Defining the Physiochemical, Biological and Habitat Requirements for the Upper Extant of *Oncorhynchus mykiss* Distribution

Emily Powers
Biology Department
Bemidji State University

The distribution of rainbow trout is strongly influenced by their habitat. As climatic conditions change, the distribution of rainbow trout populations will change along with them. The objective of this study was to identify the particular habitat parameters that rainbow trout select for in this lotic system and to specifically assess how this relates to the upper extant of their distribution. By assessing the distribution of the upper extant specifically, future research may be conducted to better assess climatic changes on a small and/or large scale basis. A 9,000 m section of the Clearwater River was used as the study site. Hook-and-line method was used to catch all rainbow trout throughout this reach and was used to assess the upper extant of the trout population's distribution. Available and used habitat parameters including temperature, dissolved oxygen, depth, width, stream velocity, and substrate size were assessed two times per week for three months. A t-test, displaying 95% confidence, was used to compare available habitat to habitat used by rainbow trout. T-test results indicated that temperature ($p < 0.001$), depth ($p = 0.029$), and width ($p = 0.036$) were habitat parameters that rainbow trout selected for. Trout resided farther upstream in the spring when river temperatures were cooler and depths deeper due to flooding conditions from snow melt. As temperatures increased, trout moved downstream to cooler water. While this trend is inconsistent with the River Continuum Concept, which explains physical, chemical, and biological patterns for north to south flowing rivers, the Clearwater River flows south to north and therefore may have extensive differences. As climatic conditions change, especially as temperatures increase, the distribution of trout will change also.

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Introduction

Climate change will affect aquatic systems by warming water temperatures, altering flow regimes (Poff et al., 2002), displacing suitable habitat ranges for species distribution (Parmesan, 2006), and shifting reproductive cycles of riverine fishes (Rahel and Olden, 2008). Trout have a high sensitivity to temperature and as a result they have been used largely as model organisms for examining how climate change will affect species distribution (Mohseni et al., 2003; Eaton and Scheller, 2006; Rahel and Olden, 2008; Wenger et al., 2011). Research suggests that warming temperatures will negatively influence cold water fishes the greatest (Mohseni et al., 2003). Habitat suitability for rainbow trout is predicted to decline by 36% throughout the United States (Mohseni et al., 2003). Management techniques for this popular game species are critical with climate change looming. An understanding of habitat requirements is essential for developing management techniques that will increase the likelihood of future rainbow trout success.

Optimal rainbow trout (*Oncorhynchus mykiss*) riverine habitat is characterized by clear, cold running water, rocky substrate with a 1:1 pool-to-riffle ratio, abundant stream cover, stable water flow, and vegetated stream banks (Raleigh and Duff, 1980). Rainbow trout can survive in water temperatures between 0 and 29.8°C (Rodgers and Griffiths, 1983; Currie et al., 1998). The critical thermal maximum for rainbow trout is between 24 and 26°C (Bidgood, 1980). Average summer water temperatures between 12.6 and 18.6°C result in higher trout densities (Molony, 2001). Normal fish physiological processes may be hindered at or outside this optimal range of thermal conditions. At low temperatures feeding, digestion, and development may be halted or slowed (Belkovskiy et al., 1991).

The pH tolerance of rainbow trout has been extensively studied and it varies throughout the world. Research has shown that trout can survive in aquatic systems with pH as low as 4.0 (Barlaup et al., 1996). Physiological complications occur in fish when riverine habitat conditions are outside their suitable range. Lack of viable offspring is perhaps the largest of these consequences, which results in real implications to fish populations, a working food web, and whole communities of organisms. Rainbow trout, therefore, should be most abundant at a pH that promotes growth, which is between 6.5 (Barton, 1996) and 8.5 (Brannon, 1991). In addition, rainbow trout are best suited for survival between pH's of 6 (Sedgwick, 1985; Stevenson, 1987) and 9 (Wedemeyer, 1996).

