2008

THE AGE STRUCTURE, LENGTH, CONDITION, AND MOVEMENT OF RESIDENT AND COASTER BROOK TROUT (SALVELINUS FONTINALIS) IN PICTURED ROCKS NATIONAL LAKESHORE, MICHIGAN

Paul C. Kusnierz

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By

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THESIS

Submitted to
Northern Michigan University
In partial fulfillment of the requirements
For the degree of

MASTER OF SCIENCE

Graduate Studies Office

2008

SIGNATURE APPROVAL FORM

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ABSTRACT

THE AGE STRUCTURE, LENGTH, CONDITION, AND MOVEMENT OF RESIDENT AND COASTER BROOK TROUT (*SALVELINUS FONTINALIS*) IN PICTURED ROCKS NATIONAL LAKESHORE, MICHIGAN

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Paul Clinton Kusnierz

Pictured Rocks National Lakeshore (PRNL) is the site of an ongoing coaster brook trout (*Salvelinus fontinalis*) restoration. These lake dwelling fish grew larger than the stream residents in the Lake Superior watershed and once supported a fishery on the lake and in tributary streams below the first barrier. Although the restoration project has been underway since 2000, little is known about the age composition of brook trout in Pictured Rocks National Lakeshore. Scales samples, length, and weight data were collected from brook trout in the Hurricane and Mosquito rivers as well as Sevenmile Creek. In addition, fish from the Hurricane River were tagged with Passive Integrated Transponder tags to track their movement into and out of the river. The most common age for brook trout in PRNL is age 1. Although some groups of fish differed in length at ages 0 and 1, and condition factor (K) at age 1 ($\alpha = 0.05$), this was lost by age 2. Coaster and resident brook trout from the Hurricane River did not differ in length at any age but did for K at ages 1 and 3 for all sampled fish. Peak movement by coasters occurred during the fall, which agrees with a previous study done in PRNL and with published data for other brook trout populations. The similarity in size and condition suggests that brook trout in PRNL are living under similar growth conditions regardless of stream or access to Lake Superior and/or enough movement of fish between the streams and stream reaches is taking place to make it appear as though one population exists.

ACKNOWLEDGEMENTS

I thank my advisor, Dr. Jill Leonard for all of her help and guidance with this project. Her assistance in the field, lab, and in the formulation of this thesis is greatly appreciated. I also extend thanks to Dr. Alan Rebertus and Dr. John Bruggink for their help and insight. Thank you to Bill Artwich and the other undergraduates who helped collect data in the field. Also thank you to graduate students Carla Serfas and Sara Ruiter for helping out in the field.

I would like to recognize and thank Lora Loope, Jerry Belant, and others from the National Park Service as well as the Fred Waara and Paul Young Chapters of Trout Unlimited for providing funding, equipment, and manpower.

Thank you to my parents, Dennis and Victoria Kusnierz who have always been supportive and instilled an appreciation for life and the environment. Thank you to Lisa Kusnierz for your love, support, and keeping me going through the hardest times.

The research for this thesis was funded by the National Park Service, Trout Unlimited, and Northern Michigan University.

The references for this thesis follow the format prescribed by the Canadian Journal of Fisheries and Aquatic Sciences.

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CHAPTER 1: LITERATURE REVIEW

Lake Superior once contained a popular recreational fishery for brook trout, *Salvelinus fontinalis* (Scott and Crossman 1973). These fish were called "coasters" because they were typically caught near the Lake Superior coastline (Becker 1983). Coaster brook trout were known for being easy to catch and reaching a large size. Today there is functionally no fishery for these fish, but widespread interest in restoring it exists (Wiland 2006).

The brook trout is a widely studied charr species native to much of eastern North America (Power 1980). Since the settlement of Europeans in North America, the brook trout has been successfully introduced to new areas of North America as well as other parts of the world. Brook trout have been so successful where introduced that they now threaten the species native to the watersheds and attempts have been made to eradicate them (Meyer et al. 2006; Thompson and Rahel 1996). Not only does this fish have at least 22 common names, including speckled trout, squaretail, brook charr, and salter, but also has many different body morphologies (Power 1980). In addition to being a popular game fish, it is perhaps because of this species' many forms and ability to live in many different geographical areas that the brook trout has been so well studied.

Brook trout tend to inhabit cool, well-oxygenated water, but otherwise can survive in a variety of physical habitats from low elevation spring-fed or coastal streams (Ritzi 1959) to acidic water (Frenett and Dodson 1984) and high alpine lakes (Gowan and

Fausch 1996). In streams, brook trout primarily use pools and habitat rich in large woody debris (Logan 2003). The general body form of the brook trout is similar to other salmonids although it is deeper bodied than other charr species such as Arctic charr (*Salvelinus alpinus*). Slight differences in body shape may allow brook trout to use different habitats and feeding guilds. For example, Bourke et al. (1997) found that brook trout in the benthic zones of two lakes within the Mastigouche Reserve, Quebec, Canada, had longer pectoral fins than those living in the pelagic zones. Dynes et al. (1999) also studied brook trout in the Mastigouche Reserve and were able to demonstrate differences in pectoral and dorsal fin length and body length behind the dorsal fin between fish living in the littoral and pelagic zones.

Variability exists in the life history traits of the brook trout. Brook trout are among the 54% of diadromous fish that are capable of being anadromous (McDowall 1987). Although capable of living in salt water, many brook trout never enter a saline environment. Among these fish that do not enter salt water, there are fluvial fish that reside in streams and are called stream residents, adfluvial fish that grow in lakes and spawn in streams, and lacustrine populations which live their entire lives within a lake (Northcote 1997). In a given population there will be fish that grow faster and mature more quickly than others (Hutchings 1993; Hutchings 1996; Wilson et al. 2003). How fast an individual grows and matures is the result of many variables including the individual's genetic make up, feeding guild, and life history.

As previously explained, brook trout are capable of diadromy, but exhibit many different migratory patterns as well as non-migratory strategies. The basis for brook trout migration in streams follows a regular pattern of movement from spawning habitat to feeding and survival habitat and finally back to spawning habitat (Northcote 1997). In situations where brook trout have access to the ocean or a lake, some brook trout will go to those habitats to spend part of their lives. This is called partial migration and is readily seen in streams containing anadromous brook trout (Smith and Saunders 1958; Doucett et al. 1999). Density dependent overwinter survival may be the most important cause of partial migration for a population (Kaitala et al. 1993) although energetic differences between juvenile resident and anadromous brook trout have been demonstrated in some populations (Morinville and Rasmussen 2003).

Brook trout are mobile fish. Although stream-resident brook trout often move less than 1600 m in a season, long distance movement does occur (Shetter 1968; Lê 1999; Logan 2003; Hansbarger 2005; Roghair and Dolloff 2005; Gowan and Fausch 1996). Upstream movement of brook trout can be limited by vertical barriers greater than 73.5 cm, the maximum height a brook trout can jump under ideal circumstances (Kondratieff and Myrick 2006). Brook trout being < 20 cm in length and the presence of shallow plunge pools (< 40 cm) below waterfalls decrease the barrier height a brook trout can surpass. Most resident brook trout movement occurs in the spring during run-off and in the fall in association with the spawning season (Gowan and Fausch 1996; Hilderbrand and Kershner 2000; Josephson and Youngs 1996). Likewise, anadromous brook trout exhibit peaks in movement during the spring and fall (Smith and Saunders 1958; Curry et al. 2002; Lenormand et al. 2004). Although little movement by brook trout occurs during the winter (Smith and Saunders 1958; Josephson and Youngs 1996), summer movement often occurs in association with temperature change (Marod 1995; Hansbarger 2005).

Gowan and Fausch (2002) describe summer movement as the result of brook trout monitoring habitat conditions and searching for food.

Little is known about the age at which adfluvial coasters leave their natal stream and migrate to Lake Superior. Because the movement patterns of adfluvial coasters are similar to anadromous brook trout, the ages at which these movements take place may be similar as well. The age of first downstream migration in the Saguenay River, Quebec was determined by Lenormand et al. (2004) to be primarily age 2, with age 1 making up nearly a third of all migrants. Likewise, Dutil and Power (1979), Smith and Saunders (1958), and Castonguay et al. (1982) found most migrations of anadromous brook trout to occur at age 2 and older. Work by Huckins and Baker (In Press) indicates that adfluvial coasters from the Salmon Trout River make their first spawning migration at age 2 which would indicate outmigration to Lake Superior at either age 0 or 1.

The Lake Superior watershed contains fluvial, lacustrine, and adfluvial populations of brook trout (Huckins et al. In Press). Because the lacustrine and adfluvial fish spend part of their lives in Lake Superior they are locally called “coasters” (Becker 1983). Coasters were historically found in many of Lake Superior’s north and south shore streams including tributary streams within what is now Michigan’s Pictured Rocks National Lakeshore (PRNL). Today, coaster populations are thought to be small with only the Salmon Trout River on the south shore, the waters around Isle Royale National Park, the Nipigon River system (Wiland 2006), and PRNL containing coasters (Stimmell 2006). Because coaster populations are likely small, it was not surprising that no recreationally caught coasters were reported in an extensive angling survey of Michigan’s

Lake Superior waters in the summer of 1998 (Lockwood et al. 2001). There are many hypotheses for the reduction in coaster numbers, but some combination of habitat degradation, introduction of non-native species, and overfishing may have played a role.

To understand why coasters have struggled in the Michigan waters of Lake Superior, it is helpful to consider the physical changes that have taken place in Lake Superior's watersheds since the arrival of Europeans. Michigan's Upper Peninsula was heavily logged in the past. Logging has been shown to simplify stream morphology (Ralph et al. 1994) and cause greater embeddedness (Eaglin and Hubert 1993). Bull trout (*Salvelinus confluentus*), a close relative of the brook trout, construct fewer redds in areas with more logging roads, which suggests a lasting effect on the species' population even after timber harvest has ceased (Baxter et al. 1999). Burns (1972) demonstrated decreases in dissolved oxygen and the number of salmonids and increased sedimentation as a result of logging and logging road construction. Habitat degradation in the form of sand deposition can also have a negative effect on brook trout (Alexander and Hansen 1983). Increased amounts of sand reduce the physical variability of a stream, decrease the survival of the young brook trout and ultimately lead to a decrease in the brook trout population (Alexander and Hansen 1986).

In addition to the physical environment, the fish community in the Lake Superior watershed has changed dramatically. Lake Superior's native salmonids are restricted to brook trout, lake trout (*Salvelinus namaycush*), and at least eight whitefish species (*Coregonus* spp.). Today these native species are depleted and coho (*Oncorhynchus kisutch*), chinook (*O. tshawytscha*), and pink salmon (*O. gorbuscha*), as well as brown trout (*Salmo trutta*), steelhead (*O. mykiss*), and splake (*Salvelinus fontinalis* x *namaycush*) are among the salmonids inhabiting the lake. Most of these fish were introduced to Lake Superior to augment the sport fishery. Problems associated with the introductions of these species include overlap in redd choice by brook and brown trout (Witzel and MacCrimmon 1983) and competition for resources between juvenile brook trout and coho salmon (Fausch and White 1986). The historical balance in Lake Superior has been tipped such that today a larger number of species are competing for limited resources.

Coaster brook trout are subject to the recreational fisheries in Lake Superior because of their common use of near shore, shallow habitat (Newman et al. 1999). This use of habitat easily accessible to humans once supported a fishery used by many (Roosevelt 1865; MacCrimmon and Gots 1980) where large quantities of fish were harvested (Shiras 1921). Today there is virtually no fishery for coasters on the south shore of Lake Superior. Over time, fishing regulations have become increasingly more restrictive for brook trout in Michigan as an increase in minimum size may result in larger fish (Clark et al. 1981). Recently, new length and bag limit restrictions have been set in Lake Superior and some of its tributaries to specifically protect coaster brook trout (Lockwood et al. 2001; Huckins et al. In Press).

Today, states, Canadian provinces, tribes, universities, government agencies, and nonprofit groups are working together to study the status of coaster brook trout, and options for coaster brook trout restoration in Lake Superior (Wiland 2006). One project pertaining to coaster restoration is currently under way in PRNL. The three streams involved in this project are Seven Mile Creek, and the Mosquito and Hurricane Rivers. From 2000 to 2005, more than 211,000 Tobin Harbor strain brook trout were stocked in the three streams. Each fish was given a distinct fin clip for the year and stocking stream. In addition, from April 2003 to the present, both hatchery and wild brook trout in the three streams have been PIT tagged and monitored with stationary PIT antennas for movement. A short term means of evaluating the reintroduction is to identify hatchery clipped fish in the stream, especially during the fall when spawning takes place and to track the movements of tagged fish. The hope of this reintroduction was to establish two distinct brook trout life histories. The first consists of the non-migratory, resident fish, which should exhibit movement that is limited to the area between the stream mouth and headwaters or first upstream barrier. The second consists of coasters that exhibit high movement rates into and out of the lake, especially in the spring and fall when migratory brook trout move the most.

Stimmell (2006) monitored hatchery and wild brook trout movement in the three Pictured Rocks streams from May 2003 to November 2004. During that time, most brook trout movement, both by stocked and wild fish, took place in the spring and the fall. In addition, the study revealed that photoperiod was correlated with movement to Lake Superior and that condition of wild PRNL brook trout was significantly greater than the stocked Tobin Harbor strain. Studies by additional graduate students took place in PRNL during 2005 and 2006. The goal of these studies was to determine the effects of invasive coho salmon and steelhead in relation to habitat availability for brook trout in Sevenmile Creek and the Mosquito River. The data collected indicate a positive relationship between the presence of brook trout and juvenile steelhead in Sevenmile

Creek whereas this relationship is negative in the Mosquito River (T. Anderson, G. Cain, J. Leonard, Northern Michigan University, personal communication).

Although these studies have revealed much insight into some of the physical attributes, movement patterns, and habitat use of brook trout in the three restoration streams, no work has been done with regards to the age and growth of these fish. It is not known whether wild brook trout in one of the streams grow faster than those in the others, at what ages brook trout are being captured and tagged, or how old these fish are when mature. My work in PRNL was aimed at answering such questions.

The goals of my project were to 1) describe the age structure of coaster and stream resident brook trout in the three Pictured Rocks Streams and 2) summarize the movement of coaster brook trout in the Hurricane River from 2003 to 2007 using data collected by Stimmell (2006) and other graduate students, including me. To do this I examined the scale age, length, weight, and condition factor of brook trout captured in the three Pictured Rocks streams. Fish from the Hurricane River were examined for a difference in these variables between known coasters and presumed resident brook trout. I also examined the movement patterns of PIT tagged fish based on the stationary antenna systems currently in place on the three PRNL streams. Using this information, I was able to determine whether a brook trout was a resident or a coaster and at what age these brook trout exhibited the most movement. Although this type of analysis has been performed by a previous graduate student (Stimmell 2006), the age of the fish being tagged was not examined. Using the age data allowed me to characterize the age classes present in the Hurricane River and to look for differences in length and condition factor at a given age for resident versus coaster brook trout. This second aspect of the age analysis is especially important because although coasters are generally thought to grow larger than stream resident fish, little evidence has been collected to support this hypothesis (J. Leonard, Northern Michigan University, unpublished data) in the PRNL streams. Hurricane River was chosen for this project because it has the largest proportion of brook trout that coast of the three PRNL study streams (J. Leonard, Northern Michigan University, unpublished data).

