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MIGRATORY ACTIVITY OF TWO STRAINS OF BROOK TROUT (Salvelinus fontinalis) IN PICTURED ROCKS NATIONAL LAKESHORE CHARACTERIZED USING STATIONARY RFID SYSTEMS

Sean P. Stimmell

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By

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ABSTRACT

MIGRATORY ACTIVITY OF TWO STRAINS OF BROOK TROUT (*SALVELINUS FONTINALIS*) IN PICTURED ROCKS NATIONAL LAKESHORE CHARACTERIZED USING STATIONARY RFID SYSTEMS.

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Efforts to restore migratory, lake-dwelling coaster brook trout (*Salvelinus fontinalis*), to Pictured Rocks National Lakeshore (PRNL) began in 1997 when coaster strain brook trout were stocked in three Lake Superior tributaries. Subsequent stocking has occurred every year since 2000. Basic information on what drives migratory behavior in brook trout and seasonal movement patterns they display is sparse, mainly from anecdotes and limited information from the few surviving populations. Using stationary radio frequency identification systems (RFID) that detect passive integrated transponder (PIT tags), it was possible to effectively gather information on the of seasonal timing of wild (PRNL) brook trout and coaster strain brook trout (TBH) movements to and from Lake Superior in 2003 and 2004. Low numbers of fish moving were recorded at the antennas throughout the study, with peaks occurring during the spring and fall of 2003, and spring 2004. Photoperiod correlated with lake-run activity in both years ($p \leq 0.05$), although water temperature may have played a minor role in Sevenmile Creek movements during 2004 ($p \leq 0.05$). Differences were found in condition between the PRNL and TBH strains ($p \leq 0.05$) as well as between lake-run and resident brook trout during the 2004 season ($p \leq 0.05$) (spring and summer).

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: LITERATURE REVIEW

Migration of fish is described as a persistent directed movement between different habitats within the lifetime of an individual (Northcote 1997). This definition is a blanket statement that can cover a large number of migratory strategies that have evolved in fish. Migration can occur in freshwater (potamodromy), saltwater (oceanadromy), or between these two habitats (diadromy). Freshwater migration can be further broken down as occurring within lakes (allacustrine), within streams (fluvial), or between the two (fluvial-allacustrine) (Varley and Gresswell 1988, in Northcote 1997). Migration between saltwater and freshwater are also divided into categories. Anadromy involves the migration into freshwater to spawn whereas catadromy is migrating to saltwater for reproduction. Amphidromous species migrate between fresh and saltwater, but not for spawning purposes (McDowall 1987). One of the difficulties with this classification is that species do not always fit within the definitions of these categories. Many fish referred to as diadromous display behaviors that don't really align with the anadromous or catadromous categories to which they have been designated (Dodson 1997).

Fish migration entails more than simply moving from one place to another. Throughout the world, teleost fishes conduct migrations of varying degrees. The migration of one fish might be measured in meters while others, such as some Pacific salmon (*Oncorhynchus* spp.) spawning in the Snake River, Idaho, will travel over 1500 km (Waples et al. 2001). During migration, fish are potentially subjected to greater mortality, higher energy expenditure, and variable environmental conditions (Dodson 1997). Although each individual fares differently, some survive the journey while others die after spawning, migration continues to be a successful life history strategy among fishes. This implies there must be some selective advantage that allows the migratory phenotype to persist within a species.

The advantage of migration lies in its ability to enhance an individual's reproductive success (Thorpe 1994, Fleming 1996, Dodson 1997). In order for migratory behavior to evolve and remain within a population, the reproductive benefits must exceed the costs associated with migration (Dodson 1997). Migratory salmonids often delay maturity for several years while individuals living as stream residents spawn at an earlier age (Thorpe 1990, Bohlin et al 1990, Fleming 1996). Thus, all of the costs of migration (predation, high energy expenditure, extreme environmental changes) as well as changes within an individual to overcome them cannot exceed the increase in fitness that is gained by undertaking migration. Presumably, if these costs were higher than the gain, mating migration behaviors would not persist in populations as a successful life history strategy.

Although increased reproductive success is the ultimate objective, it is clear that not all migrating fish achieve this the same way. The evolution of migration depends on resources, environmental factors, and habitat that a fish is able to use to its advantage. The origins of migratory behavior are likely not the same in each species, even though some have converged towards outwardly similar life history strategies. Fish of different species may be moving into similar habitats for reproduction and yet have entirely different reasons for doing so. Members of the herring family (*Alosa* spp.) are fish of marine ancestry that most likely evolved a diadromous behavior as a means of placing young in a habitat (freshwater rivers) where they will experience the greatest chance of survival, maximizing recruitment to the population (Dodson 1997). Atlantic salmon (*Salmo salar*) often migrate out to the ocean, yet also return to freshwater to spawn. In this situation, fish of putative freshwater origin migrate to the ocean to take advantage of rich ocean feeding grounds and greater growth potential. Female salmon, which invest much more heavily in reproduction than males, benefit from greater size. Increased size leads to more and larger eggs, increasing the fecundity of the individual (Gross 1987). Anadromous males of increased size can better aggressively compete for mates during the spawning season. Both herring and salmon spawn in freshwater, yet herring likely do so to increase offspring survival, while salmon are using an oceanic rearing habitat to enhance juvenile growth. If fish have the opportunity to increase fitness through migration, it can become a successful life history strategy (Maekawa and Nakano 2002). Although only about 1% of the world's teleost fish species are diadromous (McDowall 1987), Scott and Crossman (1973) found 21% of the freshwater fish in Canada showed some form of diadromy and 55% of Canada's freshwater fish showed a degree of migratory behavior.