Perhaps the most important habitat requirement for rainbow trout is the presence of suitable dissolved oxygen concentrations. Dissolved oxygen levels that are below 5.0 – 6.0 mg/L can result in mortality (Doudoroff and Shumway, 1970; Weithman and Haas, 1984). Optimum growth occurs for adults as well as rainbow trout eggs at or above 5.0 mg/L (Soderberg and Mead, 1992), whereas asphyxiation occurs at or below 4 mg/L (Mathias and Barica, 1985). Low dissolved oxygen concentrations are exacerbated with higher water temperatures and greater salinity (Molony, 2001).

Perennial streams are preferred by trout. Perennial streams are those whose late summer flow should be greater than 55% of the average daily flow rate (Molony, 2001). Annual stream flows that have little variation are preferred over intermittent flow (Molony, 2001). Streams that are extremely narrow or extremely wide are not conducive for trout habitat. Widths between 5.4 – 6.6 m have higher densities of trout, which may be due to the ratio of stream width to cover available (Molony, 2001). Trout live at a minimum depth of 0.12 m (Thompson, 1972; Bjornn and Reiser, 1991).

Higher trout densities are found in rivers that move at a faster rate per unit volume. Trout densities are highest in water velocities of 45.6 – 76.0 cm/sec (Molony, 2001). Maximum velocity for trout is 1.22 m/sec (Thompson, 1972; Bjornn and Reiser, 1991). Substrate is important in a number of ways for rainbow trout. The size and type provides habitat for spawning (sediments and gravel), shelter from predators (cobble and boulders), a resting place from turbulent flow (Baltz et.al,, 1991), and food (periphyton on substrate).

Despite the extensive research that has been conducted on rainbow trout habitat, factors limiting the upper extant of their distribution are yet to be understood fully. The goal of this study is to determine the biological, chemical and ecological influences that determine the upper extant of rainbow trout distribution in a river system. Research in this area will provide a sound knowledge base about the ecological, biological, economic, social, and management implications where climate change is imminent. Research on fish location, chemical concentrations, and habitat will provide insight on the distribution of rainbow trout populations and their future chance of survival as climate change accelerates.

Methods

Rainbow trout were studied on a 9,000 m reach of the Clearwater River. River distance (m) increases when moving upstream towards 9,000 m, while numbers decrease when moving downstream towards 0 m. The study was conducted from the end of May to the middle of August in 2013. This river section has been designated a trout stream specific to rainbow trout by the Minnesota Department of Natural Resources (MNDNR, 2013). Preliminary fish observations took place during the last two weeks of May using hook-and-line. This preliminary data was used to establish a starting point to study the upper extant of rainbow trout distribution on the river

The study began the first week of June and continued through August. Hook-and-line method was used throughout the study using the same bait; a light weight jig head with a white mimic scud. Only adult rainbow trout were observed, counted, and used for identifying suitable habitat in conjunction with trout distributions within the stream.

The upper extant was first established in June by fishing 3,000 m above where the last fish was caught during the preliminary study and continuing downstream. Random site habitat parameters were measured every 250 m and at each site where a rainbow trout was caught. Fishing continued downstream until roughly 8-16 fish were caught beyond the upper extant location for that day. For subsequent dates the starting point for sampling began downstream and continued upstream. This was to minimize the amount of scent, sound, and sediments disturbed, which could alarm and affect distributional changes for trout.

Starting downstream the researcher walked upstream using hook-and-line and direct observation for fish locations. Available habitat was measured by randomly selecting a point along a transect spanning the width of the river every 250 m. Used habitat was measured for each fish caught or observed on each date. The survey for the day would continue until 1000 m upstream from the last rainbow trout caught for that day. For each sample location, whether measuring available or used habitat, the following measurements on habitat were collected: velocity, width, depth, water temperature, conductivity, dissolved oxygen concentrations, pH, and substrate size.