CHAPTER 2: THE AGE STRUCTURE OF BROOK TROUT (*SALVELINUS* FONTINALIS) FROM THREE LAKE SUPERIOR TRIBUTARIES IN PICTURED ROCKS NATIONAL LAKESHORE, MICHIGAN

CHAPTER SUMMARY

Brook trout (*Salvelinus fontinalis*) from Lake Superior and its tributaries exhibit a variety of life histories and presumably different growth characteristics. The goal of this study was to compare the length, condition factor (K), and relative growth of brook trout at a given age from three Lake Superior tributaries found in Pictured Rocks National Lakeshore, Michigan. Brook trout were aged using scales. Aging was validated using two readers and scales of known age. Scales from 523 brook trout were aged and placed into six groups based on stream, capture location in relation to a barrier, and hatchery strain. Final reader agreement was 92 %. Up to four age classes (ages 0 - 3) were sampled from the streams with age 1 being the most common (n = 322). Mean length was greatest at age 0 ($\chi^2 = 23.698$; df = 4; $p < 0.001$) and age 1 ($\chi^2 = 64.736$; df = 5; $p < 0.001$) for the Mosquito River above Mosquito Falls. K was greatest for the Hurricane River above Hurricane Falls at age 1 ($\chi^2 = 28.929$; df = 5; $p < 0.001$). Mean length and K were not significantly different at any other ages. Relative growth generally decreased with age. The data suggest that wild trout in the three streams have the potential to grow as large as Tobin Harbor strain brook trout. Two hypotheses for the similarity in length and K between the three streams are 1) overall similar growth conditions and 2) mixing of fish between streams and stream reaches.

INTRODUCTION

Lake Superior and its associated tributaries contain populations of brook trout (*Salvelinus fontinalis*) that exhibit a variety of life history characteristics (Huckins et al. In Press). While some of these fish are fluvial (stream resident), adfluvial (stream-lake migratory), and lacustrine (lake resident) fish also exist. Although adfluvial brook trout in the Lake Superior watershed never enter the ocean and are thus not anadromous, the life cycle of these fish is similar. The adfluvial and lacustrine brook trout present in the Lake Superior watershed (including Lake Nipigon) are locally called "coasters" because they spend at least a part of their life in one of the two large lakes and historically were caught near the coastline.

Within a single stream, adfluvial and fluvial brook trout may be sympatric. This situation is called partial migration and is common in brook trout populations where anadromy takes place (Doucette et al. 1999; Genevieve and Rasmussen 2003; Smith and Saunders 1958) and occurs in other salmonine species including Arctic charr (*Salvelinus alpinus*), (Naslund et al. 1993) and brown trout (*Salmo trutta*) (Forseth et al. 1999). Where partial migration exists, it is not well understood why one fish may remain in a stream its entire life while another, perhaps even a sibling, may instead adopt a migratory life history. Although size (Theriault and Dodson 2003) and energetic (Morinville and Rasmussen 2003) differences between stream resident and anadromous brook trout have been documented in some populations, Kaitala et al. (1993) make a case for density dependent overwinter survival being the most important cause of partial migration for a population.

If one life history (i.e., migratory versus non-migratory) has a growth benefit over the other, a difference in the size of a fish at a given age should be measureable. To make this type of comparison, some method of aging must be employed. Brook trout can be aged by examining their scales or otoliths (Cooper 1951; Alvord 1954; Bishop 1955; Allen 1956; Hall 1991; Pfeifer 2005; Meyer et al. 2006; Thériault and Dodson 2003; Wilson et al. 2003). In cases where trout cannot be sacrificed, using scales is the only aging option. Power (1980) questioned the validity of using scales to age brook trout, but Cooper (1951) found 100% accuracy for scales of brook trout with a known age and Quinn et al. (1994) verified the accuracy of brook trout scales using otolith derived aging.

The presence of two distinct behaviors for a single species within a stream can create problems for those attempting to conserve or manage one of the specific groups, especially if there is no apparent size or coloration difference that can easily distinguish the groups. As part of a coaster brook trout restoration, Tobin Harbor strain (a coaster-origin strain) brook trout were stocked in three Pictured Rocks National Lakeshore (PRNL) streams from 1996 to 2005. Prior to stocking, wild brook trout were present in the streams and were presumed to be stream residents. Stimmell (2006) found that some of the wild brook trout exhibited coasting behavior. As a result of the stocking efforts there is now the potential that at least three genetic groups of brook trout are present in the three streams (wild, Tobin Harbor, and mixed offspring) that exhibit fluvial and adfluvial behavior.

There were three goals for this study. The first was to describe the age structure of wild brook trout in the three PRNL restoration streams. The second goal was to compare length and condition factor (K) at different ages to determine if either varies among streams or between areas of streams where fish have access to Lake Superior (potential for coasters) and areas where natural barriers prevent access (obligate stream residents). The final goal of this study was to compare the length and K of Tobin Harbor strain brook trout stocked into one of the streams to the wild fish present in the streams to determine if this strain of fish exhibited greater growth and condition than the wild PRNL fish.

MATERIALS AND METHODS

Study Sites

PRNL is located in the eastern half of the Upper Peninsula of Michigan. The three streams from which brook trout were sampled were (from west to east), the Mosquito River (46° 31’ 33.86” N, 86° 29’ 37.2”W), Sevenmile Creek (46° 37’ 16.28” N, 86° 15’ 25.75”W), and the Hurricane River (46° 39’ 57.66” N, 86° 10’ 3.76”W) (Figure 2.1). The Hurricane River and Sevenmile Creek are second order streams and the Mosquito River is third order. All of the streams pass through mixed forests consisting of deciduous and coniferous flora. Although now protected within the National Lakeshore, the three streams are very different from their pre-European settlement condition as a result of logging and the introduction of exotic species. In addition to native brook trout, all of the study streams contain naturally reproducing populations of the exotic salmonids pink salmon (*Oncorhynchus gorbuscha*), coho salmon (*O. kisutch*), and steelhead trout (*O. mykiss*). Non-salmonids present in the streams include sculpin (*Cottus* spp.), central mudminnow (*Umbra limi*), dace (*Rhinichthys* spp.), suckers (*Catostomus* spp.), burbot

(*Lota lota*) and lamprey (*Ichthyomyzon*, *Lampetra*, and *Petromyzon* spp.). There are bedrock falls on the Hurricane and Mosquito rivers. On the Mosquito River, the falls create a barrier to upstream movement. The falls on the Hurricane River are about 2 m tall and may only be a barrier to movement during low flows. The presence of the falls in the two streams creates two distinct areas: above the falls where all fish are presumably stream resident and below where the potential for adfluvial coasters exists. Sevenmile Creek does not have any falls that could act as a barrier to fish movement and therefore could contain adfluvial coasters at any location.

Sampling

Brook trout were sampled from the Mosquito River above Mosquito Falls during 2003 and 2004, the Hurricane River during November and December 2006, and all three streams during May to November 2007 via electroshocking (Table 2.1). Of the groups, fish captured above falls were considered to be stream residents while those captured below falls were presumed to be partially migrant. After capture, the fish were weighed (g) and measured for total length (mm). Condition factor (K) was calculated for all scale sampled fish that were weighed and measured as $K=W/(L^3) \times 100$ (Nielsen and Johnson 1983) where W is the weight (g) and L is the total length (cm). With the exception of the 2003 and 2004 fish that were sampled for a different study (Sreenivasan 2006), all fish were released after capture.

Prior to July 31, 2007 of the 2007 sampling, only brook trout ≥100 mm were scale sampled. After that date all fish were sampled for scales because most young-of-the-year brook trout should have developed scales by that time (Cooper 1951). Scales were sampled from the left side between the dorsal fin and lateral line (Bishop 1955; Alvord 1956; Pfeifer 2005) using a scalpel blade to scrape from the posterior to the anterior. The scales were later wet mounted between two microscope slides (Allen 1956; Hatch 1961; Wilson et al. 2003). To prevent resampling of released fish, brook trout ≥100 mm were marked with a small upper caudal clip and fish <100 mm marked with a lower caudal clip. This mark was chosen because the fin is capable of regenerating and resulted in the lowest proportion of fin being removed. This mark also did not interfere with any other fin clips used in the region.

Age Determination

A microfiche reader and compound light microscope were used to examine mounted scales. A sudden change in growth (e.g. circuli spacing decreasing, circuli converging) was used to identify annuli (i.e. a winter period). The number of annuli on up to 10 scales (depending on the number available) was read from each sample. The age assigned to the fish was based on the number of annuli most commonly counted on the sample of scales. Brook trout that had no annuli present were described as age-0. Size was not used to aid in aging. Season of capture data were available to the scale readers. A second trained reader performed the same analysis on a subsample of all individual scale samples aged by reader 1 to give an indication of aging accuracy. Scale assignments that did not agree between the two readers were then aged a second time by both readers independent of initial age assessment. Reader agreement was calculated based on all of the scale ages after the second aging attempt. The ages assigned by reader 1 were used in analysis. Because fish could not be sacrificed, otoliths were not used for age validation of wild fish. The stocked fish samples from 2003 and 2004 were of known age and provided a means of age validation.

Data Analysis

Brook trout were assigned to one of six groups: Hur, UHur, Mos, UMos, Svn, and Stock, based on location of capture in the stream and whether they were wild or hatchery strain (Table 2.1). Scale age was used in analysis for all groups except the stocked group for which the known age was used. Kruskal-Wallace tests were used to determine significance between mean lengths and mean K for a given age. Tukey's q method was used as a post-hoc test for significant Kruskal-Wallace results. The analysis was also run using only fish captured in 2007 (with the exception of the Stock group) to account for potential annual growth differences. To look for differences in growth from one age to the next, mean relative growth (mean $\Delta L_{relative}$) was calculated for available age transitions as: $(\Delta L_{relative}) = ((\text{mean } L_2 - \text{mean } L_1)/ \text{ mean } L_1) \times 100$. When calculating mean relative growth from age 0 to age 1 for the Stock fish, mean length at time of stocking as reported by Michigan DNR (2005) was used.

RESULTS

Scale Aging

A total of 523 fish were aged for this project with each group having at least 46 fish samples aged (Table 2.2). A random subsample (20%) of the scales aged by reader 1 were also aged by reader 2. After the first scale aging attempt, overall agreement was 59% with 96% of the disagreement being within one age class. Overall agreement between readers after re-aging all scales with disagreement was 92% and ranged from 69 – 100% for the six groups. In addition, all disagreement after the second reading was within one age class. Age validation using the known age, Stock group yielded an accuracy of 83% for reader 1 and 56% for reader 2 after the second reading attempt. In all cases, the reader assigned one age class higher or lower than was true. Of the scales that reader 1 was incorrect in aging (n = 8), 75% were underaged. Reader 2 underaged 100% of the assignments that were incorrect (n = 7).

Fish were assigned to four age classes (age 0 – age 3) based on counting the number of annuli (Figures 2.2 – 2.5). Most fish were classified as age 0 (n = 119) or age 1 (n = 322) (Table 2.3). Age 2 fish were found in all streams, but only one representative of this age was captured from Sevenmile Creek. Few age 3 fish were captured (n = 4) with representatives from this age class coming from Hur, UHur, and Mos. Due to the low numbers for Svn age 2, all groups for age three and no representatives for age 0 Stock fish, the age classes for these groups are only presented as descriptive statistics.

Length and Condition Factor Analysis

Stock fish were released into the Mosquito River at age 0 with a mean length of 76.2 mm (Michigan DNR 2005). The one age 2 individual captured from Sevenmile Creek was 170 mm long with a K of 0.765. One age 3 individual was captured from HUR and had a length of 254 mm and K of 1.211. Two age 3 brook trout were captured from UHUR that had a mean length of 216 ± 17.5 mm and mean K of 1.162 ± 0.071. A single age 3 fish from MOS had a length of 208 mm and K of 0.900.

Mean length differed among groups at age 0 ($\chi^2 = 23.698$; df = 4; $p < 0.001$; Table 2.4) and age 1 ($\chi^2 = 64.736$; df = 5; $p < 0.001$; Table 2.4). Greatest mean length for brook trout at age 0 (90.7 ± 2.31 mm) and age 1 (150.7 ± 2.87 mm) was found in UMos (Figures 2.6 and 2.7). The smallest mean length at age 0 was found in Hur (75.5 ± 1.97 mm). UHur had the smallest mean length for both ages 1 (123.1 ± 1.99 mm) and 2 (185.2 ± 8.54). Mean length did not differ between any of the groups at age 2 ($\chi^2 = 5.787$; df = 4; $p = 0.253$) (Figure 2.8).

Mean K did not differ among groups at age 0 ($\chi^2 = 1.477$; df = 4; $p = 0.831$) (Figure 2.9). At age 1, K values were different among groups ($\chi^2 = 28.929$; df = 5; $p < 0.001$) with UHur having the greatest mean K value (1.01 ± 0.956) and Hur having the smallest (0.87 ± 0.011) (Figure 2.10). Post hoc analysis demonstrated that for age 1, UHur > Hur (Q = -6.100; k = 6; $p < 0.001$) and UHur > Mos (Q = 4.588; k = 6; $p < 0.001$). At age 2, mean K values did not differ significantly ($\chi^2 = 5.354$; df = 4; $p = 0.253$) (Figure 2.11).

Analysis of only the 2007 data (with the exception of the Stock group), yielded two different results when compared to all data combined, both regarding length. The first was for age 0 where UMos was not greater than Svn (Q = -2.543; k = 5; $p > 0.05$). The second was age 1 where UMos was not significantly greater than Mos (Q = -2.240; k = 6; $p > 0.20$).

Relative Growth

Because no Stock fish were recaptured at age 0, the mean length at stocking (Michigan DNR 2005) was used in calculating relative growth from age 0 to age 1 for this group. Relative growth generally decreased with age (Figure 2.12). The exception to this was UHur which had the lowest relative growth between ages 0 and 1 (47%), but displayed an increase between ages 1 and 2 (50%). The Stock group had the greatest relative growth between ages 0 and 1 (86%) and ages 1 and 2 (55%). UMos had relative growth of 29% from age 1 to 2, the lowest of the groups. Both Hur and Mos were intermediate to the highest and lowest relative growth values for the two age transitions.

DISCUSSION

The results of this study highlight the similarities between brook trout from the three PRNL streams. Despite being spatially divided, having different faunal compositions, and with regards to the Hurricane and Mosquito Rivers, having barriers, length and K values were generally similar between the groups.