Salmonid migration occurs in many species throughout their range. In general, these migrations are movements towards rich feeding grounds that improve fitness through fecundity or competitive abilities (Gross 1987). The most derived migratory behavior in salmonids is found in Pacific salmon (*Oncorhynchus* spp) and the least so in the sister taxa char (*Salvelinus* spp.) (McCormick and Naiman 1984). Even in the species with a more derived migratory behavior, migration should be considered as an alternative as all *Oncorhynchus* species (as well as *Salmo* and *Salvelinus* species) have freshwater resident individuals and/or populations (Waples et al. 2001).

The onset of migration is different among species, populations, and individuals, and can be controlled by a variety of abiotic factors that affect fish at different times and ages (Thorpe 1989). Competition can also lead to migration (Cox 1968). In all salmonids, population density could influence the decision to become anadromous. The idea that migration is an alternative strategy based on an individual's inability to compete for sufficient resources needed for maturity has been suggested (Thorpe 1994, Dingle 1996).

Salmon species show that the most derived migratory behavior are able to migrate out of freshwater at smaller sizes and younger ages. Pink salmon (*O. gorbuscha*) and chum salmon (*O. keta*) are thought to be the most derived Salmoninae. They migrate out of freshwater only a few months after hatching (Behnke 2002), while species such as Atlantic salmon, chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*) spend at least one year developing in streams before migrating to the ocean (Waples et al. 2001, Fleming 1996).

Oncorhynchus and *Salmo* individuals that migrate do so on a fixed schedule, generally set by seasonal photoperiod and temperatures. Migrating fish commonly undergo physiological changes in body size, coloration, behavior, adaptability to seawater, and delayed maturity (McCormick and Naimen 1985). Juveniles in the genera *Oncorhynchus* and *Salmo* undergo a process called smolting in which they transform physiologically and morphologically prior to migration, allowing them to make the transition from freshwater to saltwater.

Charr (*Salvelinus* spp) show a more primitive form of migratory behavior than do Pacific and Atlantic salmon. In areas where brook trout have access to estuaries, they generally do not migrate into seawater until attaining a size of 16 cm (McCormick and Naimen 1984). In the case of migratory brook trout in there did not appear to be a photoperiod-induced migration to seawater, although photoperiod did initiate male maturity, which, in turn, appeared to decrease sea water tolerance (McCormick and Naimen 1984). Osmoregulatory ability in migratory fish, with the exception of maturing males, appears to be related to a surface area to volume ratio of the gills, in which greater overall size would be an advantage (McCormick et al. 1985). In addition to size-related migration constraints, there also appears to be a physiological element involved in determining which fish within a population will migrate. Morinville and Rasmussen (2003) found that migratory brook trout had greater consumption rates, but lower growth efficiencies than those that remained resident. Charr also show shorter lengths of residency in seawater, possibly due to their inability to deal with high salinity and low temperatures. Svenning and Gullestad (2002) found that Arctic charr (*Salvelinus alpinus*), especially smaller and younger individuals, that were unable to migrate upstream to over-wintering lakes likely suffered high mortality. Physical factors can potentially affect the degree of anadromy within charr populations. Kristoffersen (1994) and Kristoffersen et al. (1994) provided data suggesting that physical stream parameters and lake morphology affect the degree of anadromy in Arctic charr populations. In these ways, charr show a variable degree of anadromous behavior influenced by a wide array of factors.

Lake Superior is currently inhabited by a number of salmonid species. Some are migratory while others exhibit a more resident lifestyle. Pacific salmon were introduced to the Great Lakes beginning in the 1800's and again during the 1960's. Currently, Lake Superior maintains populations of chinook, coho, and pink salmon, as well as steelhead trout (*O. mykiss*) (Becker 1983). Other than steelhead, these fish maintain semelparous life history strategies consistent with salmon living on the Pacific coast. Steelhead display a similar life history, but are iteroparous, potentially spawning several times. Great Lakes salmon continue to undergo physical and physiological changes that prepare them for “ocean” migration. They migrate from streams into Lake Superior, returning years later to their natal streams for spawning.

Among the native salmonids inhabiting Lake Superior, brook trout (*Salvelinus fontinalis*) exhibit an extraordinary amount of plasticity when it comes to life history strategies. Throughout their range in North America, they use streams and lakes at various life history stages. Some populations live entirely within streams while others live only in lakes (Ridgeway and Blacnchfield 1998). Between these two extremes lies an assortment of migratory strategies that involve both lakes and streams. Some populations live in lakes, but spawn in stream outlets (Baril and Magnan 2002). Others live and spawn in lakes, but juveniles migrate to stream outlets soon after hatching (Curry et al. 1997). There are also some populations living within streams that migrate out to lakes or estuaries for several months before returning to spawn or over-winter (Dutil and Power 1979, Castonguay et al. 1982, Montgomery et al. 1990).