Stream velocity (m/s) was measured using a flow meter, which was positioned slightly above the river bottom. Stream width (m) was measured from bank-to-bank. Depths (m) used by rainbow trout were measured at each fish location. Available depths (m) were measured at each 250 m river transect by randomly selecting a point along that transect. Water temperature (°C), conductivity (μS/cm) and dissolved oxygen concentrations (mg/L) were measured using a YSI instrument.

Substrate was measured by collecting 10 randomly selected pebbles from a 1 m area surrounding the site location. Each pebble was measured to the nearest millimeter, and returned to the stream. If the substrate did not contain pebbles the material that was observed was categorized (sediment, bedrock, large woody debris) or measured (cobble) to the nearest millimeter.

Finally, using available habitat data and used habitat for upper extant fish, a model, using software R, was produced to predict the upper extant of rainbow trout distribution for the Clearwater River on any given date. Two, three, and four habitat parameters were compared against one another, and a model was chosen based on the highest R^2 value.

Results

The upper extant of rainbow trout distribution moved throughout the summer (Figure 1). In June, fish were found as far upstream as 7,027 m. In July, trout moved as far downstream as the 4,605 m mark. Around the middle of August trout moved upstream and were found as far as 7,822 m.

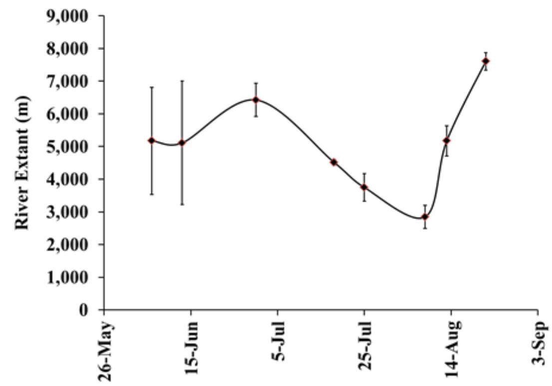

Figure 1. Rainbow trout distribution at the upper extant between June and August 2013 along the 9,000 m section of the Clearwater River. Data points were derived by averaging the river location (m) for 3 fish caught along the upper extant. Error bars represent +/- 2 SE calculated from the three fish last observed near the upper extant.

Depth (m) was the most significant habitat parameter that fish were selecting for throughout the 9,000 m reach of river. Available depths ranged from 0.12-1.45 m throughout the three month study period (Figure 2). Fish used depths ranging from 0.38-1.45 m and on average depth at fish locations was 0.80 m (Table 1).

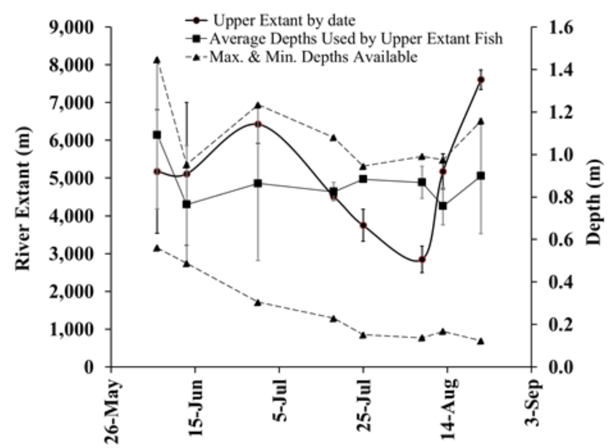

Figure 2. Rainbow trout distribution at the upper extant (smooth solid black line) from June to August 2013 is compared to maximum and minimum depths available (dashed line) and average depths used by trout (solid line with squares). River extant (m) is shown on the first y-axis, and depth (m) is shown on the second y-axis. Error bars represent +/- 2 SE calculated from the three fish last observed near the upper extant.

Water temperatures ranged from 14.2-28.3 (°C) at fish locations. When available temperatures were compared to used temperatures by fish along each of the 1000 m sections of river, fish selected habitats with cooler water (Figure 3). Temperatures, overall, grew warmer moving upstream (Figure 4). Linear regression analysis was used to compare river extant and temperature, which resulted in a p-value of $4.8E^{-8}$ and an R^2 value of 0.1487.