Overall reader agreement of 92% in this study is reasonable for brook trout as it is greater than studies that looked at agreement for white crappie (*Pomoxis annularis*; Hammers and Miranda 1991) (79%), yellow perch (*Perca flavescens*; Niewinski and Ferreri 1999) (83%), bluefish (*Pomatomus saltatrix*; Sipe and Chittenden 2002) (62%), striped bass (*Morone* saxatili*s*; Welch et al. 1993) (48%), rainbow darter (*Etheostoma caeruleum*; Beckman 2002) (38%), Yellowstone cutthroat trout (*Onchorhynchus clarki bouvieri*; Hubert et al. 1987) (72%), and roach (*Rutilus rutilus*; Musk et al. 2006) (69%), although each of these studies only used a single aging by each reader. Most disagreements between the readers were within one age class and typically occurred when reader 2 assigned an age that was one year lower than reader 1. The results of reader 2 aging known age fish show a propensity for this individual to underage brook trout.

The agreement between scale age and actual age for the stock group was low when compared to that of Cooper (1951). Problems with aging these fish included samples consisting of primarily regenerated (Figure 2.13) and dirty (Figure 2.14) scales and in the case of under aged fish, the apparent lack of annuli (Figure 2.15). Although it can take weeks for brook trout to finish laying down an annulus (Cooper 1951; Brown and Holton 1953), this was taken into consideration when aging and thus closely grouped circuli present at the outer edge of a scale during the spring and early summer were counted as an annulus. Closely spaced circuli near the scale edge were rare after the end of June, but because the previous year's annulus should have finished forming by that time (Cooper 1951; Brown and Holton 1953), they were not counted as annuli. Although false annuli or "checks" are common on brook trout scales and may be the result of environmental factors such as temperature variation (Hatch 1961), only two of the 46 Stock fish aged by reader 1 were over aged. This represents a small likelihood (4%) that fish were over aged due to thermal conditions.

Upon discussing why the two readers disagreed on scale age, both came to the conclusion that the scales in question were ambiguous, as the area counted as an annulus by reader 1, was determined by reader 2 to have spacing similar enough to surrounding circuli to be called normal growth. The increase in agreement after reexamining initially disagreed upon scales, lends support to the comments of Musk et al. (2006) that scale reading is highly subjective. The evidence from the known aged fish and comparison of reader agreement implies that in cases where the reader 1 was wrong in estimating, the fish was likely under aged and there may be additional age classes represented in the data. Because size was not considered when aging and misclassification of age was usually under aging by one year, error in aging should be the same for all groups making the relative comparisons between groups valid.

Comparisons of length and K between the groups yielded few significant differences. Although UMos had a mean length greater than both Hur and Mos at ages 0 and 1, this difference was lost by age 2. When only 2007 samples were considered, UMos fish were only significantly larger than Mos fish at age 0. Coaster strain brook trout were stocked into the three Lake Superior tributaries because it was presumed that these fish would grow faster and to larger size than the native stream residents. The accidental stocking of some of the Tobin Harbor fish above Mosquito Falls allowed us to look for differences between these fish and the native stock under common conditions. These fish were stocked in September 2002 at age 0. With a mean length of 76.2 mm (Michigan DNR 2005), these fish were smaller than all groups except Hur at age 0. Although the Tobin Harbor fish did have the greatest mean length at age 2 and greatest relative growth from age 0 to 1 and 1 to 2, they were not significantly larger than the native stream residents. At age 1 the Tobin Harbor fish actually had a smaller mean length than the native fish, though again the relationship was not significant. Perhaps more age classes would need to be compared for the expected differences in length between wild and stocked Tobin Harbor strain to become significant.

The lack of consistant differences for length and K data at all ages and presence of few links between these data to relative growth suggest that growth rates in the three streams are similar. This is despite geographical separation (the Hurricane River is at least 9 km from Sevenmile Creek and 30 km from the Mosquito River and the Mosquito River is at least 24 km from Sevenmile Creek), and the presence of natural barriers on the Hurricane and Mosquito Rivers. UMos fish were significantly larger than their Mos counterparts at both ages 0 and 1. Although UMos had the greater mean length at age 2, this difference was no longer significant. UMos fish were also significantly larger than Hur fish at ages 0 and 1, but again by age 2 there was no significant difference between the two. Both Mos and Hur fish live in similar habitats in that the stream mouths both enter Lake Superior over bedrock that provides little or no cover and both contain the same suite of native and exotic species. Competition between brook trout and the exotic coho salmon (Fausch and White 1986) and steelhead (Rose 1986) below barriers may be an explanation for the smaller size at the youngest ages. Emigration of the fastest growing juveniles at a given age has been documented in Atlantic salmon (*Salmo salar*) and brown trout in Norway (Økland et al. 1993), and Atlantic salmon in Canada (Strothotte et al. 2005) and Spain (Utrilla and Lobón-Cerviá 1999). This leads to an alternative explanation that the largest age 0 and 1 trout below Mosquito Falls are emigrating (leaving for Lake Superior) and that those that remain in the lower Mosquito River grow at rates that allow them to achieve lengths similar to their upstream counterparts by age 2.

The strain used in the reintroduction effort did not grow to significantly greater length or have higher K at either age 1 or 2 when compared to any of the wild groups, including the UMos group living under the same conditions. This suggests that despite historical fishing regulations that selected against large fish in the three streams, brook trout from any of the three may have the potential to grow to the large sizes typically associated with coasters. The lack of older age classes (> age 2) for the Stock as well as the other groups prevents this hypothesis that all of the fish studied have the potential to reach the same size from being further tested.

The potential for annual variation in both length and condition for the groups collected exists, but was not fully captured by this study. Most of the scale samples for the study were taken in 2007. Exceptions to this were the Stock group which was collected in 2003 and 2004, the UMos group collected in 2003, 2004, and 2007, and the Hur group which had 7% of samples collected in 2006. Because comparisons were made between fish of the same age that grew during different years, and possibly different conditions, the results may not be as strong as would be the case if all fish were collected over multiple years and comparisons were made between fish of the same age that lived during the same time periods. Analysis of only 2007 data did account for variability during that year and resulted in fewer significant differences between groups than when all data for each group was compared. This analysis of the 2007 data with annual variation accounted for strengthens the argument that there are few differences in length and K among the groups.

Overall, open access to Lake Superior and the possibility of a mixed population containing both coasters and residents below a barrier does not seem to result in fish of greater length or K. In addition, the presence of invasive species within the lower river reaches may not have an effect on the length or K of brook trout as compared to those above barriers. Two hypotheses for the similarities in length and K are that 1) growth conditions are similar enough that all groups of fish grow at about the same rate and reach the same size and 2) enough mixing of fish occurs that essentially one population was sampled. The second hypothesis is not likely correct for this study. Brook trout genetics work by D'Amelio (2002) indicated that there are detectable differences among tributary streams in Nipigon Bay and that even when brook trout move down over a barrier and successfully reproduce, two genetically distinct populations exist; one above the barrier and one below. Genetic analysis of samples collected from the three PRNL streams indicates that samples from each stream tend to group together (J. Leonard, Northern Michigan University, unpublished data). It seems that in-stream conditions rather than mixing between the groups is the stronger explanation for the similarities uncovered by this project.

The composition of wild brook trout populations in the three PRNL streams is similar in a variety of ways. All three streams had at least three age classes (age 0 – 2) and in two of the streams age 3 fish were also captured. Age 0 and age 1 fish were captured in the largest numbers from all wild stream groups. Generally there were few significant differences for length and K among the groups. When compared to a stocked coaster strain at ages 1 and 2 there was never a significant difference in either length or K. My results demonstrate that despite geographical separation, differences in species composition and access to lake resources, different populations of brook trout may exhibit characteristics of a single population.

Table 2.1: Grouping, descriptions, and time periods of sampling for brook trout from three Lake Superior tributaries.

Group	Description	Sampling Time Period
Hur	Hurricane River below Hurricane Falls: partially migratory population	November – December 2006 and May – November 2007
UHur	Hurricane River above Hurricane Falls: Presumed stream resident population	June – October 2007
Mos	Mosquito River below Mosquito Falls: partially migratory population	June – November 2007
UMos	Mosquito River above Mosquito Falls: Presumed stream resident population	May – November 2003, May –December 2004, and November 2007
Svn	Sevenmile Creek: partially migratory population	June – November 2007
Stock	Stocked Tobin Harbor strain above Mosquito Falls	July – November 2003 and May – December 2004

Table 2.2: Number of scales read by reader 1 and reader 2, percentage of age assignments within one age class after the first aging, and percent agreement between the two readers for the six stream groups.

Group	N		Percent Agreement After First Aging	Percent of Disagreement Within One Age Class After First Aging	Final Percent Agreement
	Reader 1	Reader 2			
Hur	107	19	63	100	100
UHur	89	20	35	100	85
Mos	124	17	76	94	100
UMos	105	19	42	91	95
Svn	52	15	93	100	100
Stock	46	16	56	71	69
Total	523	106	59	96	92

Table 2.3: Number of fish sampled of each age group (as determined by scales with the exception of the known age, Stock group) from three Lake Superior tributaries. When two numbers are present, the first is the total number of fish aged and the number used in length analysis and the second is the number used in condition factor analysis.

Group	**N**				
	Age 0	**Age 1**	**Age 2**	**Age 3**	**Total**
Hur	31/30	67	8	1	107/106
UHur	14	59	14	2	89
Mos	34	79	10	1	124
UMos	19	77	9	0	105
Svn	28/22	23/18	1	0	52/41
Stock	0	17	29/28	0	46/45
Total	126/119	322/317	71/70	4	523/510

Table 2.4: Comparisons with significant differences after Kruskal-Wallace testing and Tukey's q post hoc analysis between stream reaches for mean length at ages 0 and 1.

	Comparison Result	**Statistic**	**k**	**P-value**
Age 0	UMos > Hur	Q = -4.167	5	p < 0.001
	UMos > Mos	Q = -4.191	5	p < 0.001
	UMos > Svn	Q = -3.203	5	p < 0.02
Age1	UMos > Hur	Q = -5.820	6	p < 0.001
	Svn > Hur	Q = -4.232	6	p < 0.001
	Mos > UHur	Q = -3.182	6	p < 0.05
	UMos > UHur	Q = -6.376	6	p < 0.001
	Svn > UHur	Q = -4.932	6	p < 0.001
	UMos > Mos	Q = -4.155	6	p < 0.001
	Svn > Mos	Q = -2.977	6	p < 0.05

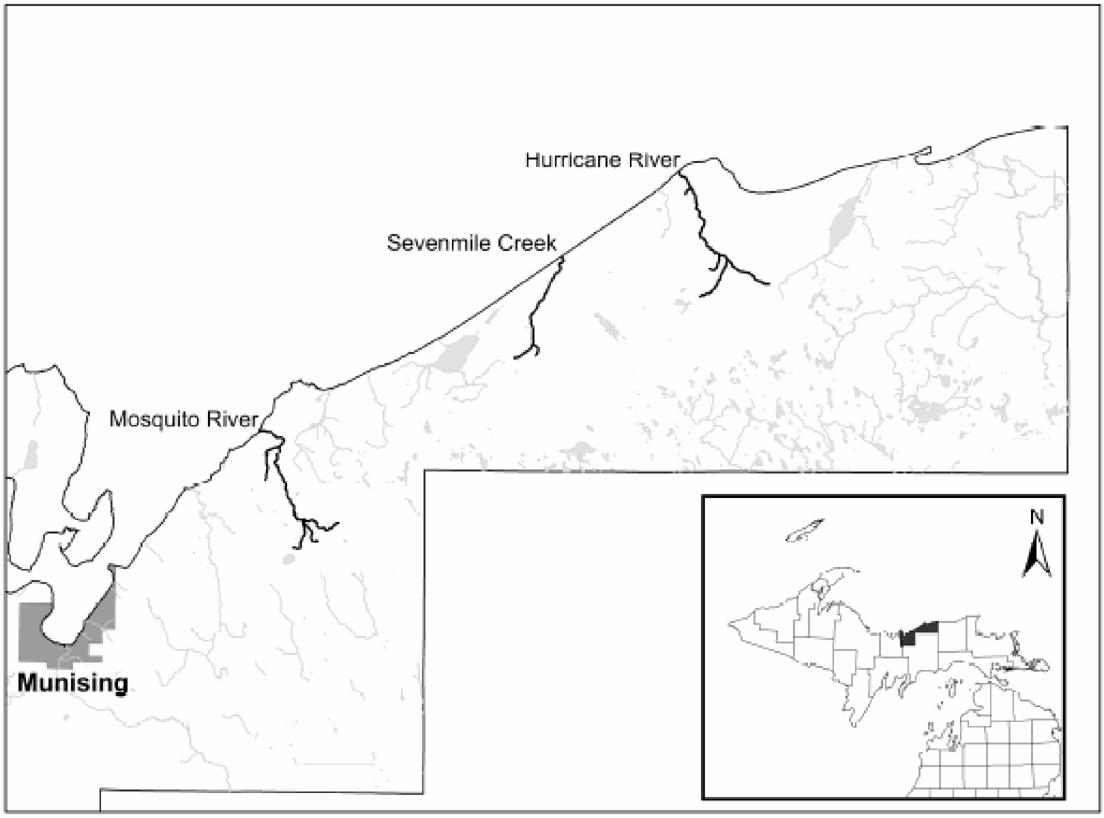

Figure 2.1: Location of the three coaster restoration streams in Pictured Rocks National Lakeshore, Alger County, Michigan. The inset shows the location of Alger County in the Upper Peninsula of Michigan.

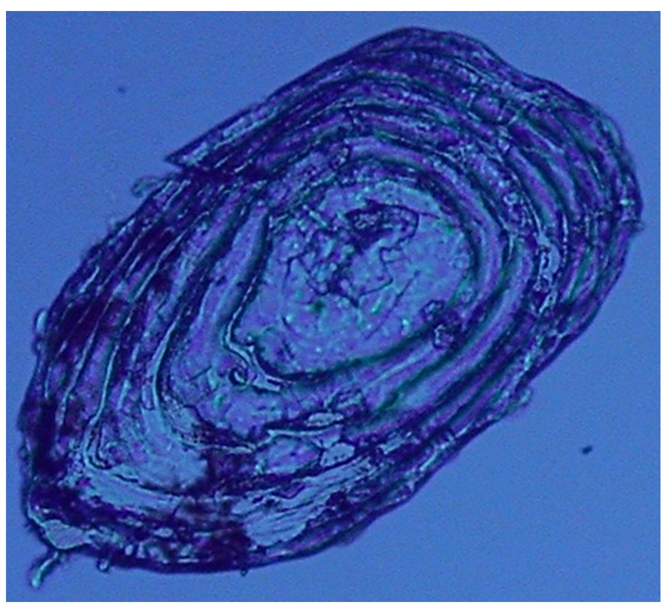

Figure 2.2: Age 0 brook trout scale from Mos. There is even circuli spacing and no annuli present.

