCrimmon & Marshall 1968) but have been exported nearly worldwide and are now established on six continents. Their dominance in places where they are present can be traced to their adaptability and tolerance of variation in stream temperature and water quality (Carlson et al. 2007) as well as their aggression in competitively displacing native salmonid species (Cunjak & Power 1986, Wood & Budy 2009).

Brown trout worldwide are fall spawners, clearing away places (known as redds) on the stream bed to deposit their eggs, which are buried several centimeters into the spawning gravel (Skoglund & Barlaup 2006). Hatchling trout typically hatch in winter and remain in the sediment feeding off their yolk sacs for a period extending until spring. At that point, the young trout (fry) emerge from the sediment and disperse from the redd, eventually settling in an area of suitable flow and depth from which they can forage for prey, usually aquatic insect larvae (Heggenes et al. 1999).

The objective of my study was to monitor the presence of young-of-the-year brown trout in a set of nine first-order study streams within the Emmons Creek network. I also evaluated the habitat and hydrological features of each stream, to determine what combinations of factors (depth, discharge, velocity, food availability, presence of cover items) were connected to fish occupation. The presence of fish within these streams would provide evidence of their usefulness, and make the case that the streams are worthy of consideration by conservationists looking to preserve trout habitat. In addition, the changes in trout abundance within the streams as the year progresses was evaluated as well to begin to assess at what point trout enter and leave the streams, and what habitat variables determined the timing of occupation by the young fish.

CHAPTER II

USE OF FIRST-ORDER TRIBUTARIES BY BROWN TROUT (*SALMO TRUTTA)* AS NURSERY HABITAT IN A CENTRAL WISCONSIN COLDWATER STREAM NETWORK

Introduction

Numerous studies have demonstrated the contributions of headwater (first- and second- order) streams to the health of river networks, largely focusing on their importance in nutrient processing (Alexander et al. 2007, Craig et al. 2008) and delivery of dissolved organic compounds and invertebrates to the main channel (Wipfli et al. 2007). First-order streams (Strahler 1957) are typically very low in discharge (< 5 L/s) and incapable of holding large adult fish for extended periods. Thus, they are often ignored by fish ecologists, with the exception of studies on spawning behaviors (Freeman et al. 2007, Meyer et al. 2007), or as part of larger studies of fish assemblage structure by stream order within an entire stream network (Beecher et al. 1988, Matthews 1986).

Many first-order streams experience high temporal variability in flow regime and water chemistry and are susceptible to disturbance by both human activity (e.g. deposition of debris during logging, depletion of groundwater sources as a result of irrigation for agriculture, physical modification including channelization) and natural events, such as floods or tree falls (Miltner & Rankin 1998, Whiteside & McNatt 1972). These attributes of 1st-order streams can pose challenges for fishes that attempt to occupy them. First-order streams in warmer climates are particularly variable and subject to complete drying at certain times of the year (Meador & Matthews 1992) precluding permanent residence by fishes. Perennial first-order streams by contrast are often spring-fed and are more common in forested regions (Dodds et al. 2004).

In this thesis, I describe the use of first-order spring-fed streams by fishes in a wadeable, coldwater stream network in Central Wisconsin across four seasons. I focus on the presence of the dominant species in the stream network, the brown trout *Salmo trutta*. Native to Europe and parts of Eastern Asia and North Africa (Klemetsen et al. 2003), the brown trout has become widely established on 6 continents and is noted for its aggression and competitive superiority in excluding native species (Heggenes et al. 1999, Townsend 1996). Brown trout tend to spawn in autumn and hatch in late winter or early spring, with the timing of both events influenced by stream temperature (Skoglund & Barlaup 2006). The newly hatched alevins remain in the sediment initially while feeding off their yolk sac, then emerge from their redds to establish feeding territories, which they vigorously defend from other trout (Elliott 1990).

Understanding habitats suitable for YOY trout is critical for trout population management and, in particular, efforts to maintain recruitment. While older trout prefer deeper habitats with faster-flowing water, young-of-the-year (YOY) trout often seek out slower, shallower water with finer sediment, such as that found along the channel margins of larger streams (Maki-Petays et al. 1997, Armstrong et. al 2003). These low-velocity, shallow conditions are also commonly found in low-gradient first-order tributary streams. The time period immediately following emergence (post-emergent period) is critical for young trout, when access to abundant habitat is essential (Armstrong & Nislow 2006, Titus 1990). Though several studies have examined the use of shallow habitats within larger streams by YOY trout (Kennedy and Strange 1982, Bardonnet and Heland 1994, Maki-Petays et al. 1997), the present study is the first to my knowledge that has examined the use of first-order tributaries by YOY trout. I hypothesized that low-discharge (<5 L/s) spring-fed 1st-order streams could provide viable nursery areas for YOY trout within the Emmons Creek Stream Network. Further, I hypothesized that YOY trout abundance would be related to several habitat features in first-order streams, including flow regime (velocity and discharge) and the abundance of cover (in the form of either woody debris or emergent macrophytes), based on prior work on the habitat preferences of juvenile trout (Armstrong et al. 2003).

METHODS

Emmons Creek Network.

Emmons Creek is a Class I trout stream beginning in 6.2 hectare Fountain Lake in southwestern Portage County, WI (44° 18’ N, 89° 15’ W) (Fig. 1). The third-order reach of the creek has a mean discharge of approximately 400 L/s (Stelzer et al. 2011) and flows northeast into Long Lake, a 45.3 ha lake which is part of the Waupaca Chain of Lakes in southeastern Waupaca County, WI. Long Lake contains a resident population of brown trout, which migrate into Emmons Creek in the fall to spawn (Al Niebur, Wisconsin Department of Natural Resources, personal communication). A large part of the Emmons Creek catchment is comprised of the Emmons Creek Fishery Area which consists of 1500 acres of public land that is managed by the Wisconsin Department of Natural Resources (WDNR). All of my study sites were located within the public fishery

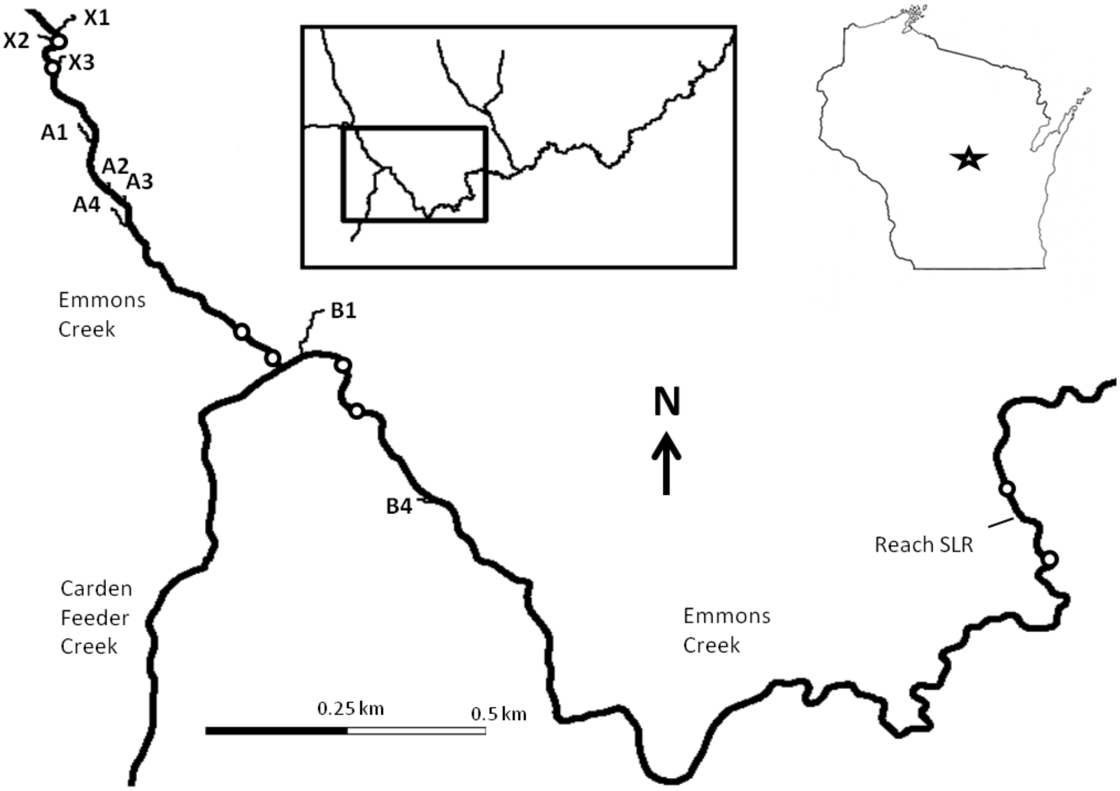

Figure 1: Map of Emmons Creek network, Portage County, Wisconsin. First-order study streams (X1-X3, A1-A4, B1-B4) are labeled and the start and end of each corresponding study reach in the main stem of Emmons Creek (X, A, B, SLR) are indicated with open circles.

area. The riparian zone within the fishery area is mostly forested with hardwood species (including red maple *Acer rubrum*, American basswood *Tilia americana*, swamp white oak *Quercus bicolor*, and white birch *Betula papyrifera*) being dominant. The watershed also includes oak savanna, as well as row-crop fields outside the boundaries of the fishery area.