River widths ranged from 2.44-15.24 m. While all available widths were used, fish selected for widths in the middle of this range (Figure 5). T-test results from the remaining habitat parameters, including velocity ($p = 0.055$), dissolved oxygen ($p = 0.12$), pH ($p = 0.250$), and substrate size ($p = 0.823$) resulted in p-values greater than 0.05, indicating trout were not selecting for these habitat parameters

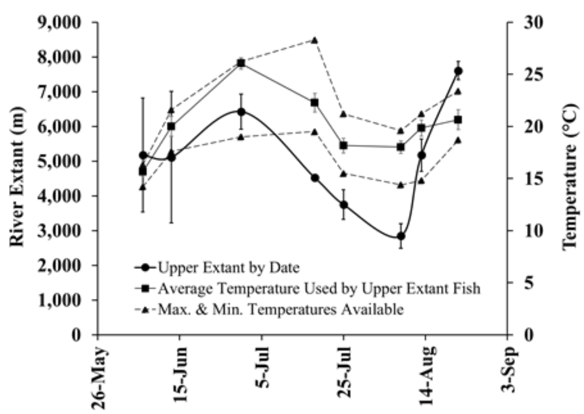

Figure 3. Rainbow trout distribution at the upper extant (smooth solid black line) from June to August 2013 is compared to maximum and minimum temperatures (°C) available (dashed line) and average temperatures used by trout (solid line with squares). River extant (m) is shown on the first y-axis, and temperature (°C) is shown on the second y-axis. Error bars represent +/- 2 SE calculated from the three fish last observed near the upper extant.

Fish densities were highest along the 3,000 m river section (Figure 6). The density for this stream reach was 0.036 $Ind.m^{-1}$. Fish densities declined rapidly in river reaches downstream from the 3,000 m reach. Fish densities decline more slowly above this stream reach and eventually result in no fish beyond 8,000 m.

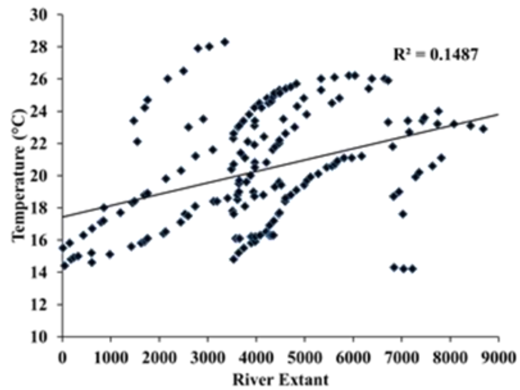

Figure 4. Temperature profile of the Clearwater River along the 9,000 m study reach for the summer months of June through August of 2013. River extant (m) is shown on the x-axis and temperature (°C) is shown on the y-axis.

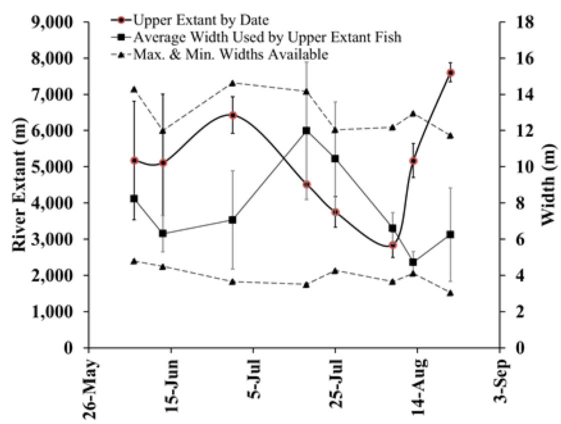

Figure 5. Rainbow trout distribution at the upper extant (smooth solid black line) from June to August 2013 is compared to maximum and minimum widths (m) available (dashed line) and average widths used by trout (solid line with squares). River extant (m) is shown on the first y-axis, and width (m) is shown on the second y-axis. Error bars represent +/- 2 SE calculated from the three fish last observed near the upper extant.