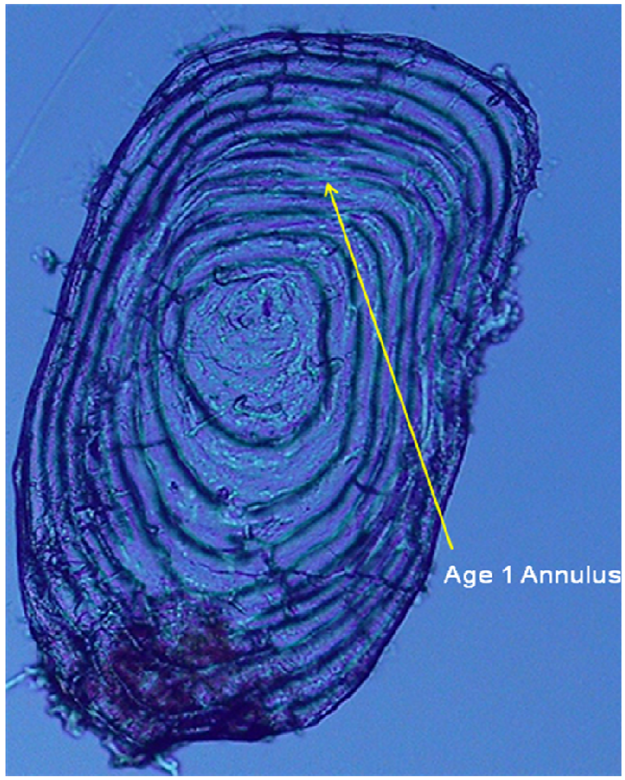

Figure 2.3: Age 1 brook trout scale from Hur.

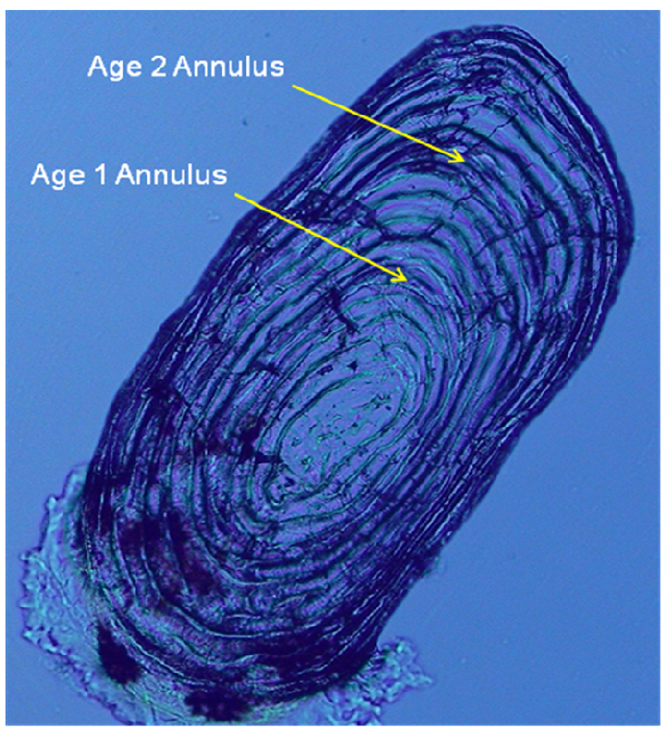

Figure 2.4: Age 2 brook trout scale from Hur.

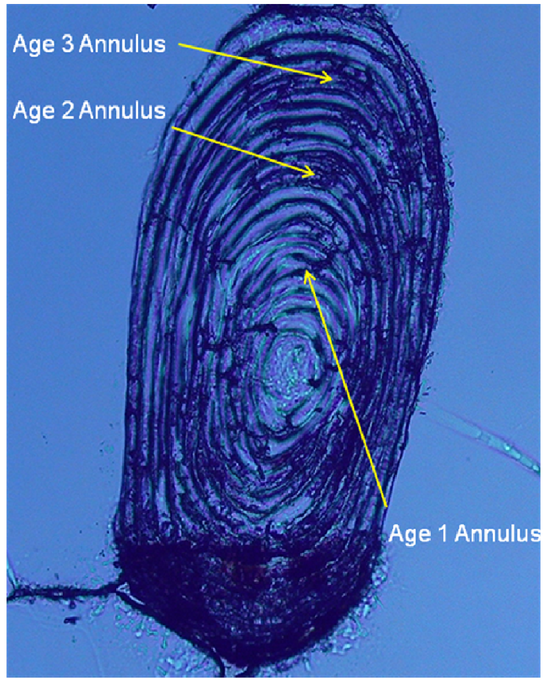

Figure 2.5: Age 3 brook trout scale from UHur.

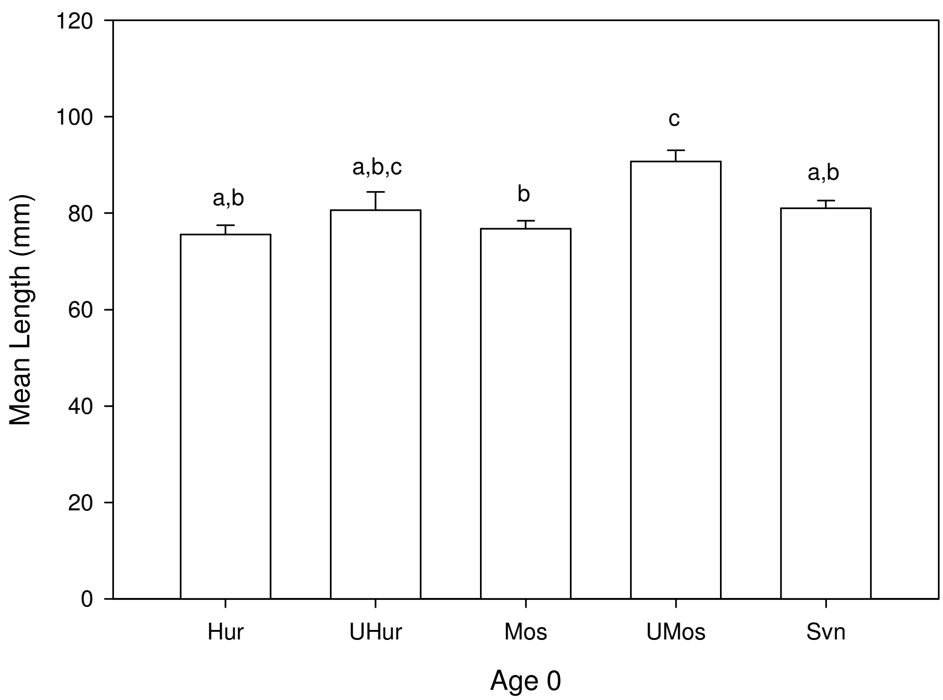

Figure 2.6: Mean length of brook trout at age 0 from three Lake Superior tributaries. Error bars represent standard error. Shared letters denote no significant difference (α = 0.05) after Tukey's q post hoc test.

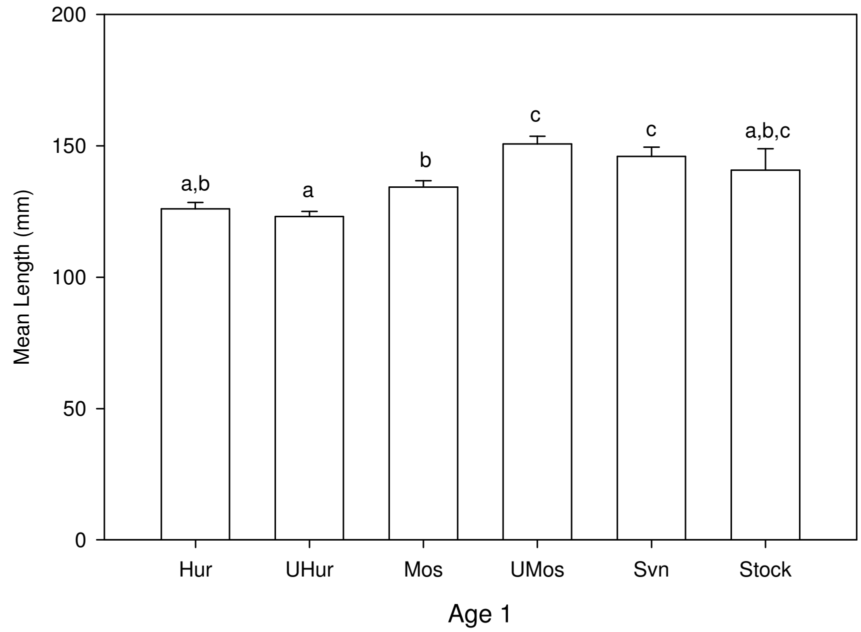

Figure 2.7: Mean length of brook trout at age 1 from three Lake Superior tributaries. Error bars represent standard error. Shared letters denote no significant difference (α = 0.05) after Tukey's q post hoc test.

Figure 2.8: Mean length of brook trout at age 2 from two Lake Superior tributaries. Error bars represent standard error. Shared letters denote no significant difference (α = 0.05) for the Kruskal-Wallace test.

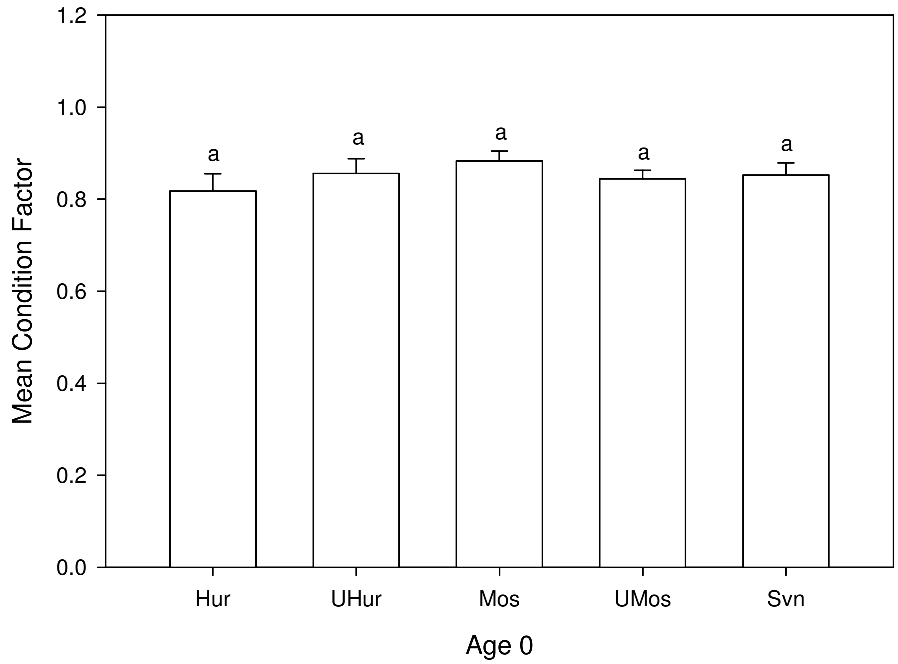

Figure 2.9: Mean condition factor of brook trout at age 0 from three Lake Superior tributaries. Error bars represent standard error. Shared letters denote no significant difference (α = 0.05) for the Kruskal-Wallace test.

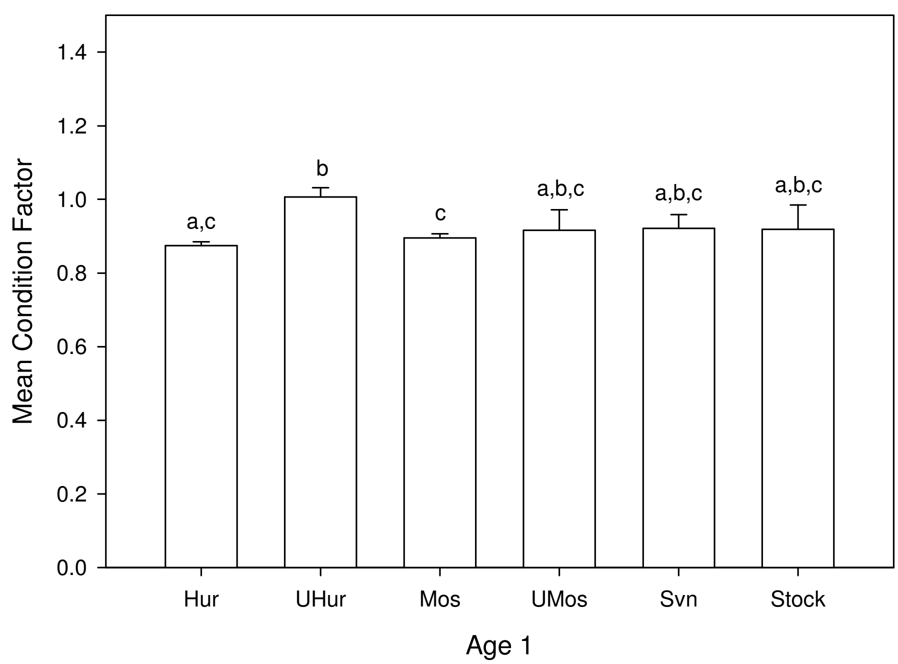

Figure 2.10: Mean condition factor of brook trout at age 1 from three Lake Superior tributaries. Error bars represent standard error. Shared letters denote no significant difference (α = 0.05) after Tukey's q post hoc test.

Figure 2.11: Mean condition factor of brook trout at age 2 from two Lake Superior tributaries. Error bars represent standard error. Shared letters denote no significant difference (α = 0.05) for the Kruskal-Wallace test.

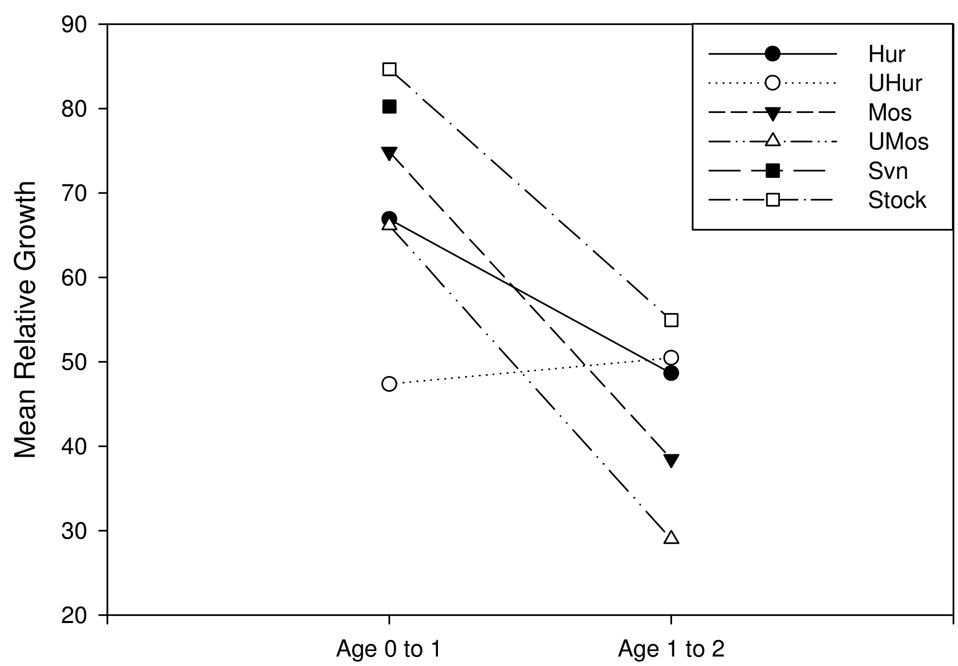

Figure 2.12: Mean relative growth of brook trout from three Lake Superior tributaries.