Study Stream Selection.

Nine spring-fed first-order tributary streams (Fig. 1) were selected for study along an approximately 3.2 km reach of Emmons Creek. Only perennial streams with suitable accessibility for fish sampling were included. The selected streams ranged from 12 to 95 meters in length and from 0.1 to 3.4 L/s in mean discharge. Two reaches in the second order section of Emmons Creek (above the confluence of Emmons and the Carden Feeder Creek to the southwest) and two reaches in the third-order section were also selected for fish sampling (Fig. 1). Sampling of second- and third- order reaches was performed to assess the fish community of Emmons Creek in order to determine the pool of potential species that could inhabit the first-order tributary streams. The starting point of these reaches was selected largely based on ease of entry with electrofishing equipment, while the length of stream sampled was approximately 35 times the mean wetted stream width of the reach, as recommended by Lyons (1992).

Habitat Evaluation.

Habitat evaluation of the nine first-order study streams was performed on 4/20/2013 and 9/2/2013 and included assessment of water depth, wetted-channel width, substrate composition, percent cover by emergent macrophytes, and density of large woody debris (one meter in length, in contact with the water). Assessment of depth, width, and substrate composition was performed along twelve equally-spaced transects perpendicular to stream flow, a modification of methods recommended by Simonson et al. (1994). I recorded water depth and dominant substrate type at three points (1/4, 1/2, and 3/4 the distance across the length of the wetted channel) along each transect. Substrate types were classified based on WDNR recommendations for stream habitat assessment (Simonson et al. 1994), and size classes of substrate were as follows: silt<0.06 mm, sand 0.06-1.9 mm, gravel 2-64 mm, and cobble 64-256 mm.

I measured discharge (5/3/2013 and 8/21/2013), water velocity (5/16/2013 and 8/6/2013), and dissolved oxygen concentration (5/3/2013 and 8/6/2013) in spring and summer in the first-order streams. Water velocity was measured at the three transect points (at 4/10ths of the water depth from the sediment) along each of the twelve transects used in the assessment of depth and substrate. Brown trout, particularly YOY, are known to extensively utilize margin habitat in streams due to the lower energy expenditure necessary to maintain swimming position (Tetzlaff et al. 2005, Armstrong et al. 2003), and so determination of velocity along transects at points both inside and outside of the thalweg was necessary in order to properly characterize the flow conditions that fish could encounter. Stream discharge was measured at the mouth of each first-order stream using the velocity-area gauging method (Millidine et al. 2012). All water velocity measurements were taken with a Marsh-McBirney 2000 flow meter. Dissolved oxygen and water temperature were measured near the mouth of each stream using a YSI 85 dissolved oxygen and temperature probe.

Invertebrate Sampling and Processing.

I sampled first-order streams for benthic invertebrates on 4/16/2013, 6/11/2013, and 8/10/2013. On each sampling date three benthic samples were collected from each stream at randomly chosen locations. Sampling was performed using a steel cylinder (45 cm height, 15 cm diameter) inserted about 2 cm into the substrate as described in Shupryt & Stelzer (2009). The top 2 cm of substrate was removed using a 0.5 mm mesh scoop and filtered through a 1 mm mesh steel sieve. The material retained on the sieve (macroinvertebrates, sediment and plants) was placed in 95% ethanol. Samples were stained with a 2,000 mg/L solution of Rose Bengal (Williams & Williams 1974), and the invertebrates were then sorted under 6.3x magnification and placed in 70% EtOH for final preservation. Insects and amphipods were identified to family, and other macroinvertebrate taxa were identified to class or order (nematodes and nematomorphs were identified only to phylum). The maximum body widths of all amphipods, trichopterans, and chironomids were measured to the nearest 0.25 mm with a stage micrometer. These taxa were selected for measurement due to their prevalence in the streams as well as their likely importance in the diet of trout (Elliott 1967, Kelly & Dick 2005).

The size of prey that can be consumed by young trout is constrained by maximum mouth gape and by gill raker spacing (Bannon & Ringler 1986). I used a metric developed by Wankowski (1979) for atlantic salmon *Salmo salar* to determine the maximum width of prey consumable by a YOY trout.

$$\text{maximum prey width} = 0.06 \text{ X fish fork length} \qquad \text{(Equation 1)}$$

Mean fork lengths of YOY brown trout at the times of invertebrate sampling were estimated based on the mean fork lengths of trout sampled on dates adjacent to the invertebrate sampling dates. Total lengths were converted to fork lengths using a conversion recommended by the USDA Forest Service Stream Systems Technology Center (www.stream.fs.fed.us).

$$\text{brown trout fork length} = \text{total length}/1.037 \qquad \text{(Equation 2)}$$

While a lower limit of consumable prey size for trout based on gill raker spacing has been described previously (Wankowski 1979, Bannon & Ringler 1986), I included no lower limit in my definition of the subset of invertebrates consumable to trout.

Fish Sampling.

Fish were sampled in four reaches of the main stem of Emmons Creek in 2012. I sampled the two third-order reaches (B and SLR, Fig.1) on 7/18/2012 using a towed barge electroshocking unit (150 V, 4.5 A). Second-order reaches (A and X) were sampled on 8/16/2012 by two operators positioned side-by-side with custom backpack electroshocking units (200 V, 2 A). First-order streams were sampled using a single backpack electroshocker (200 V, 0.75 A) initially on 10/10/2012 and then monthly from February to August 2013. The second- and third-order reaches and first-order streams were sampled with a single pass in an upstream direction. In the first-order streams fish sampling began at the mouth and ended either at the front edge of the stream's feeder spring or at the point at which effective sampling was not possible due to dense plant cover or large woody debris. Sampling in first-order streams took place between 8:00 AM and 3:00 PM CDT on each sampling date, with the goal of reducing the possible influence of diel movement by trout in and out of the streams (Roussel and Bardonnet 1999). After capture, fish were anesthetized with supersaturated CO_2 (Post 1979, Prince et al. 1995). CO_2 was administered to fish by placing them in an aqueous solution consisting of 15% seltzer water. Fish were measured for total length to the nearest 0.5 cm and placed in a recovery vessel containing fresh stream water. Fish that had regained proper orientation and were no longer showing signs of respiratory distress were then released at the site of processing. Fish which failed to recover adequately or those kept as voucher specimens (five fish total over the course of the study) were euthanized in a concentrated solution of MS-222 (600 mg/L), and preserved in 70% EtOH. Fish densities were calculated based on surface water area within the sampled reach.

Statistical Analysis.

One-way ANOVA was used to compare the mean densities of YOY trout and benthic invertebrates among first-order streams across all sampling dates. One-way ANOVA was also used to compare mean total lengths of YOY trout among first-order streams on individual sampling dates. In cases where means were shown to be different, Tukey's Honestly Significant Different (HSD) Tests were used to determine where differences occurred between streams. Linear regression was used to assess relationships between trout density (overall and separately for spring and summer) and all habitat variables and invertebrate densities. Linear regression was used to determine if mean total length of YOY trout was related to mean trout density on each sampling date. All analysis was performed using the statistical program R, with alpha for each statistical test set at 0.05.

Results

Habitat and Hydrology in First-order Streams.

Sand and silt were the most common substrate types in the first-order streams, followed by gravel. Cobble was absent in six of the nine study streams, and never accounted for more than 19% of the substratum in any stream (Table 1). Substrate composition varied among streams, but fine sediment (sand and silt) ranged from 52 to 97% among streams and was thus was more abundant than coarse (gravel and cobble) sediment in all cases. Mean percent fine sediment in the streams was negatively associated (linear regression, $P=0.047$, $r^2=0.452$) with mean discharge. Large woody debris was present in all streams and density ranged from 0.08 to 0.75 m^{-2} among streams (Table 1). Mean estimated cover by emergent macrophytes (mostly watercress, *Nasturtium officinale*) ranged from 0 to 83%. In all streams besides B1 (which had zero estimated macrophyte cover in both spring and summer), estimated macrophyte cover declined between spring and summer, a die-back which was first noticeable in June.