Brook trout in Lake Superior are currently classified as one of two types. Stream-resident brook trout inhabit the tributaries of Lake Superior and are common throughout the watershed. Stream dwelling brook trout generally mature quickly, males sometimes by the end of their first year (89 mm) and females as yearlings (127 mm), and rarely live for more than five years (Becker 1983). The other morphotype of brook trout, once common to Lake Superior, is known as the coaster. Unlike their stream counterparts, coasters were known for attaining large sizes. Coasters are defined as any brook trout that spends any part of its life in Lake Superior (Becker 1983). However, the term is generally used for fish that migrate out into the lake and then return to their natal streams in late summer (adfluvial or migrant coasters) or in reference to the lake dwelling brook trout (e.g. from Tobin Harbor on Isle Royale, MI) that remain in Lake Superior for their entire life (lacustrine coasters). Historically, adfluvial coasters were commonly found along the shoreline of the lake during summer months, annually returning to their natal streams to spawn. Unlike Pacific salmon, coasters are iteroparous, surviving to spawn during multiple years. Although very little is known about the biology of coasters, their migratory strategy appears to be most closely related to the sea run brook trout known as 'salters' inhabiting streams on the Atlantic coast. These brook trout, which reside in streams and rivers that access the ocean, generally migrate out to the estuaries during spring (Castonguay et al. 1982, Dutil and Power 1979, Montgomery et al. 1990). Southern populations (Cape Cod, MA) emigrate towards the ocean in the fall (Bigelow and Schroeder 1953) as do trout in Ellerslie Brook, Prince Edward Island (Smith and Saunders 1958). Several possible migration cues have been associated with this downstream migration. Castonguay et al. (1982) found migration to be in sync with lunar cycles, while others correlated movements with seasonal discharge and water temperature (Dutil and Power 1979, Montgomery et al. 1983, 1990). Migration was undertaken by fish aged 2 years and greater in most cases (Dutil and Power 1979, Castonguay et al. 1982). Anadromous brook trout remained in the estuary for up to four months, using rich feeding grounds before returning in late summer (Montgomery et al. 1990). During those months in the estuary, trout experienced greater growth than stream resident fish, and possibly greater fecundity (Naimen et al. 1987). There was no evidence that migrating brook trout delay sexual maturation, possibly due to the more primitive state of anadromy displayed as compared to other salmonids that can postpone sexual maturity (Montgomery et al. 1990). Fish over-wintered in estuaries, adjacent lakes, or in spawning streams (Smith and Saunders 1958, Dutil and Power 1979, Castonguay et al. 1982, Montgomery et al. 1990).

Coasters of Lake Superior are similar to many other brook trout populations in that they are prized as a sport fish and can be notoriously easy to catch. Already becoming rare due to habitat destruction and overfishing by the late 1800's, coasters were extirpated from all but a few streams by the mid 20th century. Although some populations on the less exploited north shore of Lake Superior persisted, nearly all runs of fish indigenous to the southern coast were eliminated. The last known Lake Superior stocks in Michigan are found in the Salmon Trout River, Marquette County, and around Isle Royale (Baker et al. 1999).

Since 1997, efforts to restore migratory brook trout populations to parts of their historic range along the southern shore have been made by the Michigan, Minnesota, and Wisconsin Departments of Natural Resources, the U.S. Fish and Wildlife Service, the Great Lakes Fisheries Commission, and the National Park Service (NPS). Lake Nipigon stock fingerlings have been introduced to the Carp River (Gogebic County) and the Gratiot River (Keweenaw County) in Michigan in an effort to restore coasters to the Keweenaw Peninsula (Dr. Casey Hutchins, Michigan Technological University, personal communication 2002). Efforts are also being made to reintroduce self-sustaining populations to rivers in Pictured Rocks National Lakeshore (Baker et al. 1999). Over 155,000 fingerling and yearling brook trout from Tobin Harbor, Isle Royale strain brood stock have been planted in the Mosquito and Hurricane Rivers as well as Sevenmile Creek between 1997 and 2004 (Lora Loope, National Parks Service, personal communication 2004). Isle Royale, where Siskiwit River migratory coasters and Tobin Harbor lacustrine coasters still persist, maintains a hatchery brood stock from both strains although the Tobin Harbor strain is the only one presently available for distribution away from the island.

In order to properly monitor and manage coasters, it is important to understand the fish's life history and the factors that affect their behavior. Unfortunately, the majority of coaster brook trout populations were depleted or extirpated before there was any real effort made to study them. The only records available are brief written references and anecdotes, neither of which provides a reliable picture of coaster brook trout behavior. Although the remaining populations are being studied, they are in difficult areas to conduct research and are heavily protected. With the biology of these fish mostly unknown, we must start at the beginning and try to determine behavioral and physical differences that separate coasters from stream resident brook trout.

This project contains three components that were conducted simultaneously in an attempt to create a better understanding of the biology of coaster brook trout in Pictured Rocks National Lakeshore. 1) This first section examines the effectiveness of using radio frequency identification (RFID) systems that detect passive integrated transponder (PIT tags) for monitoring brook trout movements in the remote locations within PRNL. 2) The objective of the second section was to use data from these systems to determine seasonal movement patterns of brook trout at the mouth of three rivers in PRNL and the influence of water temperature, photoperiod, and rainfall on these lake-stream movements. 3) Fish condition factor (K) and relative weight (W_r) was examined in the final section to determine if there were any potential metabolic differences apparent between moving and non moving fish as well as between the different strains (PRNL wild and TBH) over the study period.