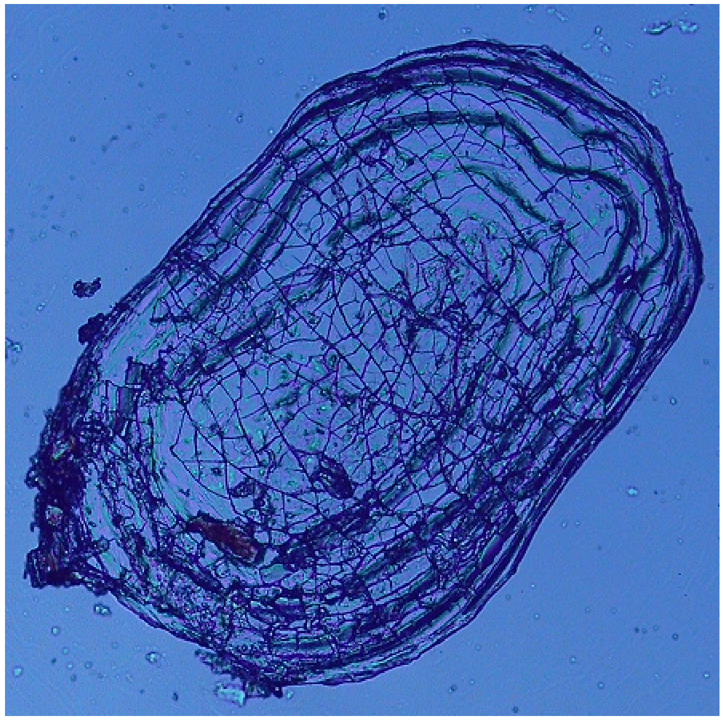

Figure 2.13: Regenerated brook trout scale. The scale focus is large relative to the size of the scale and few, uneven circuli are present.

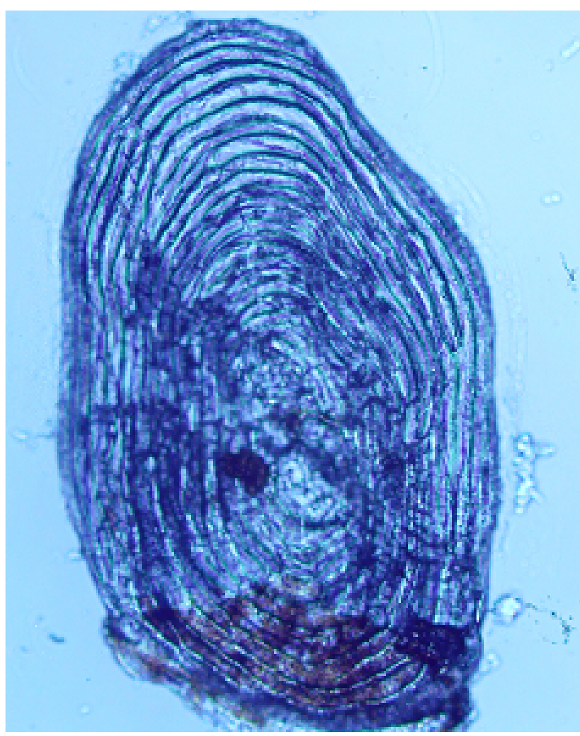

Figure 2.14: Dirty brook trout scale. This scale is smudged (likely by mucus) making it difficult to age.

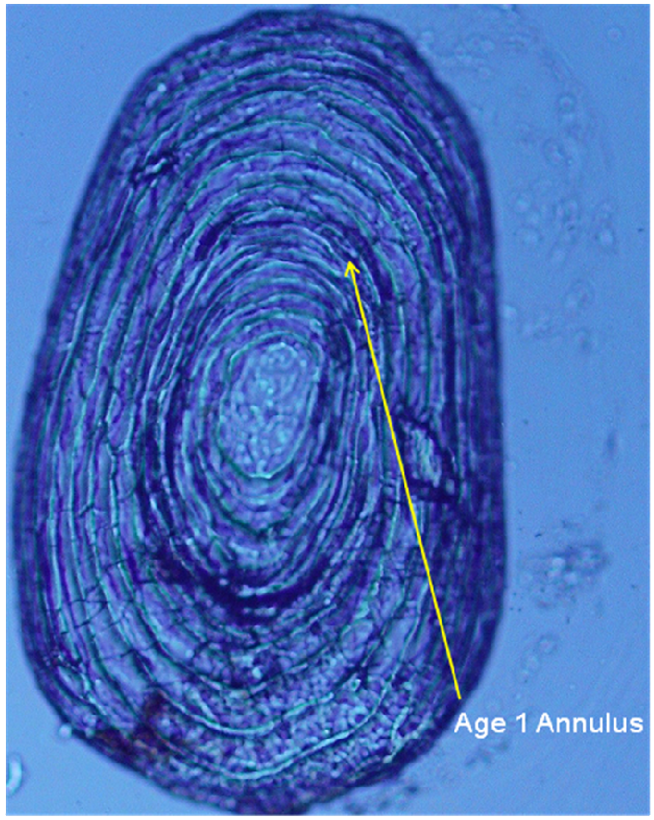

Figure 2.15: Age 2 stocked brook trout lacking a definitive annulus for age 2.

CHAPTER 3: THE MOVEMENT, LENGTH, AND CONDITION OF BROOK TROUT (*SALVELINUS FONTINALIS*) IN THE HURRICANE RIVER, PICTURED ROCKS NATIONAL LAKESHORE, MICHIGAN

CHAPTER SUMMARY

Coaster brook trout (*Salvelinus fontinalis*) were once found throughout Lake Superior, Lake Nipigon, and their tributaries. These fish were popular with sport fishermen and were known to grow larger and mature later than their stream resident counterparts. The impetus for this study was to compare the movement patterns, age, length, and condition of wild coaster and resident brook trout from the Hurricane River, Pictured Rocks National Lakeshore, Michigan. Wild brook trout ≥ 100 mm from the Hurricane River below Hurricane Falls were tagged with passive integrated transponder (PIT) tags and monitored for coasting behavior from May 2003 to November 2007. In 2007, additional trout were tagged above Hurricane Falls to determine if fish were entering the sampling area from above the falls. Fish that were not detected leaving the Hurricane River were deemed residents. During 2006 and 2007, brook trout were scale sampled to construct a regression line that was used to calculate the age of all brook trout tagged from 2003 to 2007 that were not also scale sampled. Mean length was not significantly different between coasters and residents, but K was for all tagged fish at ages 1 and 3 as well as for all ages grouped. Most brook trout movement took place in the fall with October being the peak month of coasting behavior. Discriminant analysis correctly predicted the grouping of 65-66% fish based on the variable of tagging location.

This study demonstrates peak movement by coaster brook trout in the Hurricane River during the fall which is similar to both anadromous and land-locked populations of brook trout elsewhere. The data collected suggest that all brook trout in the Hurricane River may potentially be coasters and that coasters in this stream are smaller and mature younger than fish from other coaster populations.

INTRODUCTION

Lake Superior once contained a popular recreational fishery for brook trout, *Salvelinus fontinalis*. These fish, called “coasters”, spent part of their lives in the lake and were known for reaching a large size. Coasters in Lake Superior may be adfluvial or lacustrine (Huckins et al. In Press). Lake Superior tributaries contain fluvial (stream resident) brook trout that may live side by side with adfluvial coasters. Today, coaster populations are thought to be small with only the Salmon Trout River on the south shore of Lake Superior, the waters around Isle Royale National Park, the Nipigon River system (Wiland 2006), and Pictured Rocks National Lakeshore (PRNL) naturally containing coasters (Stimmell 2006). There is functionally no fishery for these fish in United States waters, but widespread interest in restoring it exists. A restoration project is taking place on the south shore of Lake Superior in Pictured Rocks National Lakeshore (PRNL), Alger County, Michigan.

Adfluvial coasters never migrate to salt water, but do exhibit timing of movements similar to anadromous brook trout (Stimmell 2006). Peak movement for both resident and anadromous brook trout occurs in the spring during run-off and in the fall in association with the spawning season (Gowan and Fausch 1996; Hilderbrand and

Kershner 2000; Smith and Saunders 1958; Josephson and Youngs 1996; Curry et al. 2002; Lenormand et al. 2004). The basis for brook trout migration in streams follows a regular pattern of movement from spawning habitat to feeding and survival habitat and finally back to spawning habitat (Northcote 1997). For adfluvial coasters, spawning habitat is in the tributaries while feeding and survival habitat is located within the lake. Thorpe (1994), Fleming (1996), and Dodson (1997) argue that migration can enhance the reproductive fitness of an individual. If coasting behavior created such an advantage and the movement into Lake Superior was toward better feeding grounds, as is often the case for salmonids (Gross 1987), adfluvial brook trout in Lake Superior would likely be larger at a given age than their fluvial counterparts. The movement of brook trout out of a stream and into Lake Superior could be for other reasons than to seek better feeding areas. Such reasons include seeking overwinter habitat and a presence of surplus fish given the limited resources available. In either of these cases, coasting may only serve as a means by which brook trout are able to survive and may provide no observable benefit to size or condition.

Despite the release of more than 68,000 Tobin Harbor (coaster) strain brook trout into the Hurricane River from 2000 to 2005, very few large brook trout (> 300 mm) have been captured by those monitoring the restoration. A two year PIT tagging study by Stimmell (2006) indicated that both wild and hatchery trout in the Hurricane River moved into Lake Superior with most movement occurring in the spring and fall. In addition there was no significant difference in condition (K) between coasting brook trout and stream residents. The objective of my study was to use all movement data for wild brook trout in the Hurricane River from 2003 to 2007 to compare the length and K of these fish (resident versus coaster) and look at seasonal movements throughout this time period. In addition, the collection of scale samples during late fall 2006 and 2007 allowed me to compare length and K at a given age for the two groups and determine the age at which fish are coasting. The final goal of this study was to use the data collected at the time of capture to determine if discriminant analysis could be used to predict whether a young brook trout would ultimately be a resident or coaster. If coasting is beneficial to brook trout growth and condition, I expected that coasters would have greater values for these metrics after returning from Lake Superior. If length and/or condition were found to be different between coasters and residents I expected discriminant analysis to be able to predict whether or not a fish will ultimately coast. The null hypothesis to these predictions is that there is no difference in length or condition between coasters and residents and that biological and physical variables associated with captured fish will not discriminate between coaster and resident fish.

MATERIALS AND METHODS

Study Site

The Hurricane River (46° 39’ 57.66” N, 86° 10’ 3.76”W) is a second order stream located in the eastern half of PRNL (Figure 2.1). Species native to the river include brook trout, sculpin (*Cottus* spp.), central mudminnow (*Umbra limi*), dace (*Rhinichthys* spp.), suckers (*Catostomus* spp.), burbot (*Lota lota*) and lamprey (*Ichthyomyzon* and *Lampetra* spp.). The fish assemblage now includes exotic sea lamprey (*Petromyzon marinus*), steelhead (*Oncorhychus mykiss*), and coho salmon (*O. kisutch*). Pink salmon (*O. gorbuscha*) have also been observed attempting to enter the river. All fish species in the river are naturally reproducing. Fishing regulations in effect for the Hurricane River during the study period were in place to protect large coasters and included a 45.7 mm, one fish daily limit for brook trout and a season that started on the last Saturday in April and ended July 31 (Michigan DNR 2006). The study reach for this project extended from the mouth of the river at Lake Superior upstream about 180 m to Hurricane Falls. In addition, the minimum legal size for brook trout in Lake Superior is 50.8 cm with a one fish daily limit and a year-round open season. A stationary PIT antenna system consisting of a series 2000 High Power Remote Antenna-reader Frequency Module (Texas Instruments Dallas, TX) and a series 2000 Control Module (Texas Instruments Dallas, TX) was located under a walking trail bridge about 77 m from the river mouth.

Sampling

Wild brook trout from the Hurricane River were electrofished from May 2003 to November 2007 with no fish being sampled during the months of January through March. The stream was divided into two sampling units. The lower unit extended from the river mouth to the stationary PIT system (~ 77 m) and consisted of bedrock and sand, which provided little brook trout habitat. The upper unit began on the upstream side of the bridge and ended at the base of Hurricane Falls (~ 110 m). This unit contained most of the potential spawning and holding habitat available to brook trout within the study site. Each section was shocked separately and the fish were released after processing back into the unit from which they were captured. After capture, brook trout were weighed (g) and measured (mm) for total length. Condition factor was calculated for all fish that were weighed and measured as: $K=W/(L^3) \times 100$ (Neilsen and Johnson 1983) where W is the weight (g) and L is the total length (cm). All brook trout ≥100 mm were scanned for a PIT tag and sexed if possible (i.e., presence of a kype, eggs, milt). If not already present, a uniquely coded 23 mm tag (model: RI-TRP-RRHP, Texas Instruments Dallas, TX) was surgically implanted into the body cavity through a scalpel incision on the left side of the fish just anterior to the pelvic fin. An additional third group of fish was tagged above Hurricane Falls from June to October 2007 to determine if wild brook trout captured below Hurricane Falls were originating from reaches above the waterfall.

From November 2006 to November 2007, brook trout scale samples were collected from captured fish. From November 2006 to July 31, 2007, only brook trout greater than 100 mm were scale sampled. After August 1, 2007, most young-of-the-year brook trout should have developed scales (Cooper 1951), and so were sampled. Scales were sampled from the left side of each fish between the dorsal fin and lateral line (Bishop 1955; Alvord 1956; Pfeifer 2005) using a scalpel blade to scrape from posterior to anterior. The scales were later wet mounted between two microscope slides in the lab (Allen 1956; Hatch 1961; Wilson et al. 2003).

Age Determination

A microfiche reader and compound light microscope were used to age scales. Annuli were identified by a sudden change in growth (e.g. circuli spacing decrease, circuli converging). The number of annuli on up to ten scales was read from each sample. The age assigned to the fish was based on the number of annuli most commonly counted. Brook trout that had no annuli present were presumed to be age-0. A second reader performed the same analysis on a subsample of all individual scale samples to give an indication of aging accuracy. Scales that were not agreed upon were then aged a second time by both readers with neither knowing the age they originally assigned. Reader agreement was calculated based on all of the scale ages after the second aging attempt. Otoliths were not used for age validation because all fish were released alive.