Discharge, mean water velocity, mean water depth, and mean wetted channel width declined in the first-order streams between spring and summer. Discharge ranged from 0.24 to 4.44 L/s among streams in spring, and from 0.06 to 3.38 L/s in summer (Table 1). Discharge decreased between spring and summer by 16 to 75% in eight of nine streams (Table 1). Declines in mean depth and width were also observed in these eight streams, with the decline ranging from 9 to 46% for depth and 3 to 32% for width. Mean velocity ranged from 1.9 (A3) to 9.0 cm/s (A1) in spring, and from 0.9 cm/s (X3) to 5.8 cm/s (X1) in summer, and declined in all nine streams between spring and summer. The decrease in water velocity between spring and summer was not uniform among streams, ranging from 15% (A3) to 87% (X3).

Table 1: Habitat variables for first-order streams in the Emmons Creek network. All values besides stream length and discharge are means across all measurement dates. Stream discharge for each stream is listed by date.

	Stream Length (m)	Stream Width (m)	Water Depth (cm)	% Silt	% Sand	% Gravel	% Cobble	Macro-phyte Cover (%)	Large Woody Debris Density (m^{-2})	Stream Discharge (L/s)		Stream Velocity (cm/s)	DiO_2 (mg/L)	Temp. (°C)
										5/3/13	8/21/13			
X1	50	1.6	5.9	11	44	31	14	16	0.66	4.44	3.3	6.66	7.1	9.8
X2	44	2.3	11.3	45	8	28	19	83	0.36	4.07	3.38	2.77	8.5	10.0
X3	25	0.5	5.7	69	3	28	0	3	0.08	0.44	0.92	4.18	8.0	11.0
A1	44	1.3	7.0	34	50	16	0	35	0.39	2.76	2.01	6.50	9.7	10.5
A2	12	0.8	5.4	14	61	25	0	38	0.33	1.47	0.88	4.64	9.4	9.8
A3	13	0.5	4.4	17	61	22	0	11	0.46	0.24	0.06	1.72	9.3	10.4
A4	55	0.8	5.5	42	52	6	0	7	0.29	1.29	0.94	3.96	9.5	9.8
B1	95	1.0	7.1	47	5	42	6	0	0.23	4.28	1.08	3.67	8.4	10.0
B4	12	1.1	6.9	53	44	3	0	32	0.75	1.52	1.2	1.82	8.8	10.0

Benthic Invertebrates.

Chironomid larvae, amphipods (Gammaridae), trichopteran larvae (mostly Limnephilidae and Lepidostomatidae), and oligochaetes were the most abundant invertebrate taxa sampled (Table 2). Non-chironomid diptera were abundant in April, with members of Ceratopogonidae making up 78% of that group. Bivalves (Sphaeriidae) and gastropods (mostly Physidae) were also frequently encountered (at least one physid was sampled on each date in six of nine streams, at least one sphaeriid was sampled on each date in five of nine), though their relative abundances were consistently low (Table 2). All other taxa sampled were grouped together in the “other” category in Table 2, with nematodes making up the majority of that group (>60%) in both April and August, and copepods making up the majority in June (52%). Overall, chironomids were the most abundant taxon in April and August, and amphipods were most abundant in June (Table 2).

Table 2: Mean (+SE) benthic invertebrate relative abundances (%) by major taxonomic group and sampling date in first-order streams of the Emmons Creek network.

Taxon	4/16/13	6/11/13	8/10/13
Chironomidae	31 (4.7)	19 (4.1)	21 (4.0)
Gammaridae	17 (6.5)	32 (6.0)	20 (7.5)
Trichoptera	11 (2.4)	19 (3.2)	10 (3.6)
Oligochaeta	9 (1.8)	9 (2.7)	16 (4.3)
Other Diptera	14 (4.0)	3 (0.6)	6 (3.8)
Bivalvia	5 (2.8)	2 (1.7)	2 (1.3)
Gastropoda	8 (1.6)	7 (1.9)	6 (1.5)
Other	5 (1.6)	9 (3.3)	19 (5.3)

Even though invertebrate densities showed a large range among sampling dates for some streams (Table 3), no significant difference in invertebrate density across all streams was found among sampling dates (One-way ANOVA, P=0.965). Changes in invertebrate density through time were inconsistent among the first-order streams (Table 3). Among streams, mean densities of invertebrates of consumable size differed significantly (One-way ANOVA P=0.044), while mean densities of total invertebrates and chironomids were not significantly different (One-way ANOVA P>0.07). Within the consumable invertebrate subgroup, only streams B1 and B4 had significantly different mean densities (Tukey HSD, P=0.04). Consumable width thresholds were set at 1.25 mm in April, 2.25 mm in June, and 3.0 mm in August. All chironomids were deemed consumable on each sampling date, while the percentage of gammarids (53% in April, 96% in June, 100% in August) and trichopterans (75% in April, 89% in June, 100% in August) sampled of consumable width increased with time.

Emmons Creek Fish Community.

A total of 794 fish were sampled in the four main-stem study reaches of Emmons Creek. Species richness and diversity were low and the community was dominated by brown trout (Table 4). Mottled sculpin (*Cottus bairdi)* had their highest density in reach SLR, which was approximately 2.5 km downstream from the most downstream first-order study stream (B4). In the reaches of Emmons Creek adjacent to the first-order study streams (B, A, X) brown trout accounted for over 90% of all fish sampled (Table 4).

Table 3: Densities (m^{-2}) of all benthic invertebrate taxa, chironomids, and invertebrates of consumable size (Trichoptera, Chironimidae, Gammaridae) across all first-order streams by sampling date.

	All Taxa				Chironomids				Invertebrates of Consumable Size			
	4/16/13	6/11/13	8/10/13	Mean	4/16/13	6/11/13	8/10/13	Mean	4/16/13	6/11/13	8/10/13	Mean
X1	2264	4471	4188	3641	340	340	453	377	1358	3622	2264	2415
X2	5942	5716	10526	7395	2603	2094	4244	2981	2943	2490	5546	3660
X3	5263	2660	1924	3282	1641	340	340	773	2094	1585	849	1509
A1	3848	3452	3113	3471	849	1415	509	924	1698	2716	1754	2056
A2	1641	5942	9791	5791	113	1188	2207	1170	1019	3169	3565	2584
A3	10696	3396	2490	5527	3735	736	226	1566	5150	1585	509	2415
A4	1811	3792	1075	2226	113	283	57	151	340	2264	283	962
B1	1698	1641	1698	1679	170	396	0	189	566	736	1132	811
B4	8829	10809	4018	7885	3396	1019	283	1566	4867	7810	2943	5207

Table 4: Fish density by species (m^{-2}) and Shannon-Wiener Diversity (H) in summer 2012 from second- and third-order reaches of Emmons Creek.

Fish Species	Reach X	Reach A	Reach B	Reach SLR
Brown Trout *Salmo trutta*	0.31	0.44	0.26	0.23
Mottled Sculpin *Cottus bairdi*	0	0	<0.01	0.04
Bluegill *Lepomis macrochirus*	0.01	<0.01	0.01	<0.01
Brook Trout *Salvelinus frontinalis*	0	0	<0.01	0
Shannon-Wiener Diversity Index (H)	0.171	0.067	0.286	0.512

Trout Abundance in First-order Streams.

All fish sampled in the first-order study streams were brown trout, with the exception of a single central mudminnow (*Umbra limi*) collected in stream X1 in March 2013. Based on both trout total lengths and the timing of occurrence in the streams I determined that all brown trout were members of either the 2012 or 2013 year class. Occupancy of streams by brown trout from the 2012 cohort varied temporally, with 7 of 9 streams containing at least one fish from this cohort in October 2012, 5 of 9 in February 2013, and 3 of 9 in March 2013. Trout from the 2012 cohort in the first-order streams were most abundant in October, followed by February after which they continued to decline (Fig. 2). Trout from the 2013 cohort (YOY) were first collected from the first-order streams in April (Fig. 2), when they were present in 7 of 9 streams (Fig. 3). YOY trout were first observed in streams A2 and A4 during March of 2013 but were too small to be sampled effectively with the electrofishing unit. Brown trout abundance increased dramatically in April as the result of the appearance of YOY fish and peaked in July (Fig. 2). The timing of peak YOY density varied by stream (Fig. 3) with peaks in April (A2), May (X3 and B4), June (A3 and A4), July (A1), and August (X1 and X2). Density of YOY brown trout differed among the 1st-order streams (1-way ANOVA, $P<0.001$). Streams A4 and A2 had higher mean YOY densities than X2, B1, and A3 (Tukey HSD $P<0.02$) and stream A1 had a higher mean YOY density than A3 ($P<0.045$).