CHAPTER 2: EVALUATING A TEXAS INSTRUMENTS RFID SYSTEM AS A MEANS OF MONITORING FISH MOVEMENTS IN PICTURED ROCKS NATIONAL LAKESHORE

CHAPTER SUMMARY

Over the past decade, radio frequency identification (RFID) systems used to detect passive integrated transponders (PIT tags) have become an effective method of monitoring movements of individual fish in streams and fish passages. Although these systems allow long term monitoring with minimal handling (after tagging), their applications in remote locations are constrained by power requirements. As part of a project to assess movement of migratory brook trout (Salvelinus fontinalis), RFID stationary PIT systems were installed in three remote streams in Pictured Rocks National Lakeshore, Michigan. Power requirements for the 4.5-5.5 m antennas were supplied by a battery bank (three 12 volt deep cycle batteries supplying 252 amp hours) in 2003 and further supplemented by solar power during 2004. This stationary system was able to run continuously on a three battery bank for approximately eight days without any alternative power sources. Additionally, the range at which each system could detect tags at the stream bottom and surface was measured to provide an estimate of the antenna's ability to detect tags at high water velocities. Ranges were best toward the middle of the antenna with the tag in a perpendicular orientation to the antenna field.

Larger RFID systems in remote locations create smaller detection fields and providing power year round can be difficult, making these systems difficult to maintain. With proper power supply selection and stream antenna site selection, however, these systems can be used as an effective monitoring tool for migratory fish in smaller rivers

and streams. The read range of a tag is limited by the size of the antenna and the choice of a power source must be based on the distance and ease of access to the system.

INTRODUCTION

In the last decade PIT technology has become an important tool in monitoring migratory fish behavior (Castro-Santos et al. 1996, Roussel et al. 2000, Mahaptra et al. 2001, Zydlewski et al. 2001, Aarestrup et al. 2003, Riley et al. 2003). The applications have advanced from hand scanning for tagged fish (Ombredane et al. 1998) to monitoring fish passage through dams and streams (Zydlweski et al. 2001) and stream tracking of fish using portable hand held systems (Roussel et al. 2000). Passive integrated transponder technology has proven to be adaptable to the needs of biologists. Texas Instruments RFID systems utilizing 23 mm PIT tags (Texas Instruments, Dallas, TX) are effective in several applications involving the movement of fishes. The advantage of these systems are the ability to detect tags at a range of approximately one meter, not barring the passage of fish moving within a system, and a tag with the potential to last several years. Previous research involving juvenile steelhead in 2003 and 2004 has shown tag loss (5.0-7.2%) and tagging related mortalities (< 2.0%) to be low (Hill et al. 2005). Stationary PIT systems that use the RFID equipment have been effective in monitoring fish passage through dams (Castro-Santos et al. 1996) and movement of salmonids within streams (Zydlewski et al 2001). A schematic of a stationary system is shown in figure 2.1. A wire loop antenna encircles a cross section of the stream and is attached to the reader, data logger, and power source. Tagged fish passing down or upstream are detected and their unique ID code as well as the date and time of passage are recorded.

Passive integrated transponder systems operate on radio frequencies, similar to more traditional radio tags that have been used in many fisheries applications. One main difference is that PIT tags use an electromagnetic signal to transmit data (Texas Instruments 1996) whereas traditional radio tags are equipped with a battery to power sending a coded signal. Instead of fitting PIT tags with size-restrictive batteries, these systems are powered at the antenna. The antenna resonates at a frequency of 134.2 kHz, generating an electromagnetic field around it. When a tag reaches the electromagnetic pulse produced, it stores energy until charged. Upon reaching full charge, the tag then waits for the antenna to finish its ‘send burst’ and begin ‘listening’ for a tag response. The tag then sends its programmed information back to the reader/control unit where it is stored (Texas Instruments 2000a). This process, as configured for our systems, takes place in a time period that allows for 7 reads per second. While read range is restricted to a relatively short area around the antenna, these systems do have several advantages over traditional radio tags. The lack of battery allows for smaller tag size (23mm), and the tagging of smaller fish. The tag (as long as they are not compromised) also can last up to several years, continuing to read as long as an antenna provides power (Texas Instruments 2000b).

RFID systems do have limitations. Antenna size is limited in order to provide an adequate read range (Texas Instruments 2000a) and thus ensure the detection of tagged fish. Larger antennas, while providing a larger signal sending range, are also susceptible to greater amounts of background noise which decreases the ability to discern tag responses. The transponders are also only able to respond to the antenna signal over a certain distance. Another limiting factor is the power source. Many of the locations in which these systems are used have access to a permanent power source. In remote locations where there is no permanent power source available, a system is able to run only as long as its temporary power source lasts. In these situations, alternative power supplies, such as solar or propane, can be expensive and difficult to install and maintain depending on site access and solar availability.

The first objective of this study was to examine the effective run time of a stationary system on a battery bank. The second objective was to examine the different ranges exhibited by each antenna and estimate the antenna's ability to detect tags at different water velocities based on range testing at these three systems.