Data Analysis

Brook trout were assigned to two groups based on their movement. Fish that were detected by the stationary antenna and never detected again either through electroshocking recapture or passive detection on the antenna were presumed to be moving toward Lake Superior and hence called coasters. Fish that were never detected by the stationary antenna or were last detected by capture within the stream were presumed to be residents. Any fish that succumbed to in-stream mortality would also be included in this resident group. Data were split up into two additional groups when comparisons between ages were made: scale-aged fish and all fish where ages for scale-aged fish and calculated-age fish were combined. To calculate ages for fish not directly scale sampled, "Curve Estimation" in SPSS 15.0.1 (SPSS 2006) was used to find the equation of the regression that best fit the scale aged data set. The Mann-Whitney U test was used to determine differences in mean length, K, and age among all scale aged and all tagged coasters and residents. Mann-Whitney U tests and T-tests (depending on the data distribution) were used to evaluate differences between length and K for coasters and residents at a given age. Coasting data was organized by month and season of coasting. Season was as described by the calendar for a given year. A variety of variables and variable interactions were tested for both the scale aged group of fish and all fish tagged in the Hurricane River (Table 3.1). All comparisons between coaster and resident length and K were as measured at the time of tagging. In all cases, coasting occurred in the same year as age was determined. To test for significance, $\alpha = 0.05$ was used in all analyses.

RESULTS

Scale Aging and Regression

Three hundred and fifteen wild brook trout were tagged during the study. Twenty-four percent (n = 75) of all tagged fish were also scale sampled. Of the scale sampled fish, seven were identified as female and nine as male. The scale age of 107 wild brook trout was determined (see below). Thirty-one of these fish were not tagged because their total length was < 100 mm. Assigned ages ranged from age 0 to 3. Most fish were assigned age 0 (n = 31) or age 1 (n = 67). Eight fish were assigned age 2 and a single individual age 3. Final reader agreement for a subsample of 19 scales was 100%.

A quadratic trend line ($R^2 = 0.753$; $F = 158.1$; $p < 0.001$) was used to calculate the ages of fish that were not scale sampled because it predicted mean length values at a given age that were the closest to the means for each age of the scale aged fish and because when extrapolated to greater ages, the resulting lengths were biologically plausible (Figure 3.1). The equation of the quadratic trend line was:

$$Y = 75.467 + 45.725x + 4.877x^2$$

Where Y is total length (mm) and x is age in years.

When solved for age, the resulting equation was:

$$Age = (\sqrt{((length + 31.849)/4.877)}) - 4.691$$

The calculated age was determined by normal rounding of the estimated age thus making a - 0.5 – 0.49 calculated age fish age 0, a 0.5 – 1.49 calculated aged fish age 1, etc. This resulted in minimum and maximum lengths for each age similar to those from the actual scale aged samples (Table 3.2). The quadratic trend line correctly classified 91% of the scale aged fish using this method of rounding. One hundred percent of the misclassifications ($n = 7$) were within one age class of the scale age.

Coaster versus Resident: Length, K, and Age

The mean length of all scale aged fish was 135.3 ± 3.7 mm and K was 0.896 ± 0.015. There was no significant difference between scale aged coaster and resident trout for overall mean length and K (Figure 3.2). There was also no significant difference between scale aged coasters and residents at either age 1 or 2 for mean length or K (Figure 3.3). The mean length of all tagged brook trout from the Hurricane River was 154.3 ± 2.46 mm and K was 0.941 ± 0.008 with no significant difference between coasters and residents for mean length. Residents (0.967 ± 0.135) overall had significantly greater K than coasters (0.925 ± 0.130; Figure 3.4). Coasters and residents did not differ for mean length at any age. Residents had significantly greater K than coasters at ages 1(0.954 ± 0.014; 0.914 ± 0.013) and 3 (1.091 ± 0.034; 0.947 ± 0.045) (Figure 3.5). The most common age for scale aged coasters ($n = 36$) and residents ($n = 28$) was 1. Age 1 was also the most common for all tagged coaster ($n = 94$) and resident (n =113) fish. Statistical analyses between coaster and resident brook trout for mean length, K, age, and length and K at ages 1 and 2 for scale aged fish and ages 1 – 3 for all fish are summarized in Table 3.3.

Coaster Movement

Sixty-nine wild brook trout from the Hurricane River were tagged and scale aged from May to November 2007. Forty (58%) of these fish were detected on the stationary antenna and were presumed to have coasted. Most detections occurred in the fall (n = 18). Summer had the second highest detection rate (n = 14) with the spring having the smallest number of coasters detected (n =10). October (n = 10) was the month with the greatest number of coasters detected in 2007 with September (n = 8) having the next highest (Figure 3.6).

One hundred and fifty-three (49%) of the wild brook trout tagged in the Hurricane River fish presumably moved out to Lake Superior. The most detections occurred in the fall (n = 80) with summer showing about half the amount of movement (n =38) and spring slightly less (n = 35). When broken down into month, a bimodal distribution of movement was present (Figure 3.7). Most movement by coasters took place in October (n = 54). June had the second highest number of coasters (n = 23), less than half that of October.

Two percent (n = 2) of the fish tagged that were deemed coasters were redetected or recaptured in the Hurricane River in a year following tagging. Eight percent (n = 13) of the fish that left the Hurricane River were later detected on a stationary PIT antenna located in Sevenmile Creek.

Discriminant Analysis

Discriminant analysis indicated that tagging location was a significant factor in predicting whether or not a tagged fish would ultimately become a coaster for both scale aged fish ($\chi^2 = 13.562$; $p < 0.001$) and all tagged fish ($\chi^2 = 57.400$; $p < 0.001$). The two locations included in the analysis were 1) fish tagged between the antenna and Lake Superior and 2) fish tagged between Hurricane Falls and the antenna. The fish captured between the antenna and Lake Superior were the most obviously associated with coasting. The canonical correlation for the scale aged group was 0.413 and 0.459 for all tagged fish. Location allowed for 65% of original group cases to be classified correctly for scale aged fish and 66% correct classification for all tagged fish.

Immigration From Above Hurricane Falls

Seventy-eight wild brook trout ≥100 mm were tagged above Hurricane Falls from June 6 to October 31, 2007 (Figure 3.8). During this same time period, 61 fish ≥100 mm were tagged below Hurricane Falls. Mean length of fish from above the falls (136.0 ± 3.79 mm) was not significantly different from those below (134.5 ± 3.87 mm). Fish tagged above the falls had a higher mean K (1.007 ± 0.021) compared to those below (0.887 ± 0.011; $Z = -4.935$; $N = 147$; $p < 0.001$). Recaptures of fish tagged below Hurricane Falls ranged from 0 – 20% of the total number of fish tagged before that sampling date and occurred on every sampling trip after June 6. The greatest number of recaptures (n = 9) took place on July 31. The mean number of recaptures per trip was 3.3 ± 0.82. No fish tagged above the falls were later recaptured below the falls. Six fish tagged above Hurricane Falls (8%) were detected by the stationary PIT antenna below the falls. All of these fish were detected between September 28 and October 31, 2007 (Figure 3.9) and fit the definition of a coaster for this study. The movement of these fish does not seem to be linked to rainfall (a surrogate for discharge) during this time period as fish moved on and after days with varying amounts of precipitation. Five of the fish were scale age 1 (no suitable scales were taken from the sixth), and five were ≤ 123 mm. One of the fish had a length of 161 mm, was scale age 1, and was identified as a gravid female on October 17, 2007. This fish was the last of the fish tagged above Hurricane Falls to be detected.

DISCUSSION

The results of this study largely support the findings of Stimmell (2006). There was no significant difference between the mean length or age of wild coasters compared to resident brook trout from the Hurricane River during the May 2003 to November 2007 time period. The use of scale age and the development of a length at age regression allowed me to predict the age of all tagged fish that were not sampled for scales based on their length. This allowed for the comparisons of mean length and K at a given age for coaster and resident brook trout; there were only three significant differences between these two groups at any age examined. Movement data collected over the five year period support the finding that most movement in the Hurricane River takes place during the fall. Grouping fish movement by month yields a bimodal distribution with the largest peak being in October and the second highest in June.

The quadratic function used explained 75% of the variability in the scale age data. The remaining 25% is likely due to error in scale aging and the season during which a fish was captured (e.g. a fish captured during the fall at age 1 could have a length that corresponds with an age 2 fish in the spring). Because of the high agreement rate between the predicted age of the quadratic function and scale aged fish and high reader agreement for the subsample of scale ages, error by the scale reader and season of capture do not seem to have been major issues.

The movement of coaster brook trout in the Hurricane River closely follows that documented for other populations of anadromous and stream resident brook trout (Gowan and Fausch 1996; Hilderbrand and Kershner 2000; Smith and Saunders 1958; Josephson and Youngs 1996; Curry et al. 2002; Lenormand et al. 2004). Reasons for brook trout movement in the spring and June in particular may include smolt-like behavior of 1- or 2-year old fish or movement in and out of the stream to feed on the eggs of steelhead, suckers (*Catostomus* spp.), and dace (*Rhinichthys* spp.) that congregate and spawn in the Hurricane River from April through June (Stimmell 2006). Fall movement is typically linked to spawning as gravid and spawned out females and males were documented in the Hurricane River during the falls of 2006 and 2007. Fall movement by fish that could not be sexed (i.e. did not appear to be sexually mature) could be movement out of the stream because of a lack of resources as winter approaches (Kaitala et al. 1993) and is associated with a reduction in condition (Stimmell 2006). Another possible reason for fish to leave the stream is the restriction of habitat as ice forms. The Hurricane River was 100% covered with ice at times during the winter of 2006 – 2007 and water flow was restricted in some areas (personal observation). Lenormand et al. (2004) associated this occurrence with a lack of anadromous brook trout recaptures in pool habitat in the Sainte-Marguerite River, Quebec.

Although the second highest peak for coasting was in June, spring as a season had fewer fish coasting than did either summer or fall. This may be the result of limited function of the PIT antenna during the spring as records for the Hurricane River indicate the antenna being nonfunctional for days and/or weeks during the months of April and May (J. Leonard, Northern Michigan University, unpublished data). During the winter of 2006 – 2007, ice built up on the antenna in late fall and early winter eventually rendered the antenna nonfunctional. The antenna could not be repaired until early May due to access to the site and spring runoff. During the spring when the antenna historically has had limited function, access between the stream and Lake Superior is often possible and any fish that were tagged in the stream that left before the antenna was repaired would not have been detected.

Few differences in length and condition and tagging location being the only variable to discriminate a coaster from a resident in the Hurricane River suggests that there is no size or condition benefit to coasting if the fish tagged in the stream had entered from the Lake prior to tagging. The significant difference in K between all tagged coasters and residents overall, and at ages 1 and 3 suggests that perhaps there is a condition disadvantage to being a coaster but that this is not always the case. If brook trout tagged in the Hurricane River had not entered Lake Superior prior to tagging, the data suggest that fish with lower condition might be more prone to migrating to the lake.

An alternative hypothesis that I favor is that all fish tagged below Hurricane Falls are coasters. A PIT antenna does not always detect a tag as it passes. If more than one tag passes through the antenna closely enough, some or all of the tags may not be read (Brännäs et al. 1994; Morhardt et al. 2000). Also, if the speed of the fish is high, tag orientation is not optimal, and/or the antenna is detuned, tags can be missed (Stimmell 2006; Morhardt et al. 2000; Zydlewski et al. 2001; Cucherousset et al. 2005). The antenna systems were not running continually for the five year period and fish also may have coasted during these periods. Additional evidence for this all coaster hypothesis is that late in the fall, electrofishing yields few or no brook trout, tagged or otherwise (Figure 3.10). In the spring this is also the case making it seem as though the Hurricane River is virtually devoid of trout. Reduced efficiency of electrofishing gear is probably not the reason for the lack of fish captured during these times, as conductivity in the Hurricane River is stable at 100-125 µS (Rybczynski 2005). Although some of the tagged fish that were deemed "resident" may have ascended Hurricane Falls, it seems unlikely considering the lack of any recaptures of fish above the falls that were tagged below during 2007. It is also possible that some of the "resident" fish were in-stream mortalities or expelled their tags. This likely only happened in rare instances as survival and retention rates of PIT tagged fish are typically high (S. Stimmell, Northern Michigan University, unpublished data; Dare 2003; Buzby and Deegan 1999, Gries and Letcher 2002; Roussel et al. 2000; Mahapatra et al. 2001; Zydlewski et al. 2001; Hill et al. 2006). Mortality unrelated to tagging was not estimated for this project.

In studying the Hurricane River, it was initially assumed Hurricane Falls was a barrier to fish movement during most flows. Electrofishing above Hurricane Falls yielded adult steelhead during the spring and juvenile steelhead during all seasons as well as adult coho salmon in the fall. Adams et al. (2000) documented brook trout ascending a 1.2 m high falls and found that steep slopes were less effective barriers to brook trout movement than vertical falls. Hurricane Falls is about 2 m tall, angled, and has “steps”. Brook trout were often electrofished from small eddies located about halfway up the falls providing some suggestion that they may be able to ascend the falls. Although multiple electrofishing trips took place above Hurricane Falls during 2007, no fish tagged below the falls were ever recaptured above it. The lack of a stationary antenna above the falls; however, prevents elimination of this possibility.

The biggest question the Hurricane River has presented is: Where are all of the brook trout coming from? The stream reach below Hurricane Falls is relatively short and contains only three pools and limited large woody debris, habitat preferred by brook trout (Logan 2003). Despite this, nearly every sampling trip yielded new untagged fish. Early in the spring and late in the fall, the stream appears to be largely devoid of brook trout. If the fish went out to the lake in the fall, where did the new fish come from in the spring and throughout the summer and fall? Because the fish captured and tagged below the falls are ≥100 mm when tagged, it is apparent that they are not all young-of-the-year. Only 8% of the trout tagged above the falls were ever detected below. These fish were not recaptured, but were detected on the stationary antenna and in fact exhibited what is currently considered coasting behavior although it may represent simple dispersal. The movement of these fish was during the fall and well after they were tagged (14 – 136 days); they were likely not simply displaced downstream after tagging. Also, these fish moved on days during and after which various amounts of rain fell (including none) and were not likely washed downstream by high flows. Future tagging of fish above the falls and detection of these fish either by recapture or detection on the stationary antenna may give additional insight to how often these fish drop down to the lower river.

Clearly, some of the fish in the Hurricane River below the falls are coming from above the barrier, but how many enter the stream from Lake Superior is unknown. All study fish were tagged in the Hurricane River. Because tagging takes place in-stream, a fish must go out to Lake Superior and then return again for us to know if it came from the lake. Though there are some instances of fish that were detected coasting and then redetected or captured at a later date in the Hurricane River, nearly seven times as many fish have been detected on a stationary antenna in Sevenmile Creek. This demonstrates that brook trout are indeed moving from the lake into streams, but does not help explain how many brook trout enter the Hurricane River from the lake or why almost no tagged fish return. Multiple detections of fish from below the antenna suggest that after tagging some brook trout may go back and forth between the Hurricane River and Lake Superior multiple times before leaving the stream permanently (J. Leonard, Northern Michigan University, unpublished data; Stimmell 2006). Without placing a weir that effectively blocks the Hurricane River at the mouth, it may be impossible to determine how many of the fish in the stream actually come from Lake Superior.