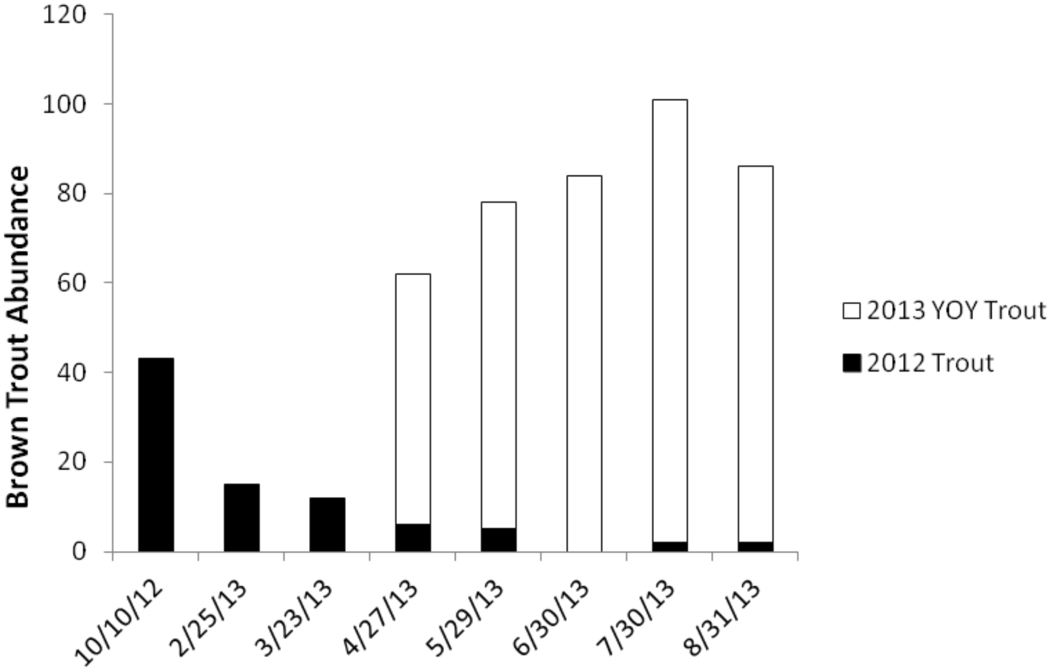

Figure 2: Abundance of brown trout from the 2012 and 2013 year classes in the first-order study streams.

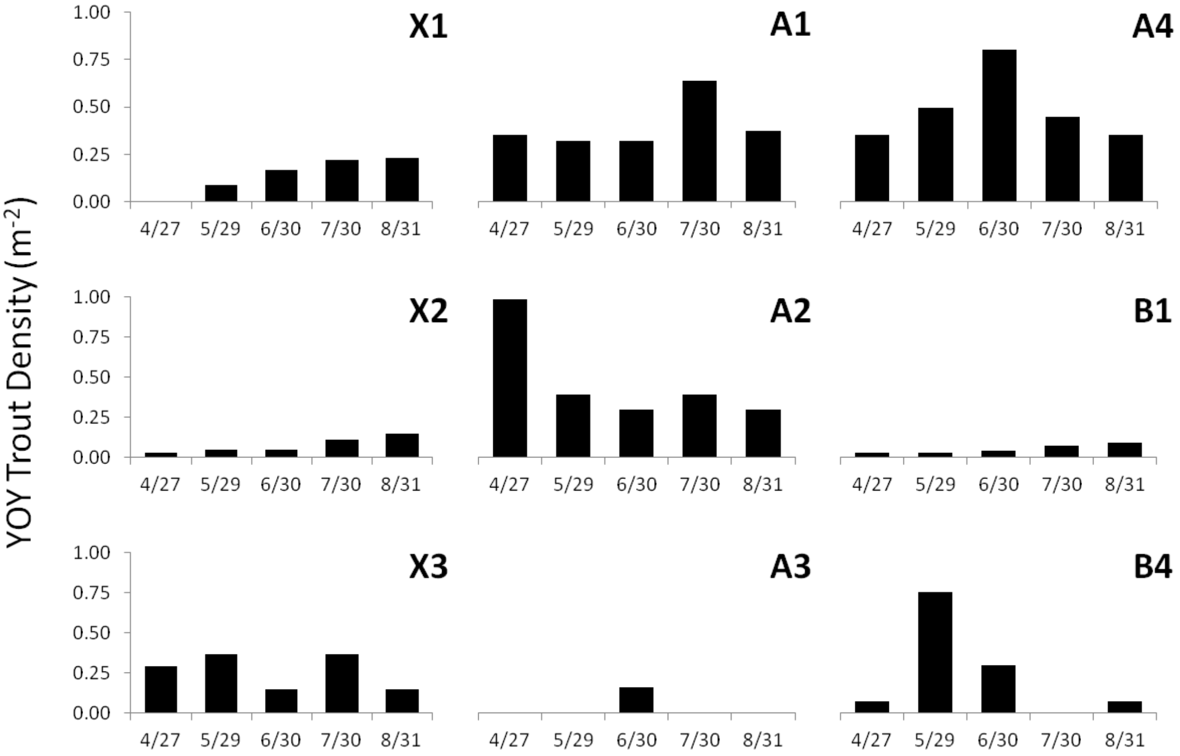

Figure 3: Young-of–the-year (YOY) brown trout density (m^{-2}) by first-order stream and sampling date from 4/27/13 to 8/31/13 in the Emmons Creek network.

Brown Trout Body Size.

Mean lengths of YOY trout differed among 1st-order streams in every month from April through August ($P<0.001$). Mean lengths of YOY among streams ranging from 2.2-3.5 cm in April, 3.3-4.4 cm in May, 3.8-5.8 cm in June, 4.8-6.6 cm in July, and 4.8 to 8.5 cm in August (Table 5). Divergence in mean trout lengths increased among 1st-order streams as the study period progressed. There were only two differences among streams in mean length in April (Tukey HSD; X2-A2, $P=0.02$; X2-A4, $P<0.001$), three in May ($P< 0.004$), four in June ($P<0.003$), nine in July ($P<0.048$), and twelve in August ($P< 0.003$). Significant differences (and similarities) in mean total length of YOY brown

Table 5: Mean total lengths (cm) of 2013 YOY brown trout sampled by date and first-order stream (NF=No YOY fish sampled).

	X1	X2	X3	A1	A2	A3	A4	B1	B4	Mean
4/27/2013	NF	3.50	2.75	2.75	2.45	NF	2.17	2.67	3.00	2.58
5/29/2013	4.36	4.40	3.50	3.58	3.50	NF	3.29	3.50	4.2	3.70
6/30/2013	5.81	5.50	4.25	4.47	4.00	4.00	3.78	5.13	5.13	4.66
7/30/2013	6.35	6.6	5.1	5.57	4.75	NF	4.76	5.64	NF	5.61
8/31/2013	6.97	7.40	5.75	5.81	4.83	NF	5.23	7.06	8.5	6.37

trout among streams in August produced two groupings. Mean YOY lengths from streams X1, X2, B1, and B4 were not different from each other (Tukey HSD, P 0.54) but were all higher than those in a second group (A1, A2, and A4, Tukey HSD P<0.025). A negative relationship between mean YOY trout length and YOY trout density occurred in

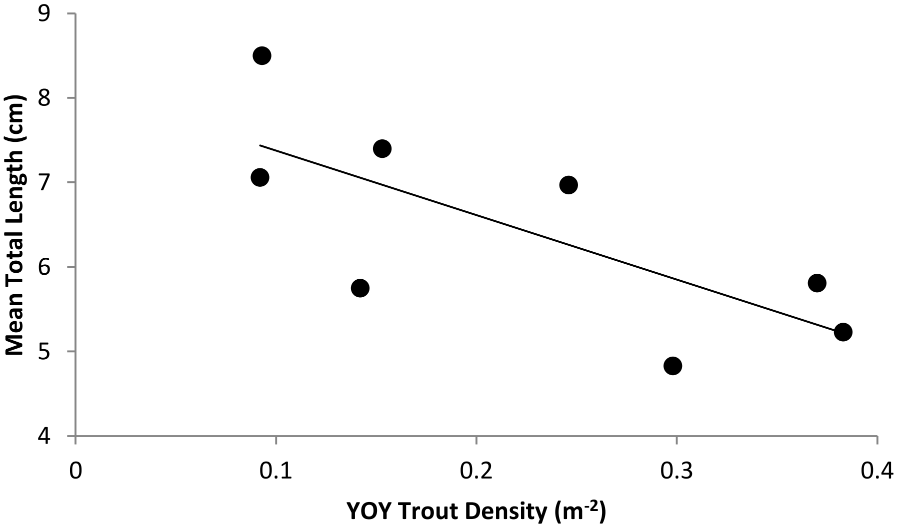

Figure 4: Relationship between YOY brown trout density and mean total length in August among the first-order streams.

August (P=0.039, r^2= 0.536, Fig. 4) but was not present in any other month during the study (P>0.17).