MATERIALS AND METHODS

The PIT equipment being used in Pictured Rocks National Lakeshore (PRNL) was manufactured by Texas Instruments (Dallas, TX). The specific RFID model used was based on the relatively large antenna size and remote location of the study sites. The equipment necessary to run a RFID system consisted of 2 parts: a reader system with computer and power supply, and a tuning box and antenna (Figure 2.1)

Part one, enclosed in a weather proof box, was the reader, data logger, and power supply. The reader consisted of a series 2000 High Performance Remote Antenna-reader Frequency Module (Texas Instruments Dallas, TX) and a series 2000 Control Module (Texas Instruments Dallas, TX). The data logger, a Hewlett Packard 200lx palmtop PC (Hewlett Packard, Palo Alto, CA) was connected to the reader and recorded the date, time, and identification number of the PIT tagged fish crossing the antenna. The power supply for this system was a battery bank connected in series containing three Sun Xtender 12 volt batteries (Concorde Batteries, West Covina, CA) providing 252 amp hours.

The reader/power supply was connected to the tuning box and antenna via a section of twin-axial cable (model EWN01A, Black Box Corporation, Lawrence PA). The antenna was a wire loop running above the water surface and along the stream bottom. The wire was 8 gauge OFHC Stinger brand wire (Clearwater FL). An antenna tuning board (RI-ACC-008B, Texas Instruments Dallas, TX) was required to ensure the antenna was tuned to the reader's output frequency of 134.2 kH and thus attained maximum read range.

Power supply

A RFID system draws approximately 0.6 amps continuously while operating on a DC power source. With an adapter, it is possible to connect the system to an AC power source and run it continuously. In PRNL, there was no external power source available. This resulted in stored power being the only option for running the systems. A balance of power supply longevity had to be matched with ease of transport as the energy source had to be transported on foot 0.4-0.8 km into the park to reach the RFID systems. The power supply chosen for the systems consisted of a battery bank made up of three Concorde Sun Xtender PVX-840T absorbed glass matt deep cycle batteries. Each battery provided 85 amp/hr of power per unit and weighed approximately 27 kg. These batteries were selected in an attempt to maximize power longevity and still have a power source that could be carried. High quality deep cycle batteries were also used to prevent damage from extreme cold temperatures, which can increase the drawdown of a battery's power and possibly freeze water filled lead-acid batteries. In addition, absorbed glass matt batteries are sealed (i.e. no water needs to be added, none can leak out without cracking open a battery). This means there was far less danger of leaking battery acid into the RFID system or PRNL environment.

Battery discharge is also be affected by temperature**.** Although voltage is not influenced, the discharge rate increases in cold temperature environments, shortening the run time of a system. In an attempt to reduce the effects of temperature, each battery bank was placed in a weather proof box containing 10 cm of extruded polystyrene insulation. Additionally, the reader unit and power source produced heat as a byproduct of operation (Dr. Alex. Haro, USGS Conte Fish Laboratory, personal communication 2002).

It was essential to determine how long a RFID system with our particular parameters could run continuously on this power source. Therefore, between May 23, 2003 and June 20, 2003 three and four trips were made to the Mosquito and Hurricane River systems respectively. During each of these trips, the voltage on each battery bank was measured to determine average power loss over time. Priority was given to maintaining the system without operation gaps due to power shortages. This, coupled with the distance to sites and difficulty of getting batteries to sites, in many cases prevented drawing batteries down to their lowest possible voltages.

Antenna range

The RFID systems were placed at the Hurricane River (46^0 39’ 57.66” N, 86^0 10’ 3.76”W), The Mosquito River (46^0 31’ 33.86” N, 86^0 29’ 37.2”W), and Sevenmile Creek (46^0 37’ 16.28” N, 86^0 15’ 25.75”W) (Figure 2.2). All of these rivers are within Pictured Rocks National Lakeshore, Alger County, MI. Placement of each RFID system in PRNL was chosen based on its proximity to Lake Superior, the structure available for antenna support, and the lack of good holding water where trout could linger indefinitely. A tagged fish remaining in the antenna range can fill a 4 MB data logger in less than half a day. Another concern was antenna size. With increased antenna size, the read range decreases. Optimally a PIT transponder approaches, within a fish, perpendicular to the plane of the antenna. Perpendicular orientation puts the tag's antenna in the best position to pick up and respond to the antenna's power field (Texas Instruments 2000a). As soon as it reaches the range of the electromagnetic field generated by the antenna, it sends its information which is then recorded on the data logger. The read rate, which is the maximum rate at which information is sent (Texas Instruments 2001), sends and receives around 7 times per second at a baud rate setting of 9600 bits per second. Read range was not expected to be the same over the length of the antenna, however. The fields generated by the antennas are lobes pulsing off the wire loop (Figure 2.3). This effect creates different read ranges from the end of the antenna towards the center as well as from the bottom or top of the antenna to the mid line.

To model the range of the antennas at each system, the following protocol was used. Across the length of the antenna, at 0.25 meter intervals, the farthest possible read range from the plane of the antenna was determined at two locations. Point one was at the water surface and point two was on the stream bottom. It is important to note that this is the optimal read range possible. Tag orientation is not considered in detail due to the almost infinite number of positions possible that would create numerous reduced read ranges. The least favorable position is parallel (Figure 2.3) to the antenna and in this orientation, the tag's range can be reduced to almost 0 cm. At Sevenmile Creek and the Mosquito River, I determined the read range using tags parallel to the antenna.