Although many of the fish tagged over the last five years have been detected while presumably coasting, they were not significantly larger than those that were not detected making such movements. The fact that most of the coasters tagged in the last five years (a mix of juveniles and adults) were < 200 mm breaks the stereotype of coaster brook trout being large fish. Hurricane River coasters look very much like what one would consider to be a stream resident brook trout. The only difference is that these fish spend some amount of time in Lake Superior. Additional evidence against the archetype of the coaster is that two (female) scale sampled coasters from the Hurricane River in 2006 and seven in 2007 (two female, 5 male) were documented as sexually mature at age 1. This is counter to the hypothesis that coasters mature later in life than stream residents (Becker 1983). The quadratic growth curve constructed from scale aged fish predicts the length of a 3 year old brook trout from the Hurricane River below the falls to be 256.5 mm. The Salmon Trout River (Marquette, County, MI) is the nearest stream containing a remnant population of adfluvial coasters. The coasters in this river are considered small when compared to fish from populations in Lake Nipigon and on the North Shore of Lake Superior and yet typically reach 250 mm by age 2 (Huckins et al. In press). The oldest age class provided in Huckins et al. (in press) indicates the greatest age of coasters in the Salmon Trout River to be age 6. At this age the fish are approximately 460 mm in length. Based on the regression used in this study, brook trout from the Hurricane River would be 525 mm long at age 6 and be more similar in length to coasters from Lake Nipigon.

Although they are not the large brook trout of historical accounts, Hurricane River does contain coasters. Reasons for why these fish are small could include that large size and longevity were selected against by historical fishing regulations (minimum length of 178 mm) or simply that the fish are not living long enough to reach potential larger lengths. The data suggest a partially migratory population as at least some fish from both above and below the Hurricane Falls coast. The lack of tagged fish returning to the Hurricane River makes it appear to be a source of coaster brook trout, though not a destination for large spawners.

Coaster brook trout have managed to persist in the Lake Superior ecosystem despite overfishing, habitat manipulation and degradation, and the introduction of many exotic species. The research and reintroduction efforts focused on coasters around the Lake Superior Basin are beginning to shed light on the life history of these unique fish. Through further research and scientifically based management practices, the potential exists for coaster brook trout to persist in Lake Superior waters well into the future.

Table 3.1: Variables (as measured at time of tagging) and interactions between variables used in discriminant analysis for the Hurricane River to predict whether a given fish would likely be a coaster or resident.

Variables	Interactions	
Location	Season x K	Season x Weight
Season	Season x Length	Month x K
Month	Month x Weight	Month x Length
Length (mm)	Age x K	Age x Weight
Weight (g)	Age x Length	Location x K
K	Location x Weight	Location x Length
Age	Location x Age	Season x Age
	Month x Age	

Table 3.2: Minimum and maximum total length values for ages 0 – 3 for the quadratic trend line using standard rounding and for scale aged fish from the Hurricane River sampled November 2006 to October 2007. * Denotes one individual captured.

	Min and Max Total Length (mm) for Each Age Class	
Age	**Quadratic**	**Scale Aged**
0	54 – 99	55 – 95
1	100 – 155	93 – 185
2	156 – 220	151 – 223
3	221 – 295	254 *

Table 3.3: Comparisons made between PIT tagged coaster and resident brook trout from the Hurricane River. Analyses were split into two groups, the first contained only scale aged fish, while the second contained all fish tagged in the Hurricane River from May 2003 to October 2007. * Denotes a significant difference at $\alpha = 0.05$.

Group		Comparison	Statistic	df/ N Ranks	P-value
Group	Scale Aged Tagged Fish Only	Mean Length Coaster v. Resident	Z = -0.667	75	0.505
		Mean K Coaster v. Resident	Z = -1.249	75	0.212
		Mean Age Coaster v. Resident	Z = -0.061	75	0.951
		Mean Length at Age 1 Coaster v. Resident	Z = -1.212	64	0.226
		Mean Length at Age 2 Coaster v. Resident	Z = -1.358	10	0.175
		Mean K at Age 1 Coaster v. Resident	Z = -1.150	64	0.250
		Mean K at Age 2 Coaster v. Resident	t = 0.195	8	0.850
	All Tagged Fish	Mean Length Coaster v. Resident	Z = -0.564	314	0.573
		*Mean K Coaster v. Resident	Z = -2.600	305	0.009
		Mean Age Coaster v. Resident	Z = -1.349	314	0.177
		Mean Length at Age 1 Coaster v. Resident	Z = -1.544	207	0.123
		Mean Length at Age 2 Coaster v. Resident	Z = -1.180	79	0.238
		Mean Length at Age 3 Coaster v. Resident	t = -0.484	20	0.634
		*Mean K at Age 1 Coaster v. Resident	Z = -1.979	203	0.048
		Mean K at Age 2 Coaster v. Resident	t = -1.377	75	0.174
		*Mean K at Age 3 Coaster v. Resident	t = -2.217	20	0.038

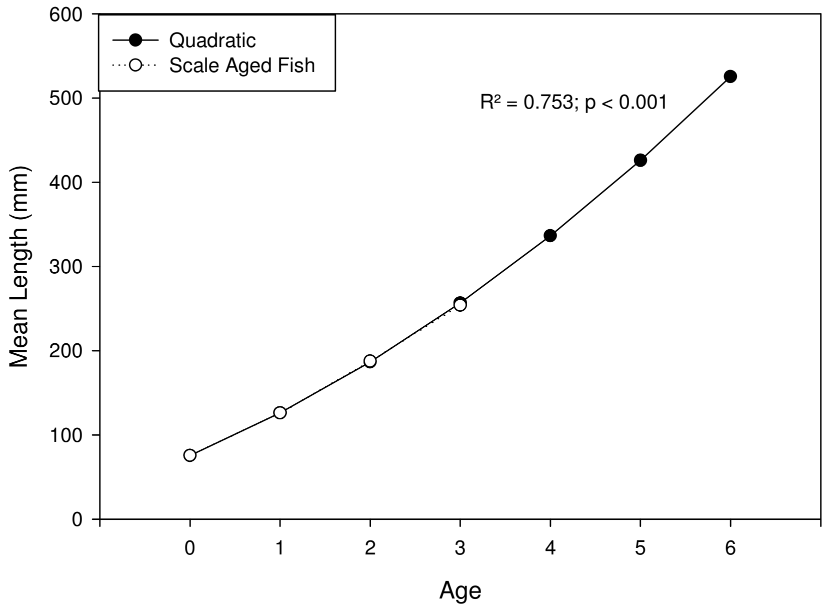

Figure 3.1: Mean length of scale aged brook trout and calculated length for wild brook trout at ages 0-6 based on a quadratic trend line fit to the scale age data. The curve is based on age 0 – 3 age classes with most data from age 0 and age 1 classes.

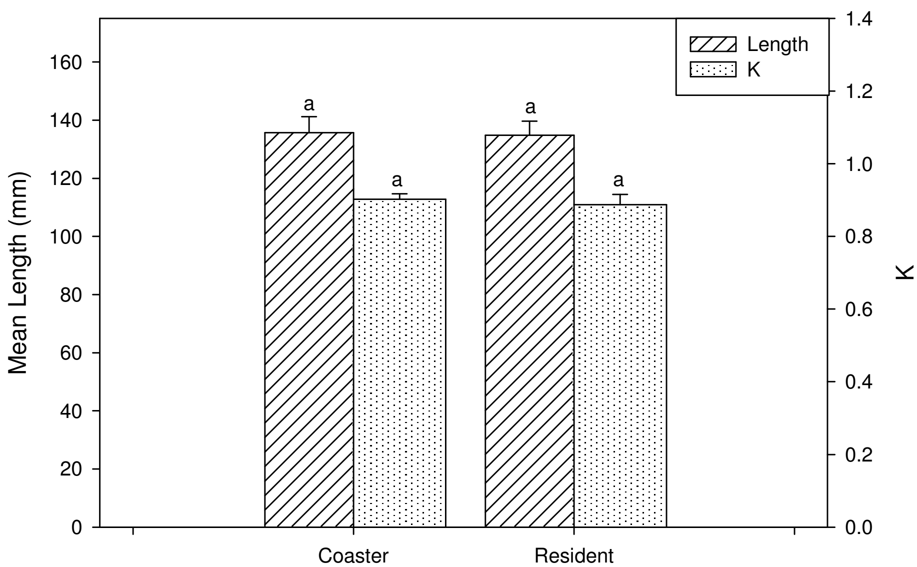

Figure 3.2: Mean length and K for all, coaster, and resident scale aged and tagged brook trout with all age classes combined from the Hurricane River sampled November 2006 to October 2007. Error bars represent standard error. Shared letters denote no significant difference ($\alpha = 0.05$).

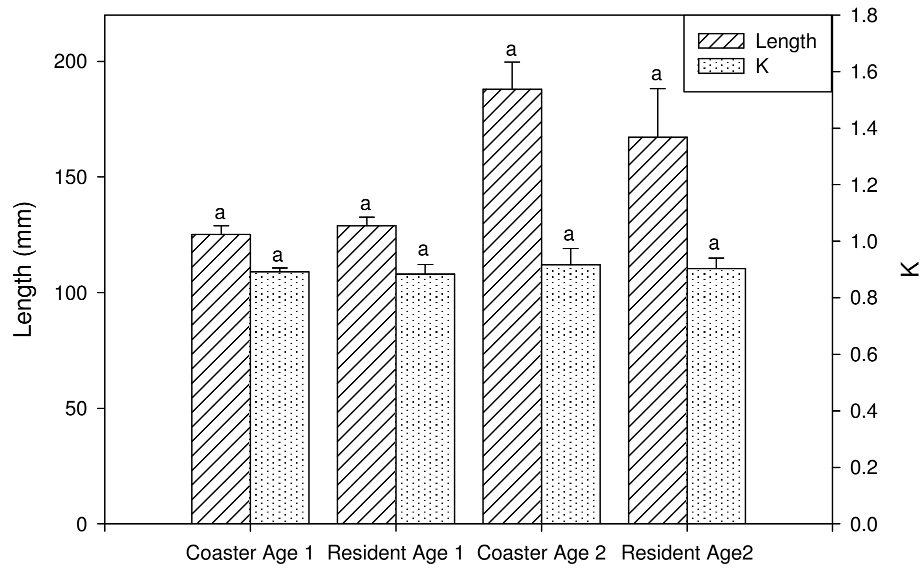

Figure 3.3: Mean length and K for coaster and resident scale aged and tagged brook trout at ages 1 and 2 from the Hurricane River sampled November 2006 to October 2007. Error bars represent standard error. Shared letters for each age denote no significant difference (α = 0.05).

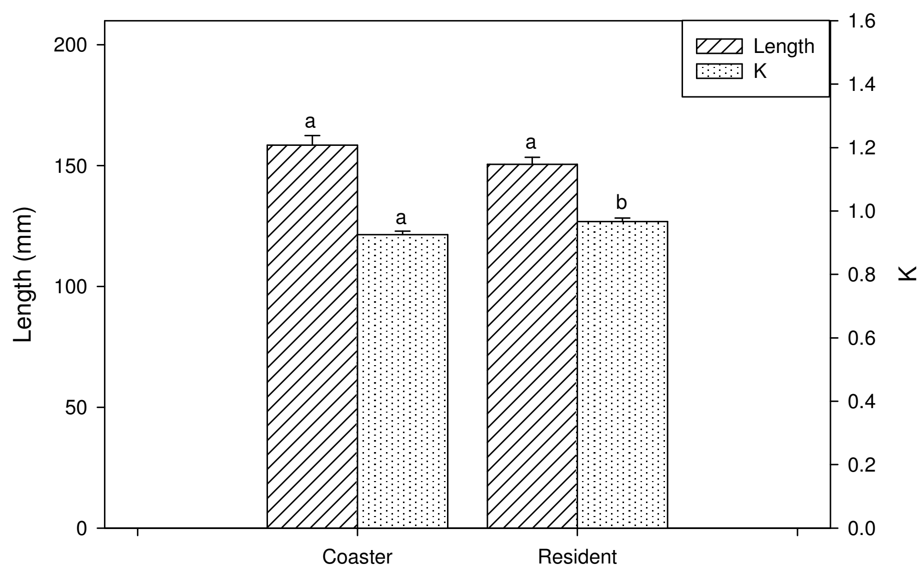

Figure 3.4: Mean length and K for all, coaster, and resident tagged brook trout with all age classes combined from the Hurricane River sampled May 2003 to October 2007. Error bars represent standard error. Shared age denote no significant difference (α = 0.05).

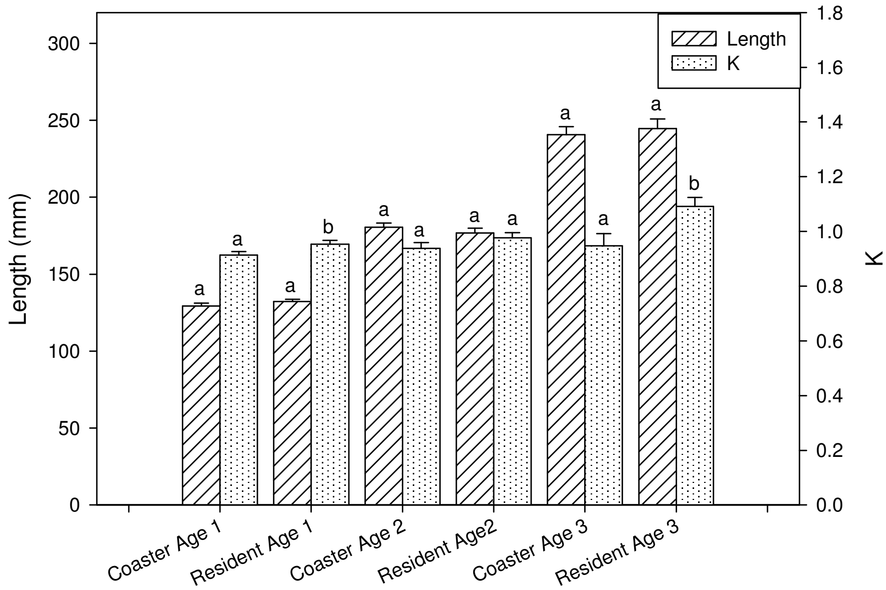

Figure 3.5: Mean length and K for coaster and resident tagged at ages 1 – 3 for brook trout from the Hurricane River sampled May 2003 to October 2007. Error bars represent standard error. Shared letters for each age denote no significant difference ($\alpha = 0.05$).