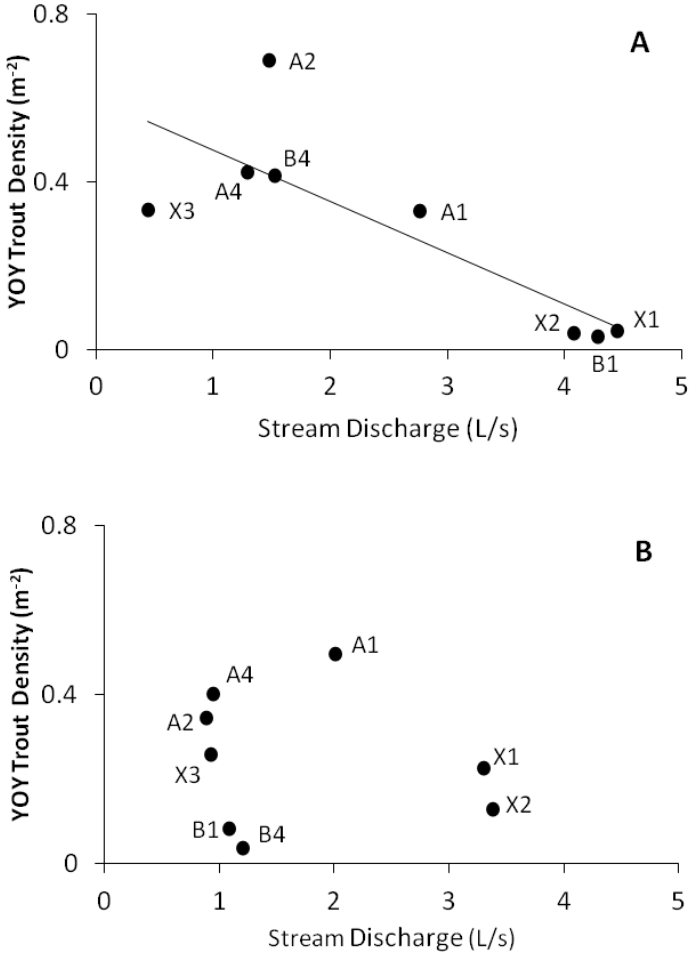

Figure 5: Relationships between first-order stream discharge and YOY trout density. Results are shown for both spring (A, April + May mean trout density) and summer (B, July + August mean trout density). Data from fishless stream A3 is not shown.

Relationships Between YOY Trout Abundance and Habitat Variables.

Linear regression analysis revealed no significant relationships between overall YOY trout density and mean values for each of the habitat and hydrologic variables when data were considered across all months. Linear regressions performed separately by season (April-May for spring, July-August for summer) however revealed significant relationships in the spring when the fishless, low-discharge stream A3 was removed from the analyses. YOY trout density was negatively related to stream discharge ($P=0.013$, $r^2=0.665$, Fig. 5A) and positively related to % fine sediment ($P=0.04$, $r^2=0.531$) in spring. No relationships between YOY trout density and discharge ($P=0.77$, $r^2=0.015$, Fig. 5B) and between YOY trout density and % fine sediment ($P=0.395$, $r^2=0.123$) occurred in the summer.

Discussion

Brown trout dominated the fish community in all stream orders examined in this study. Only a single native salmonid (brook trout, *Salvelinus frontinalis*) was sampled from the main stem of Emmons Creek and no YOY brook trout were present in any of the first-order streams. Brown trout can tolerate wider ranges in temperature and habitat types than brook trout and are more aggressive, particularly when young (Carlson et al. 2007), which may result in brook trout being confined to areas less desirable to brown trout (Wood & Budy 2009). Brown trout fry have also been shown to grow faster than brook trout fry in conspecific areas, increasing their fitness (Cunjak & Power 1986).

The YOY brown trout I collected from April through August 2013 in the first-order streams most likely immigrated to these streams. No evidence of redd formation or spawning activity was observed in the 1st-order streams during the study period. Unlike some other salmonid species, brown trout are unlikely to spawn in shallow (<6 cm) water (Grost et al. 1990). In September, a month before brown trout typically spawn in Emmons Creek, water depths were less than 6 cm in most locations within eight of the nine 1st-order streams. While stream X2 had slightly deeper depths in September, it also contained dense beds of emergent macrophytes which probably made it an unlikely spawning location (Armstrong et al. 2003). Spawning brown trout also tend to prefer higher water velocity (Shirvell & Dungey 1983) than was found in the 1st-order streams. In addition, brown trout prefer to spawn in coarse gravel (Grost et al. 1990), which provide large interstitial spaces facilitating the transport of dissolved oxygen to the eggs, which is critical for egg development and survival (Armstrong et al. 2003). While potential spawning gravels were present in varying amounts in the 1st-order study streams with five streams containing over 25% gravel (Table 1), all study streams contained at least 50% fine sediment. The combination of shallow depths and high amounts of fine sediment in the 1st-order streams means fry likely did not emerge in these streams but rather migrated into the tributaries from nearby redds in Emmons Creek.

The emergence of trout fry from the spawning gravel is largely controlled by environmental factors, most notably stream temperature and timing of fall spawning (Armstrong & Nislow 2006). Based on my YOY density data from the 1st-order streams (Fig. 3), brown trout likely began emerging in Emmons Creek in March. Upon emergence, trout fry begin to disperse from the redd location, either passively with the flow of the current or through active swimming (Carlsson et al. 2004), typically in a downstream direction (Hayes 1995). Once trout have emerged, they enter what is known as the "critical period", a time of elevated risk of mortality and increased need for suitable habitat which extends for the first several months of life (Elliott 1990, Armstrong et al. 2003). My results indicate the presence of YOY brown trout in low-discharge first-order streams during this same period, indicating their viability as nursery habitat.

The suitability of a particular area to post-emergent trout is determined by several factors, including discharge (Mundie 1974, Amrstrong & Nislow 2006), water velocity (Daufresne et al. 2005, Hayes et al. 2000), presence of cover items (Millidine et al. 2012, Flebbe and Dolloff 1995), substrate type (Heggenes et al. 2002, Lund et al. 2003), and local trout density (Elliott 1990, Maki-Petays et al. 1999). Following emergence, discharge is often cited as the most important driver of fry abundance and survival (Mundie 1974, Tetzlaff et al. 2005). Early in development YOY trout are highly vulnerable to disturbances such as floods or spates which increase discharge temporarily and lead to displacement from desired habitat (Lobon-Cervia & Mortensen 2005). This vulnerability typically leads YOY trout to seek low-discharge habitats in upstream portions of a stream network (Bagliniere et al. 1989), though there is likely a low discharge limit below which habitat is not suitable for trout (Stream A3 was the lowest-discharge stream, and was mostly fishless). My data suggest that YOY trout were sensitive to discharge in the 1st-order streams, as density of YOY trout was negatively related to discharge in the spring, shortly following emergence (Fig. 5A). YOY brown trout density was postively related to fine sediment abundance in spring. Since higher levels of discharge and/or velocity are typically associated with lower amounts of fine sediment (Heggenes et al. 2002), it is likely that the affinity of YOY trout for streams with higher amounts of fine substrate in the spring is a result of trout seeking habitats in areas of lower discharge and/or velocity (Millidine et al. 2012, Heggenes et al. 2002, Maki-Petays et al. 1999). There were no relationships between YOY density and discharge or % fine sediment in summer, possibly reflecting shifts in the habitat preferences of YOY trout as they grow (Armstrong et al. 2003).

In addition to discharge, water velocities can influence the survival and distribution of young fish. For example, high water velocities in streams have been associated with increased salmonid fry mortality (Hayes et al. 2000, Tetzlaff et al. 2005). Brown trout fry establish feeding territories in areas with acceptable amounts of invertebrate prey and suitable velocity, and territories increase in size the fish grow (Elliott 1990, Armstrong et al. 2003). The ability of fry to find areas of suitably slow water velocity is critical within the first week of life, after which time those fish which fail to set up a territory are likely to perish (Daufresne et al. 2005). Heggenes et al. (2002) determined a mean preferred water velocity for post emergent brown trout fry of 6.3 cm/s, and similar preferred velocities have been put forward by Bardonnet & Heland (1994) and Heggenes et al. (1999) for post-emergent trout fry and small trout parr, respectively. Despite the influence of water velocity on YOY trout habitat choice described by other investigators, I found no relationship between YOY trout density and velocity in either spring or summer in the first-order streams. One possible explanation for this is the narrow range of water velocities in the 1st-order streams. Mean velocities in all streams (Table 1) and the vast majority of individual velocity measurements along the transects (Fig. 6) were well below the 20 cm/s maximum threshold cited for brown trout fry by Bardonnet & Heland (1994). This suggests that the velocity regimes in all of the 1st-order streams were suitable for YOY trout.