Knowing the range at the water surface and stream bottom across the antenna gives an estimate of read range throughout the water column and along the plane that the antenna cuts across the stream. In addition to this, because it was known that the reader is sending and receiving 7 times per second, it was possible to estimate how many reads (in optimal PIT tag orientation) a tag produces when passing the antenna at different velocities with the formula: (reads/s x read range (m))/passing velocity (m/s). Measurements were made with a PIT tag at optimal positioning, perpendicular to the antenna, and therefore read ranges are a maximum estimate. The tag oriented parallel to the antenna provided the poorest read range with an almost infinite number of positions in between providing intermediate read ranges (Texas Instruments 2000a).

RESULTS

Power supply

The ability of a battery bank to provide power to a stationary RFID system showed little difference between the Hurricane and Mosquito antennas. The Hurricane RFID system, with an antenna loop of 0.5 m x 5.0 m was able to run constantly for 8 days before losing sustainable power to either the reader or data logger. Although there was potential for it to run into the 9th day, this extra day would have completely drained the batteries and resulted in an equipment failure. Additionally complete drawdown of deep cycle batteries is not recommended and shortens the overall life of the battery. For these reasons, the RFID system was not run for this extra day. In a 12 volt deep cycle battery, a reading of 11.2 volts DC is equivalent to 80% drawdown while 10.58 volts DC is 100% drawdown. Eighty percent drawdown prior to recharging is the maximum recommended for long term battery life. The batteries were used to 80 % discharge or less on all weeks recorded for the Hurricane system except for the week of May 29, 2003 and June 7, 2003 (Figure 2.4). During this week, batteries were not changed for 10 days. On May 29, 2003 a newly charged battery bank had 12.8 volts DC. On June 2, 2003, the battery bank was down to 12.24, and when checked 4 days later on June 4, 2003, the system was at

11.82. The next visit was on June 7, 2003 and at this point the bank was down to 8 volts DC and the system was no longer running, the computer logged off at 4:07 AM on June 7, 2003. A point to notice here is the way a bank of batteries discharges power. Over the first four days the voltage loss across the system was only 0.63 vDC. Over the next two days, the system lost 0.38 vDC. The last three days showed the most drastic voltage loss of 4.86 vDC. After reaching 80% discharge, the batteries quickly lost the remaining power supply and the RFID system shut down. In this application, a battery bank was only effective as a power supply at the Hurricane River site for 8 days, the amount of time it took the system to reach approximately 80% draw down of battery power.

The Mosquito River RFID site was a somewhat different situation than the Hurricane River site, differing slightly in size (0.5 m x 5.25 m), and ease of access (more difficult). Power demands seem to be consistent with the findings at the Hurricane River, however. The Mosquito River site provided 3 weeks of power consumption records during the 2003 research season. At times, due to difficulty of access, one battery was substituted to maintain the system until a full three battery bank could be brought in. The Mosquito River system ran for 9 days during two of the trials (Figure 2.5). In the first trial, the batteries were put in place and activated at 17:20 on May 28, 2003. The starting voltage was at 12.8 volts and over the first seven days the system lost only 1.54 vDC. The battery bank read a final voltage of 11.26 DC on June 6, 2004 at 11:00 when it was then replaced. The system lost 0.56 volts on average over the last 2 days. The Mosquito system was run on one battery bank again over the next 9 days with greater power loss (Figure 2.5). This time, at the end of a 9 day trial, the voltage was at 10.19, a difference of 1.07 volts. It should be noted that while the battery bank was below 100% drawdown it was still able to provide power to the reader. During the second trial week, the batteries ran an additional 4.75 hrs, showing again the drastic loss of charge during the last 20% of battery power.

Although no attempts were made to continually monitor the temperature inside the holding box, there was very little change in system run time between May and December of 2003, suggesting that the 10 cm of insulation and the heat produced by the RFID reader were enough to compensate for the cold temperature during this study. The effects of temperature during colder months may be an issue of concern.

Antenna range

For each of the three river sites there were different ranges and antenna lengths, which factored into the read distances obtained. Electronic noise within a similar range to that of the antenna (134.2 kHz) can also affect the performance of an antenna by reducing read range (Texas Instruments 2002), but was not a factor in these remote sites where there were no nearby power sources.

Hurricane River

The Hurricane River was marked off at 0.25 m from the east bank to the west bank, creating 21 points across 5 meters of wire loop. The height of this antenna was 0.5 m. The general trend on the upstream and downstream side of the antenna was a smaller range on the ends of the wire loop that becomes larger towards the center. On both ends, the maximum range was approximately 45 cm and varied very little with depth (2 cm or less). The maximum read range at the water's surface found in the upstream region of the antenna was 87 cm at the 2.5 m mark while that of the downstream side was 75 cm at 2.75 m. At the Hurricane River, at the time of analysis, the maximum depth upstream was 9 cm at both 3.25 and 3.5 m while the downstream depth maximum was 10 cm at 2, 2.5, and 2.75 m. Read ranges measured at the stream bottom tended to be reduced compared to those at the water's surface with a greater disparity towards the antenna's center (Table 2.1). Read range differences over the water column of up to 13 cm were recorded at 2.75 m where the water depth was 7 cm (Figure 2.6). Downstream showed a similar trend in general with a maximum difference of 13 cm seen at 1.5 m where the depth was also 7 cm. The mean difference between surface and bottom was 6.14 cm with a greater read range near the surface (Figure 2.6).

Based on these ranges and the fact that the reader detected approximately 7 reads/second it was possible to estimate the number of reads that should be picked up on the Hurricane antenna at different passing speeds at different points of the antenna. Read ranges for water velocities of 1, 2, and 3 m/s were calculated (Table 2.2). At 1 m/s the Hurricane should pick up between 6-11 records of a passing fish with a greater number of detections towards the center of the antenna. At 3 m/s the range is reduced to 2 to 4 records, again with the larger number of reads away from the shore.