To predict the upper extant distribution of rainbow trout the following model was produced:

Predicted Upper Extant = -79127+2562(temp)-4384(width)-11237(velocity)+6850(DO)

When observed upper extant locations were compared to predicted upper extant distributions, there was an R^2 value of 0.93 (Figure 7).

Table 1. Available habitat, compared to habitat used by rainbow trout, for each study reach throughout the three month study period on the Clearwater River. Averages were used from each site location along each river extant (m) to determine the values. Habitat parameters that were measured include: depth (m), velocity (m/s), temperature (°C), dissolved oxygen (mg/L), pH, width (m), and substrate size (mm). Used values were averaged from all fish caught through hook-and-line method or directly observed in the river, including the upper extant fish.

	Depth (m)		**Velocity (m/s)**		**Temperature (°C)**		**DO (mg/L)**		**pH**		**Width (m)**		**Substrate (mm)**	
River Extant (m)	Available	Used	Available	Used	Available	Used	Available	Used	Available	Used	Available	Used	Available	Used
0-1000	0.40	0.84	0.38	0.16	15.87	15.56	10.33	10.56	8.41	8.42	5.64	5.88	74.42	54.75
1001-2000	0.51	0.80	0.26	0.11	18.96	19.01	10.52	11.35	8.84	8.57	6.59	5.89	46.60	40.76
2001-3000	0.42	0.84	0.19	0.19	21.49	19.35	10.71	9.72	8.61	9.16	8.38	6.36	76.41	89.30
3001-4000	0.49	0.79	0.23	0.23	19.82	19.81	9.66	9.02	8.58	9.10	10.29	9.99	102.36	50.61
4001-5000	0.43	0.77	0.25	0.15	21.80	19.82	10.18	9.27	8.35	8.90	9.29	9.12	49.48	54.26
5001-6000	0.46	0.76	0.24	0.17	22.67	22.20	10.60	10.52	8.43	8.43	7.10	5.13	36.68	32.10
6001-7000	0.62	0.98	0.13	0.20	24.12	20.84	9.95	8.37	8.50	8.68	8.81	5.82	18.76	52.59
7001-8000	0.64	0.90	0.34	0.12	21.09	19.88	9.39	8.73	8.99	8.70	5.71	5.30	14.34	27.83
8001-9000	0.21		0.13		23.07		8.37		8.38		8.99		53.27	
Number Sampled	176	79	178	80	153	60	178	80	178	80	178	80	165	69

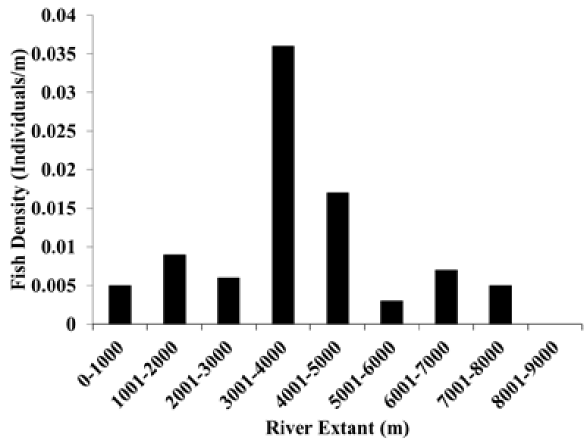

Figure 6. Trout densities (individuals/m) for each 1000 m river section of the study reach. Densities were highest among the 3,000 m range and lowest farther upstream at the 8,000 m range.