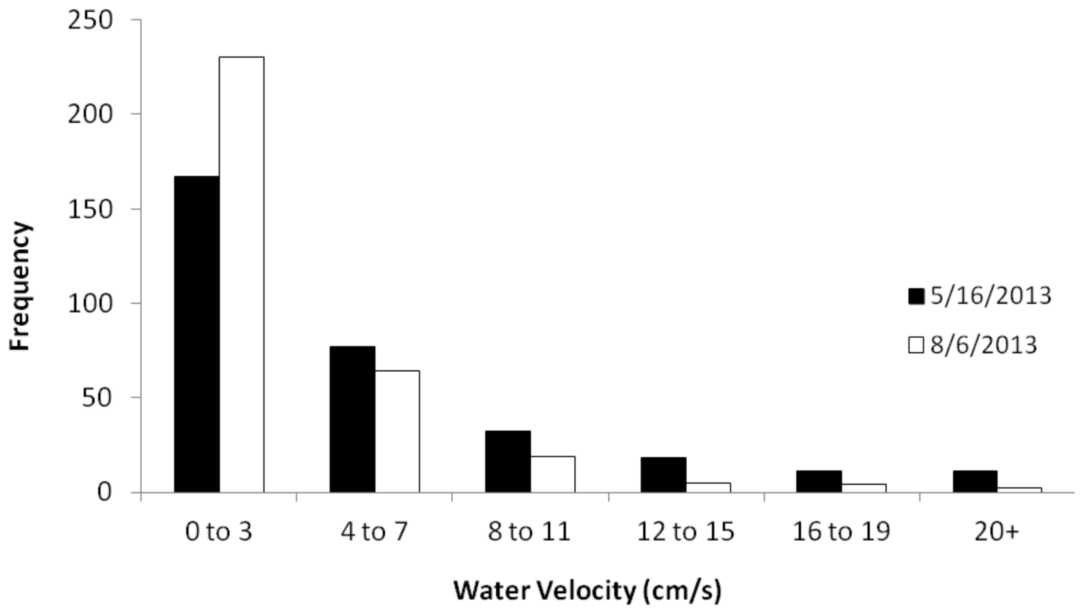

Figure 6: Frequency of individual water velocity measurements along the transects in the first-order streams in the Emmons Creek network by sampling date.

There was no relationship between trout density and the abundance of in-stream cover (woody debris and emergent macrophytes) in the 1st-order streams. These results was surprising, given the numerous studies that have shown the positive influence of cover items, particularly woody debris, on several salmonid species, including brook trout (Flebbe & Dolloff 1995), rainbow trout (Culp et al. 1996), cutthroat trout *Oncorhynchus clarkii* (Jackson & Sturm 2002), and both adult and juvenile brown trout (Sundbaum & Naslund 1998, Maki-Petays et al. 1997, Eklov & Greenberg 1998). As was the case with velocity however, it is possible the combined cover provided by woody debris and emergent macrophytes was not low enough to limit trout density in the first-order streams. Stream X3, which had a relatively low amount of large woody debris and few macrophytes (Table 1) contained abundant pieces of small woody debris which, while not quantified in this study, could have provided cover for small YOY trout.

Benthic invertebrate density was also not associated with YOY trout density in this study, and invertebrate densities did not show any discernible pattern through time. The lack of connection between YOY trout density and invertebrate abundance is not surprising, considering that previous studies have also cited no relationship (Hayes 1995, Zimmerman & Vondracek 2007).

Differences in mean lengths of YOY trout among first-order streams became more pronounced as the months progressed. These results may have been influenced by the effects of differences in trout densities among streams. Territorial behavior in brown trout increases and mean growth of YOY slows as density increases (Jenkins et al. 1999, Klemetsen et al. 2003). Territorial behavior might have driven the negative relationship between trout body size and density in the first-order streams in August (Fig. 4). While trout density never exceeded 1 /m^2 in any of the streams at the reach-scale, below the 2.5/m^2 threshold given by Titus (1990) as the density trigger point for increased territorial behavior, fish density at the patch scale may have exceeded this threshold. However, trout density at the patch scale was not quantified because the specific locations of individual trout could not be determined while electrofishing, due to the propensity of the trout to swim upstream from their initial position upon exposure to the electrical current. Differences in trout length among streams could also have been influenced by the timing of immigration and emigration between the first-order streams and Emmons Creek. For example, faster growing fish may have abandoned the smaller first-order streams earlier than slower growers (Bagliniere et al. 1989, Forseth et al. 1999). However, because immigration and emigration by YOY brown trout were not measured we cannot evaluate the potential role of fish migration on the size differences among streams.

Our sampling methodology included some potential limitations. The first of these was the use of a single electrofishing pass in each study stream, rather than the use of multiple passes. Performing multiple passes would have included several drawbacks however, including physical damage to the stream channel and increased risk of injury or death for the trout. The process of walking the streams during each electrofishing pass also left the water turbid, minimizing the potential effectiveness of a second pass. For these reasons, I elected to only perform a single pass in each stream. Size-selectivity during electrofishing is another potential source of error in my study. Because the size of YOY trout increased as the study progressed and electrofishing sampling efficiency typically increases with fish size (Anderson 1995, Dauwalter & Fisher 2007, Meador 2012) variation in capture efficiency through time may have affected estimates of trout density, possibly contributing to the observed monthly increase in YOY trout density from April through July in 2013 (Fig. 2). Finally, the presence of cover items may have interfered with fish sampling and introduced a source of bias. During an electrofishing pass, stunned fish are often able to recover and subsequently take refuge in areas beneath thick plant beds or woody debris where they cannot be netted easily (Peterson et al. 2004). This could have influenced fish capture efficiency, particularly in streams such as X2 which contained a high amount of emergent macrophytes.

Headwater streams play an integral role in stream networks. The benefits of healthy headwater streams include the maintenance of diverse and healthy invertebrate

(Clarke et al. 2008), amphibian (Fauth and Resetarits 1991), and fish (Meyer et al. 2007) communities. Despite this importance, headwater streams face a myriad of threats, including channelization during the course of urban development (Millidine et al. 2012), alteration of flow due to tree falls resulting from logging activities (Bryant 1983), agricultural runoff both in the form of chemical pollutants and excess sedimentation (Moore & Palmer 2005), depletion of groundwater due to high-capacity wells for irrigation, and the creation of impermeable surfaces (e.g. parking lots, roads) which prevent groundwater recharge after rain events (Roy et al. 2005). The cumulative effects of these factors, as well as the potential for long-term changes in flow regime and groundwater availability due to the effects of climate change (Brooks 2009) could disrupt first-order streams to the point where the available habitat and flow regimes are no longer suitable for brown trout and other fish species. My results show that YOY brown trout use small first-order streams as nursery areas, and variation in hydrology in these streams likely influences their suitability for trout. Based on these results and the known threats to small headwater streams I think these streams should be included in both management plans for fish populations and conservation and restoration plans for river networks.

Acknowledgements

I would like to acknowledge personnel from the Wisconsin Department of Natural Resources, in particular Alan Niebur for his assistance in the initial design of the project and for his help with fish sampling and Harry Hoodie for providing both the training and the backpack electroshockers for this study. This research was funded in part by a William Beck scholarship provided by the Central Wisconsin Chapter of Trout

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CHAPTER III

CONCLUSIONS

The results of this study demonstrate that young-of-the-year brown trout make use of small first order streams in the Emmons Creek stream network. YOY trout were first observed in March of 2013, and could be sampled effectively beginning with the April sampling date. The timing of fish presence between individual streams varied, likely due to the effects of discharge and flow on the suitability of the streams for young fish. Several streams (A1, A2, and A4) were occupied by YOY fishes soon after emergence, resulting in a spike in density in early spring. Streams with higher discharge in the spring (particularly X1, X2, And B1) showed low trout densities with no post-emergent spike in density. These streams supported trout that were members of the 2012 year class during the spring, and the total density of trout (including both the 2012 and 2013 cohorts) in them increased slowly as the year progressed. This, along with the corresponding drop in density seen in the lower discharge streams, could reflect changes in the flow preferences of trout as they age, as has been described previously (Heggenes et al. 2002, Heggenes et al. 1999, Lund et al. 2003, Maki-Petays et al. 1999).

Linear regression analyses revealed a positive association ($P<.05$) between trout density and fine sediment and a negative association between trout density and stream discharge in the spring, but not in the summer. This reflects previous studies of trout habitat preference in stream channels. Brown trout fry are initially poor swimmers (Daufresne et al. 2005, Hayes et al. 2000), and require slow flows in order to avoid being swept out of advantageous territory space. Streams with lower discharge and flow velocity often feature higher amounts of fine substrate, due to the lack of force in the stream necessary to flush fines out into the main channel. As trout grow and their swimming skills improve, they are able to establish territories in areas of higher velocity and discharge. In the case of my study, this shift could be seen in the fact that the significant relationships between trout density and low discharge/high fine percentage vanished as the year progressed.