Sevenmile Creek

Results of Sevenmile Creek's antenna range testing (Table 2.3) were comparable to those of the Hurricane River. The Sevenmile Creek antenna was the smallest in width with only 17 points spaced 0.25 m apart (4.25 m) and a height of 0.5 m. Sevenmile Creek, like the Hurricane River, showed smaller read range on the ends of the antenna and larger ranges towards the middle. On the west end of the antenna the read range was recorded at 70 cm upstream and 60 cm downstream at the water's surface while on the east end the range was 46 and 60 respectively. Maximum read ranges at the water's surface were 85 cm upstream at 0.75 and 1.00 m. The downstream maximum was 84 cm at 1.75 m. As at the Hurricane River, depths were measured at the time of read range determination. The maximum depth upstream was 27 cm at 2.75 m while downstream it was 23 cm at 1.25 m. Read ranges again appeared to be affected by depth as they were normally lower in the bottom readings except for several points measured on the downstream end (Figure 2.7). The reasons for this could be due to differences in stream topography or an upstream slant in the antenna.

In addition to using perpendicularly oriented tag readings at Sevenmile Creek, parallel tag orientation approaches to the antenna were also measured (Figure 2.8, Table 2.4). Water currents altering the absolute parallel status of the tag most likely affected the distance of the read range recorded by creating a greater range than would actually exist. However, changing the orientation appears to alter the end to end range as well as the surface and bottom readings in some situations. With a parallel orientation, there was greater range at the ends of the antenna becoming reduced towards the center. On the western outer edge (point 17), the range was 60 cm. The read range dropped to 20 cm at the 1.5 m mark and then returned to 50 cm on the eastern end (point 0). Downstream tag range showed a similar read distance with a range of 43 and 59 cm on the west and east ends respectively and a low range of 18 cm at 2.25 m in the middle. The read range from the bottom mimicked the surface readings with greater read range towards the ends and shorter range in the middle. Additionally, surface and stream bottom readings are less predictable, with the bottom reading often being at a greater distance than at the surface, although this might be due to the difficulty of holding the transponder perfectly parallel at depth.

The estimates for reads at different velocities at the Sevenmile system (Table 2.5) were similar to the Hurricane River's. The range was 7 to 12 reads at 1 m/s with the greater number of reads away from the shore. At 3 m/s the number of detections predicted was reduced to between 2-4 (Table 1.6). These numbers are not realistic in normal use, however, as the tag, which sits lengthwise in the fish's body cavity, would not normally be approaching the antenna perpendicularly, but would instead be moving in some diagonal plane across the antenna thereby extending the amount of time it was in the antenna's range. These values do give some indication of the reduction in the number of records by tag passage in non optimal positions. As shown in Table 2.6, the read range was from 6 to 8 on the corners and as few as 3-4 records in the center at 1 m/s. At the highest speed of 3 m/s, the estimate of records are as low as 2-3 on the corners and only 1 at points in the middle.

Mosquito River

The Mosquito River had the largest antenna with 22 data collection points across 5.25 meters. This antenna also had the most restricted read range of the three systems with detection distances up to 20 cm shorter than that of Hurricane or Sevenmile (Table 2.7). At the water's surface, the read distance ranged from 12 cm to 66 cm upstream with the 12 cm range occurring at the far edge of the antenna on the south side and the 66 cm read occurring at the 2 m mark (Figure 2.9). Downstream detections were between 10 and 54 cm with the same pattern of the smallest occurring on the south shore side, and the largest occurring at 2.25 m. Stream bottom read ranges, as in the other systems, were less than surface readings. The difference between surface and bottom reads upstream of the bridge ranged from 0 to 16 cm, with the 0 on the south side and the 16 cm read occurring at 2 m. The downstream section showed a greater difference between surface and bottom range (0 cm-24 cm). The difference of 24 cm occurred at 1.5 m where the greatest depth of 23 cm was also recorded. At the upstream end of the antenna, the deepest part of the river was at 2.5 and 3.75 m where a depth of 18 cm was recorded on the date of range testing, October 9, 2004. Estimated tag detections were similar to the other two systems (Table 2.8)

DISCUSSION

Power supply

Overall, the results of the battery bank experiments on the Hurricane and Mosquito River systems were similar. Each bank consisting of three batteries connected in series supplied enough energy to provide about eight days of operation for the RFID system. This situation only applies to a well-tuned antenna with a reader unit configured to read at 7 reads per second. The age of the batteries may also become a factor as older batteries lose their ability to hold a charge and thus discharge more quickly. Constant drawdown below 80% will also shorten the life of the batteries and cause them to lose their ability to run for eight days. It might be possible to increase the longevity of a power supply slightly by intentionally detuning the antenna or decreasing the read rate of the system. Both of these actions have obvious drawbacks however. Intentionally detuning the antenna will result in decreased read range, making it questionable as to whether or not it would be advantageous to this application as the priority of this study was to maintain these systems at all times and detect as many fish as possible. Because of this, there was no way to investigate the effects of these actions during our field application without potential negative effects on other portions of the study. Reducing the read rate of the system also presents the potential to miss more tags. In this situation, although the read range of the antenna is not shortened, the number of times the reader unit is sending and listening for tag signals is decreased. The only way to realistically increase the longevity of the power supply is to augment the system with an alternative power source, such as solar panels, which would allow the system to run at optimal configuration (high read rate, fully tuned antenna) while still providing a greater amount of run time for the system. Solar panels were added to the PRNL sites during 2004 and appear to have significantly increased the run time capabilities of the RFID systems to the point where the batteries only need replacement rarely, if at all, during the summer months (data not shown).