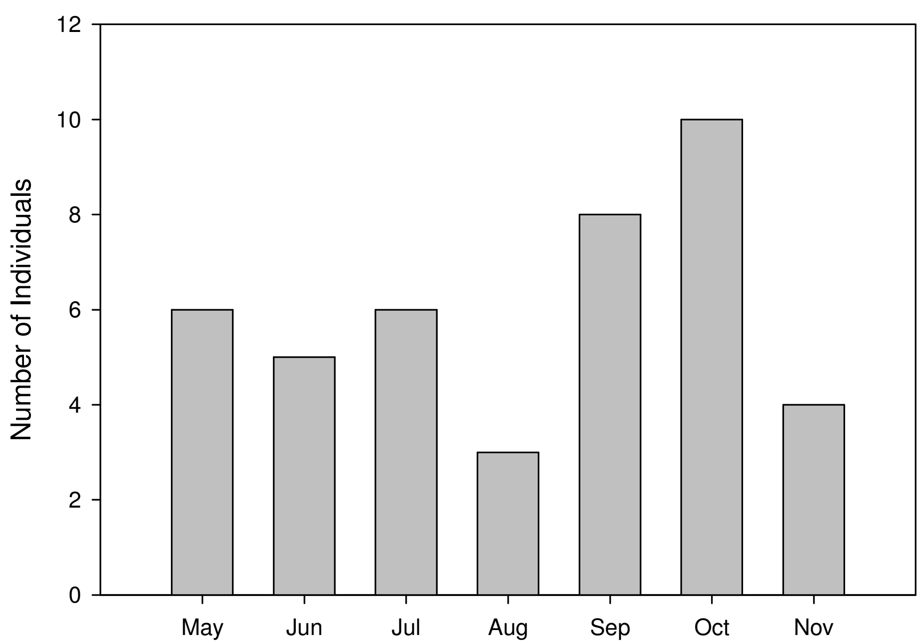

Figure 3.6: Number of scale aged brook trout from the Hurricane River that were detected at the antenna during each season from May to November 2007.

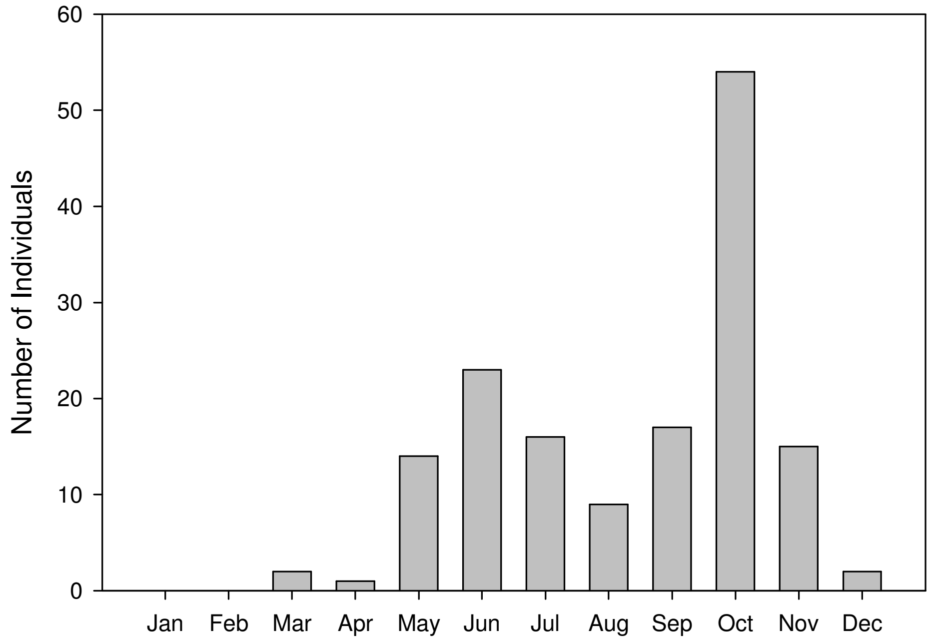

Figure 3.7: Number of brook trout from the Hurricane River that were detected at the antenna during each season from May 2003 to November 2007.

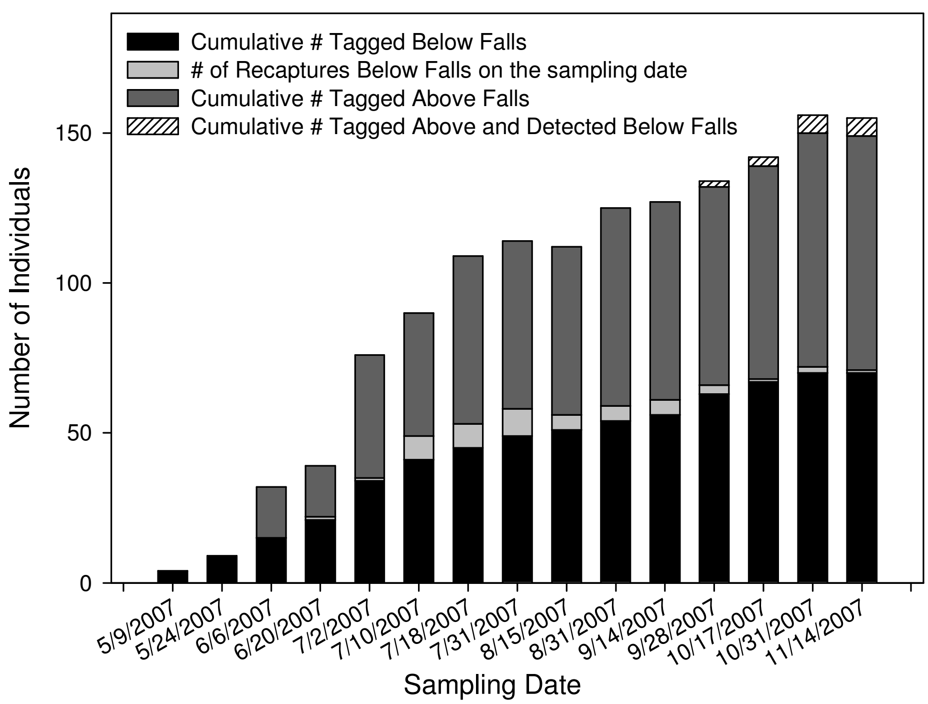

Figure 3.8: Cumulative number of brook trout from the Hurricane River tagged below Hurricane Falls, above Hurricane Falls, and tagged fish that dropped down below Hurricane Falls as of each sampling date, and the actual number of recaptured fish (tagged on previous days) on each sampling day from May to November 2007.

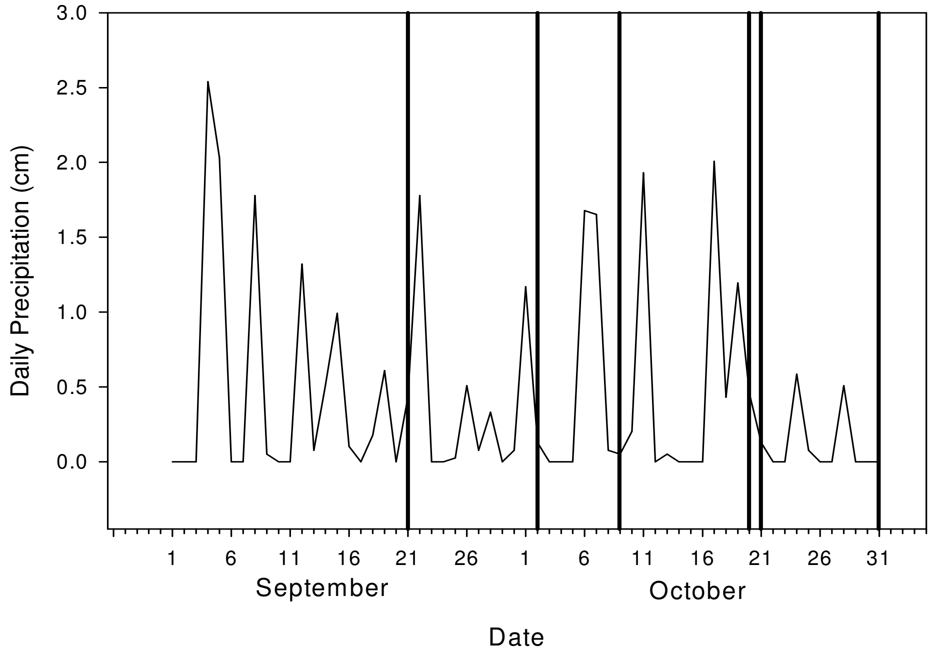

Figure 3.9: Daily precipitation in Munising, MI during September and October 2007. Vertical bars represent the date on which a fish tagged above Hurricane Falls was detected at the stationary antenna near the river mouth.

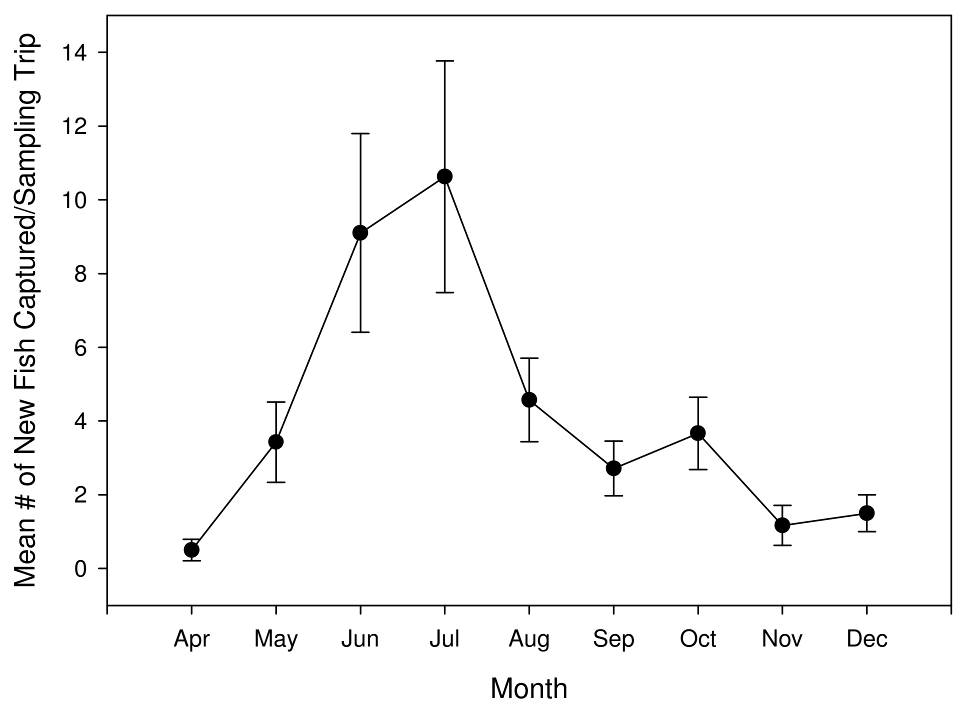

Figure 3.10: The mean number of untagged fish captured from the Hurricane River per sampling trip during the months of April to December from May 2003 to November 2007. Error bars represent standard error.

CHAPTER 4: CONCLUSIONS

The Hurricane and Mosquito Rivers and Sevenmile Creek are part of an active reintroduction of coaster brook trout to PRNL. From 2000 to 2005 nearly 212,000 Tobin Harbor strain coasters were stocked into the three streams annually. Despite this, in 2006 and 2007 after stocking had ceased, only a single fin clipped brook trout was recaptured. The lack of returning stocked coasters and the absence of large brook trout (> 350 mm) suggests that the reintroduction effort was largely unsuccessful. Genetic analysis of wild fish captured from the three streams should be done to fully understand the influence of the reintroduction effort on the current populations of brook trout in PRNL. Despite the apparent failure of the reintroduction, all three streams still contain healthy populations of wild resident brook trout and in the Hurricane River, wild coasters.

The use of scales to age brook trout in PRNL allowed me to analyze populations of brook trout at a finer scale than could otherwise be accomplished. When scales are used in aging brook trout, some form of age validation should be used. Scale aging is highly subjective and how one ages a scale is the result of experience, the quality of the scale, and how the reader interprets an annuli. When more than one reader examines a set of scales it is likely that there will be disagreement for these reasons. Because otoliths could not be used to validate scale ages, the next best option was to age fish of a known age. Although reader agreement was not perfect, the most common disagreement was reader 2 assigning an age that was one year less than reader 1. In addition, when stocked fish of known age were misclassified, it was generally under-aged by one age class.

These disagreement and misclassification results suggest that if the scale ages of some of the unknown age fish are incorrect, they are likely to be one year lower than is true. Most of the fish captured for the study were aged as 0 or 1. Because these fish are young, it is less likely that fish were over aged due to checks or under aged due to scale wearing. The use of scales to age brook trout in PRNL likely depicts an accurate picture of the age structure in the three streams and is worth continuing in the future.

The results of mean length and K at a given age show little difference between the three streams or even between areas above and below barriers where trout have open access to Lake Superior. Though relative growth data were limited for the three streams, it shows that all six groups of fish generally followed the same trend and that no one group varied substantially from the rest. The conditions under which brook trout in the three streams live are likely similar based on the data. This appears to be the case despite each of the streams having areas that contain naturalized populations of exotic salmonids. Whether or not conditions are similar in the three streams, movement over the Hurricane River barrier and between streams does occur. Stimmell (2006) documented brook trout from the Hurricane and Mosquito Rivers moving into Sevenmile Creek. It is also known that brook trout from above Hurricane Falls move to areas below. Although there may be enough mixing within streams and between streams that all of these fish are part of one PRNL population, this seems unlikely based on the genetics work by D'Amelio (2002) in Nipigon Bay and the analysis to date for the three PRNL streams (J. Leonard, Northern Michigan University, unpublished data).

The Hurricane River is an interesting case study in the coaster saga because despite having only about 180 m between Lake Superior and Hurricane Falls, with much of it flowing over beach and bedrock, an average of 24 coasters were detected each year from 2003 to 2007 (Range 12 – 37). The comparisons made between fish that were detected coasting and those that were not show only a few differences in K between these two groups. The use of discriminant analysis, which could not effectively separate a Hurricane coaster from a resident, supports the results of the comparisons. These data have led me to the hypothesis that all brook trout in the Hurricane River below Hurricane Falls are coasters as currently defined (i.e., a brook trout that spends part of its life in Lake Superior). An observation that supports this hypothesis is the dearth of brook trout in the Hurricane River in the late fall and early spring. It seems unlikely that all of the fish not detected coasting ascended Hurricane Falls or found refuge in the limited gravel available. The alternative option for these fish is to move out to Lake Superior. Although stationary PIT systems are known to be highly efficient, it is still possible for fish to pass through and not be detected. I suggest the fish considered residents in this study were more likely to have been in-stream mortalities, fish that either passed through the antenna and were not detected, or coasted during a time period where the antenna was not functioning.

The results of these studies show the many similarities between brook trout in different Pictured Rocks streams and between groups of fish presumably isolated by barriers. The lack of significant differences between groups of fish in PRNL and the absence of strong trends toward larger fish or fish of better K in specific stream segments suggests a single population despite the poor likelihood of being true. Additionally, in the Hurricane River a strong case can be made that all brook trout captured below the Hurricane Falls are or will become coasters.

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APPENDIX

Northern Michigan University

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December 1, 2005

TO: Jill Leonard
Biology Department

FROM: Cynthia A. Prosen, Ph.D.
Dean of Graduate Studies & Research

RE: **Application to use Vertebrate Animals**
Application # IACUC 035
Approval Period: May 1, 2006 – May 30, 2008

The Institutional Animal Care and Use Committee has approved your project to use vertebrate animals in research entitled "Assessment of Coaster Brook Trout Movements and Spawning activities in the Hurricane River".

If you have any questions, please contact me.

ljh

cc: Biology Department