Habitat and hydrological evaluations revealed that first-order streams are subject to changes in conditions through the course of the year. It is likely that drops in depth and velocity exacerbate the need for young fish to abandon their territories in first-order streams as they age. Since growing trout require larger territories with more depth and higher abundance of prey items with increased size, reduction in discharge in first order streams likely causes the streams to drop below the needed threshold more quickly. This is especially the case in low-discharge streams with low mean depths.

The mortality and growth rates of YOY brown trout are affected by both the availability of suitable habitat as well as trout density, with higher densities being associated with higher mortality rates and reduced growth (Jenkins et al. 1999, Klemetsen et al. 2003). In the spring, few significant differences existed between mean lengths of trout among the study streams (Tukey’s Honestly Significant Different Test; 2 out of 36 possible combinations of streams were significantly different for the April sampling date). As the year progressed however, larger fish began to be generally associated with particular streams, and in August 12 out of a possible 36 stream comparisons showed significant differences in fish total length. In addition, the mean total lengths of trout among study streams were negatively associated with YOY density in August, but not in earlier months. This introduces the possibility that density-dependent factors, such as food availability and increased levels of aggressive territorial behaviors leading to injury and reduced foraging, may have played a role in shaping the size structure of YOY trout within the study streams. In addition, the size structure of trout may have been influenced by immigration to/emigration from the study streams by trout of varying size, possibly in the search for more ideal habitat. My data does not allow for a definitive answer in either case (i.e. whether immigration patterns or density-dependent factors were more or less responsible for the divergence in mean lengths among streams), and further research will be necessary to determine the mechanism responsible for these results.

Consumable invertebrate abundance varied among streams (ANOVA, $P<.05$), but no detectable increase or decrease in abundance occurred between stream sampling dates. While several studies have described the diet of trout fry and parr as being totally composed of aquatic invertebrates (Kelly and Dick 2005, Elliott 1967, Johnson et al. 2007), no connection between invertebrate density and trout density was found among the study streams. This lack of connection continued when only chironomid larvae were considered, and when only invertebrates of consumable size were considered. It is possible that a more complete sampling of the benthos and drift within these streams would reveal a more detailed picture of the invertebrate community present in them, which could yield significant relationships to the presence of fish. More likely however, trout densities were not high enough in any of the streams at any point to begin to deplete the invertebrate food supply, meaning food abundance was not likely to be a limiting factor in the suitability of the streams to trout.

The health of stream fisheries often depends on the abundance of available habitat, not only for adult fish but for juveniles as well. While small headwater streams may not often be a major target for recreational fishermen, conservationists, or fisheries researchers, my research shows that they are in fact capable of providing habitat for fishes. The destruction or alteration of these habitats may well have a significant negative effect on trout recruitment, which could reduce the population of adult fish present in a river system. Moving forward, it will be essential for researchers and conservationists to take the viability of small streams as fish habitat into account as they craft stream management and restoration strategies.

APPENDIX A

Length-classes of brown trout sampled from second-and third- order reaches of Emmons Creek in summer 2012

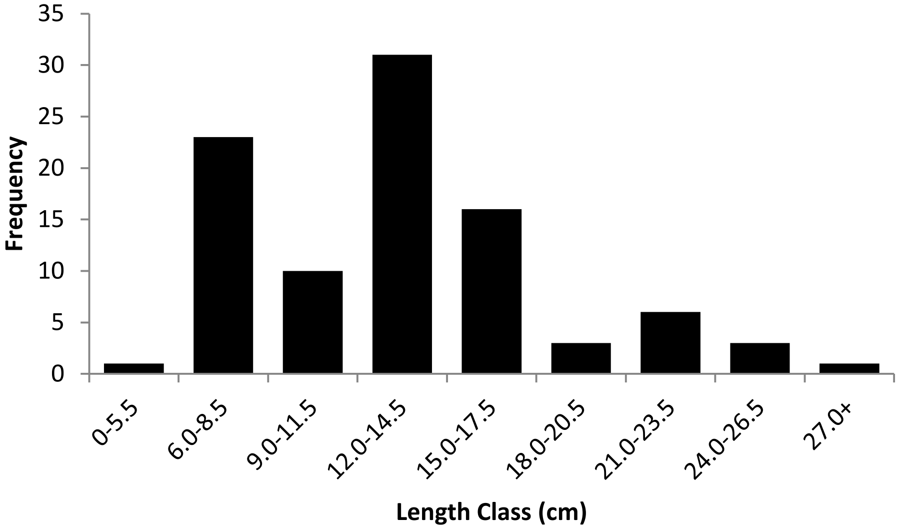

Figure 1-A. Length-class distribution of brown trout sampled from reach X, 8/16/2012.

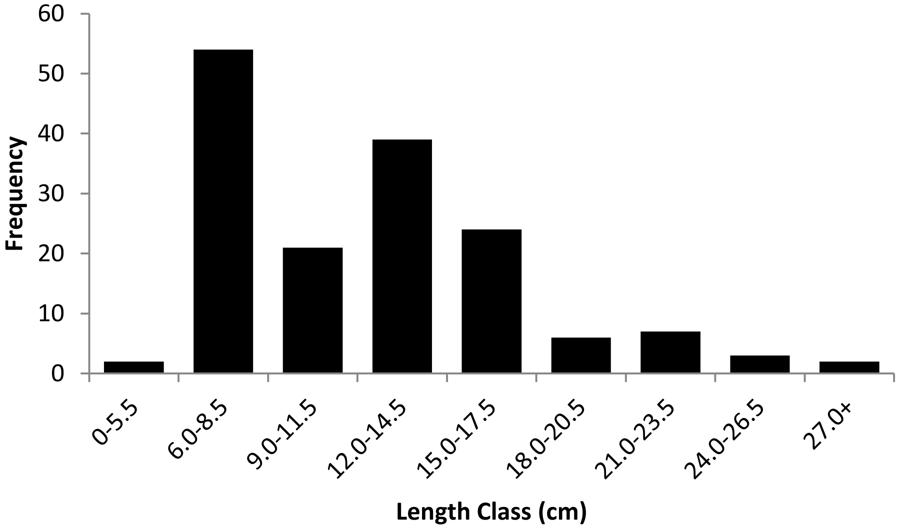

Figure 2-A. Length-class distribution of brown trout sampled from reach A, 8/16/2012.

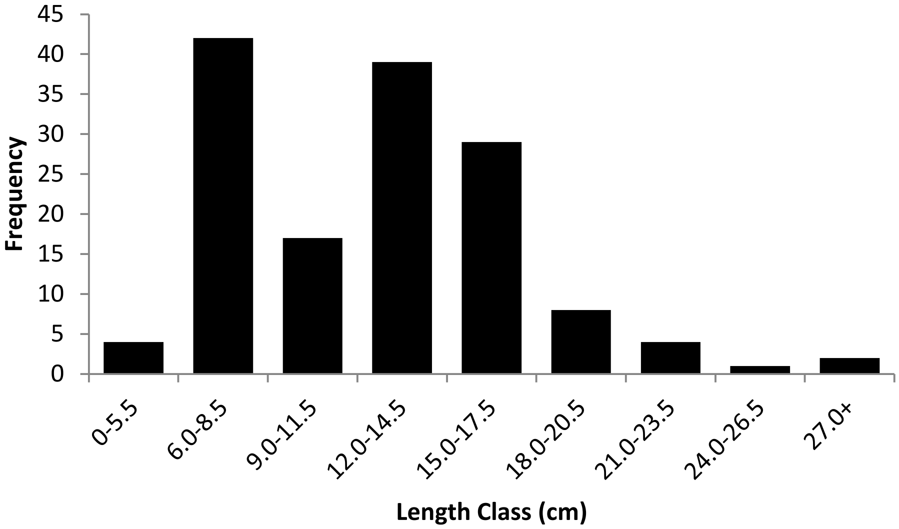

Figure 3-A. Length-class distribution of brown trout sampled from reach B, 7/18/2012

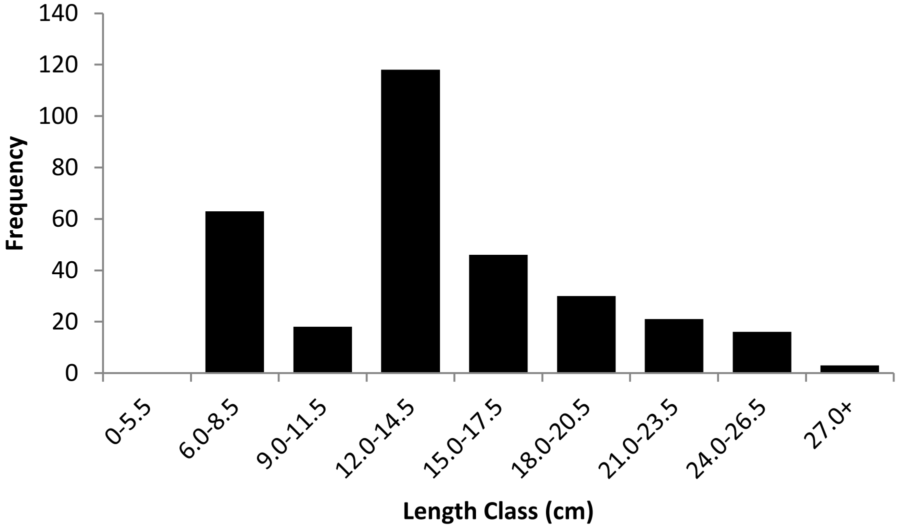

Figure 4-A. Length-class distribution of brown trout sampled from reach SLR, 7/18/2012

APPENDIX B

Summary of the abundance of invertebrate taxa sampled from first-order streams by sampling date

Table 1-B. Abundance of invertebrate taxa sampled from stream X1 by sampling date.