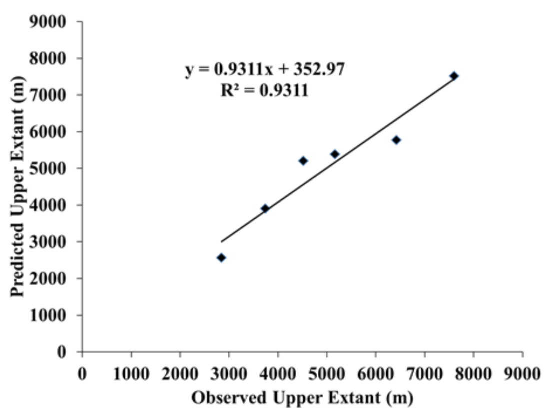

Figure 7. Observed upper extant distribution (x-axis) compared to predicted distribution (y-axis) that were established from the 4-parameter (dissolved oxygen, temperature, width, and velocity) model using program R.

Discussion

The upper extant of the rainbow trout population's distribution changed dramatically throughout the study period and was due, in part, to the habitat parameters measured within this study. While rainbow trout live at a minimum depth of 0.12 m (Thompson, 1972; Bjornn and Reiser, 1991) no trout in this study were found in water less than 0.38 m, but rather selected for depths of 0.80 m.

Water temperatures varied temporally and spatially throughout this study. Temperatures were colder in the spring, spiked in July, and again grew cooler towards the middle of August. This relationship was reflected in the upper extant for trout distribution. Trout were found further upstream in the beginning of June, moved downstream in July, and again migrated upstream in the middle of August.

While fish utilized a wide range of temperatures in this study (14.3-28.3°C), and can be found in temperatures between 0 and 29.8°C (Rodgers and Griffiths, 1983; Currie et al., 1998), fish selected for an average temperature of 19.8°C. Average summer water temperatures between 12.6 and 18.6°C result in higher trout densities, which is consistent with data from this study.

Available temperatures were consistently warmer upstream and colder downstream. While this trend is consistent throughout the 3-month study period for this stretch of river, this finding is the exact opposite of what one would expect based on the River Continuum Concept (Vannote *et* al. 1980). Several possible explanations as to why this occurs on the Clearwater River for this reach may exist. The stream distance that was designated 0-1000 m was near a very cold spring that then flowed through a culvert. From this culvert the Clearwater River runs north and eventually drains into the Hudson Bay. The River Continuum Concept has been used to determine the chemical, physiological, and biological trends in a river that flows north to south. There is no model that we know of that shows these same trends for a river that flows northward.

Widths between 5.4-6.6 m contain higher densities of trout (Molony, 2001), due in part to added cover and/or overhanging banks. As the Clearwater River has relatively few river sections that are this narrow, when available habitat widths are compared to widths used by fish, trout select for widths that are more narrow than what is available. There appears to be a correlation between width and fish movement as Figure 5 shows. As fish moved throughout the summer they selected for many different widths. What each of these selections had in common, however, was that they contained a pool that was approximately 0.8 m deep.

Temperatures became warmer as one moved upstream. In July temperatures became too warm upstream and fish moved downstream to cooler water. Temperature directly influences fish survival and growth (Stefan and Sinokrot, 1993). As atmospheric conditions change as a result of CO_2 and other pollutant emissions, the surrounding landscapes change along with them. Streams, unlike other aquatic systems, are narrower and shallower. As a result stream habitats, and the species living within or near these sources of water, will be most affected by climatic changes. Changes in the flora along the stream banks that provide structure, shading, and assist with erosion, would also likely change as a result of climatic changes.

It is expected that fish, especially those fish with narrow temperature tolerances, such as rainbow trout, will show shifts or an alternation of their geographic distribution due to climate change (Frank *et* al., 1990; Coutant 1990). Along the Clearwater River it would be expected that the rainbow trout population would migrate to colder water, and hence downstream or northward.

The difficulty of this system leaves many unanswered questions. The scope and depth of these research questions far exceeds the findings of this paper. It is the hope of the researcher that this study will inspire further opportunities for exploration of these ideas.

The model produced from data collected on the Clearwater River could be useful in assessing habitat in the future as climatic conditions change. Knowing the upper extant distribution of rainbow trout on this river could assist fisheries biologist in assessing suitable habitat for stocking trout.

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