Class	Order	Family	4/16/13	6/11/13	8/10/13
Phylum Nematoda					1
Bivalvia	Veneroida	Sphaeriidae	1		
Gastropoda	Basommatophora	Physidae	3	2	3
Insecta	Diptera	Chironomidae	6	10	8
		Simulidae		2	22
		Tabanidae			1
		Tipulidae			3
	Ephemeroptera	Baetidae	1		
	Trichoptera	Brachycentridae	1		
		Hydropsychidae		1	1
		Lepidostomatidae		2	
		Limnephilidae	1	12	
		Odontoceridae	1		
		Rhyacophilidae	1		1
		Uenoidae	4		
Malacostraca	Amphipoda	Gammaridae	19	51	30
Oligochaeta			1	2	3
Turbellaria				1	

Table 2-B. Abundance of invertebrate taxa sampled from stream X2 by sampling date.

Class	Order	Family	4/16/13	6/11/13	8/10/13
Phylum Nematoda				1	8
Phylum Nematomorpha				1	2
Bivalvia	Veneroida	Sphaeriidae		2	
Entognatha	Collembola		1	1	
Gastropoda	Basommatophora	Physidae	15	15	6
		Planorbidae	2	2	
Insecta	Coleoptera	Dytiscidae	1		3
	Diptera	Ceratopogonidae	1	1	1
		Chironomidae	46	37	75
		Empididae			2
		Dixidae	1		
		Simulidae			1
		Tipulidae	1	2	
	Ephemeroptera	Baetidae			1
		Leptophlebidae			6
	Plecoptera	Capniidae	3		
	Trichoptera	Brachycentridae	1		
		Glossosomatidae	1		
		Hydropsychidae	1		3
		Lepidostomatidae	5	5	1
		Limnephilidae	6	3	11
Malacostraca	Amphipoda	Gammaridae	7		8
Maxillopoda (Subclass Copepoda)					1
Oligochaeta			13	22	57

Table 3-B. Abundance of invertebrate taxa sampled from stream X3 by sampling date.

Class	Order	Family	4/16/13	6/11/13	8/10/13
Phylum Nematoda					1
Phylum Nematomorpha				2	
Bivalvia	Veneroida	Sphaeriidae	11	2	4
Gastropoda	Basommatophora	Physidae	8	3	4
Hirudinea					1
Insecta	Diptera	Ceratopogonidae	24		
		Chironomidae	29	6	6
		Empididae	2		
		Ptychopteridae	8		1
		Tabanidae	1	1	
		Tipulidae		2	
	Trichoptera	Lepidostomatidae		8	
		Limnephilidae	2	3	8
		Molannidae	1		
		Odontoceridae		1	
Malacostraca	Amphipoda	Gammaridae		15	3
Oligochaeta			7	4	6

Table 4-B. Abundance of invertebrate taxa sampled from stream A1 by sampling date.

Class	Order	Family	4/16/13	6/11/13	8/10/13
Phylum Nematoda					11
Bivalvia	Veneroida	Sphaeriidae	1	2	
Gastropoda	Basommatophora	Physidae	7		1
Insecta	Diptera	Ceratopogonidae	6	1	
		Chironomidae	15	25	9
		Simulidae		1	1
		Tipulidae	1	1	2
	Trichoptera	Glossosomatidae		4	13
		Lepidostomatidae	1	7	
		Limnephilidae	8	6	4
		Uenoidae	3	3	
Malacostraca	Amphipoda	Gammaridae	23	7	6
Oligochaeta			3	4	7

Table 5-B. Abundance of invertebrate taxa sampled from stream A2 by sampling date.

Class	Order	Family	4/16/13	6/11/13	8/10/13
Phylum Nematoda				2	47
Phylum Nematomorpha			1	1	
Bivalvia	Veneroida	Sphaeriidae	1	2	2
Gastropoda	Basommatophora	Physidae	3	3	17
Insecta	Coleoptera	Dytiscidae			3
	Diptera	Ceratopogonidae		3	
		Chironomidae	2	21	39
		Tipulidae		1	1
	Ephemeroptera	Ephemerellidae	1		
	Trichoptera	Lepidostomatidae		2	
		Limnephilidae	4	4	3
Malacostraca	Amphipoda	Gammaridae	15	31	22
Maxillopoda (Subclass Copepoda)				27	24
Oligochaeta			2	8	13

Table 6-B. Abundance of invertebrate taxa sampled from stream A3 by sampling date.

Class	Order	Family	4/16/13	6/11/13	8/10/13
Phylum Nematoda			5	11	12
Phylum Nematomorpha				1	1
Bivalvia	Veneroida	Sphaeriidae	12	6	1
Gastropoda	Basommatophora	Physidae	4		1
Insecta	Coleoptera	Dytiscidae	1		
		Elmidae			1
	Diptera	Ceratopogonidae	33	2	
		Chironomidae	66	13	5
		Ephydridae	1		
		Ptychopteridae	1		
		Tipulidae	5	1	3
	Trichoptera	Lepidostomatidae	4	4	
		Limnephilidae	10	10	2
		Molannidae	1		
Malacostraca	Amphipoda	Gammaridae	19	7	9
Maxillopoda (Subclass Copepoda)				2	
Oligochaeta			26	6	14

Table 7-B. Abundance of invertebrate taxa sampled from stream A4 by sampling date.

Class	Order	Family	4/16/13	6/11/13	8/10/13
Phylum Nematoda			1	1	2
Phylum Nematomorpha					3
Bivalvia	Veneroida	Sphaeriidae	2	1	3
Gastropoda	Basommatophora	Physidae	5	2	
Hirudinea			1		
Insecta	Diptera	Ceratopogonidae	3	1	
		Chironomidae	2	5	
		Simulidae			2
		Tipulidae	1	2	
	Trichoptera	Lepidostomatidae		1	
		Limnephilidae		12	1
Malacostraca	Amphipoda	Gammaridae	11	27	12
Oligochaeta			6	15	4

Table 8-B. Abundance of invertebrate taxa sampled from stream B1 by sampling date.

Class	Order	Family	4/16/13	6/11/13	8/10/13
Phylum Nematoda			1	1	
Phylum Nematomorpha			3		
Bivalvia	Veneroida	Sphaeriidae	8	5	1
Gastropoda	Basommatophora	Physidae	1	3	2
Insecta	Diptera	Ceratopogonidae	4		1
		Chironomidae	3	7	1
		Tipulidae			1
	Trichoptera	Hydropsychidae	1		
		Limnephilidae		1	4
		Uenoidae	5	1	
Malacostraca	Amphipoda	Gammaridae	1	10	18
Maxillopoda (Subclass Copepoda)				1	
Oligochaeta			3		

Table 9-B. Abundance of invertebrate taxa sampled from stream B4 by sampling date.

Class	Order	Family	4/16/13	6/11/13	8/10/13
Phylum Nematoda			5	4	1
Phylum Nematomorpha			1	3	
Bivalvia	Veneroida	Sphaeriidae		2	
Gastropoda	Basommatophora	Physidae	11	19	8
		Planorbidae		1	
Insecta	Diptera	Ceratopogonidae	12	2	
		Chironomidae	60	18	4
		Ephydridae	1		
		Tipulidae		2	
	Ephemeroptera	Leptophlebidae	1		
	Plecoptera	Capniidae	10		
		Nemouridae		1	
	Trichoptera	Brachycentridae	6		
		Lepidostomatidae		20	1
		Limnephilidae	13	30	11
		Odontoceridae	2	2	2
Malacostraca	Amphipoda	Gammaridae	28	81	27
Maxillopoda (Subclass Copepoda)				2	
Oligochaeta			4	4	3
Turbellaria			1		1

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