Antenna range

Read range is affected by external noise (electrical), the quality of the antenna, and antenna size. In Pictured Rocks National Lakeshore there was effectively no electrical noise and wire quality was not an issue. The major factor affecting our systems' read ranges was antenna size. While a larger antenna produced a stronger field that could potentially detect tags at a greater distance than a smaller antenna, the transponder's weak response as well as the large antenna's ability to detect more background noise can actually create a smaller read range (Texas Instruments 2000b). This might explain some of the greater read range of the smaller antennas at the Hurricane River and Sevenmile Creek over the Mosquito system.

All three systems showed basic similarities regardless of tag orientation. When tag orientation was perpendicular, (optimal), the read range was greatest in the center extending to within a meter of the sides. Towards the vertical sides of the antenna, the read range decreased. When tags were placed parallel to the field of the antenna, read ranges were drastically reduced in the center. If kept perfectly parallel in relation to the antenna, the range was reduced, showing less than half the read range (15-30 cm) compared to 60-80 cm in other orientations. This range increased towards the vertical sides of the antenna to 30-50 cm, exactly opposite of the previous range testing. Between the perpendicular and parallel orientations are indeterminate tag positions where the read range will fall between the two tested ranges. Although read range is reduced when the tag orientation is not perpendicular, in theory a tagged fish is forced to remain within the field of the antenna for a longer period of time. When inserted, 23 mm PIT tags lie lengthwise along the head to tail axis of the brook trout. This means that when swimming upstream or downstream, the tag will remain in its optimal position when approaching the antenna. Otherwise, the fish would have to swim diagonal to the antenna, exposing itself to a greater area of the antenna's shortened range. On the other hand, a fish would have to drift downstream sideways in order to trigger the smallest possible tag read range, a feat that, though possible, is hydrodynamically and biologically unlikely. A fish positioned parallel to the antenna would also be moving at most at the maximum speed of the water, unlike downstream swimming fish which could be moving considerably faster.

Depth can also affect read range distance. The field generated by the antenna is not evenly distributed. It pulses in lobes (Texas Instruments 2000a) that are smaller towards the sides and on the sections closest to the stream bottom when the tag approaches a perpendicular configuration. In the three PRNL systems, there was only a small difference in read range between the water surface and the stream bottom. The greatest differences were generally seen in areas where the water was the deepest in the Mosquito system. In the Mosquito River system, the greatest disparity between surface and bottom read ranges occurred at the 1.5 and 1.75 m points. Here the depths were 22 and 23 cm and the read range was 24 and 23 cm greater at the surface. Both Sevenmile and Hurricane systems also showed a smaller read range on the bottom compared to the surface, although not the depth related decrease as was shown in the Mosquito River.

While it appears that depth may play a role in the read range of an antenna, it is not creating a large discrepancy between the surface and bottom reads in these shallow systems.

RFID systems can be used as effective migratory fish monitoring devices in remote areas of Michigan’s Upper Peninsula. Two of the main concerns are power supplies and antenna size. The size and weight of the power source must be based not only on cost, but on how far from the RFID system replacements must be carried. Deep cycle batteries were effective for eight days at the PRNL sites and a bank of three was all that could reasonably be carried in once per week. Antenna size is limits to read range, but in the small streams of PRNL, it is possible to cover virtually the entire stream width while still having a range that can effectively detect fish moving at speeds of up to 3 m/s. The fact that these systems run continuously while powered, do not create a barrier to migration for fish, and are relatively inexpensive to install, make the RFID antennas effective as migratory fish monitors in Lake Superior tributaries.

Table 2.1: The maximum read range (cm) upstream and downstream of the Hurricane River RFID system measured at the water's surface and at stream bottom. PRNL, MI 2004.

	Upstream range data				**Downstream range data**				**Total range**	
Antenna Point (m)	**Surface (cm)**	**Bottom (cm)**	**Difference (cm)**	**Depth (cm)**	**Surface (cm)**	**Bottom (cm)**	**Difference (cm)**	**Depth (cm)**	**Max range (cm)**	**Max range (cm)**
0.00	49	49	0	3	45	43	2	2	94	92
0.25	81	72	9	5	60	49	11	4	141	121
0.50	83	81	2	7	60	53	7	5	143	134
0.75	86	81	5	5	64	55	9	5	150	136
1.00	83	83	0	3	63	55	8	4	146	138
1.25	85	79	6	4	65	56	9	5	150	135
1.50	85	72	13	6	68	55	13	7	153	127
1.75	83	72	11	7	70	58	12	7	153	130
2.00	85	75	10	6	71	64	7	10	156	139
2.25	85	76	9	6	72	64	8	9	157	140
2.50	87	76	11	5	72	64	8	10	159	140
2.75	85	72	13	7	75	66	9	10	160	138
3.00	86	76	10	7	71	66	5	8	157	142
3.25	82	75	7	9	70	65	5	8	152	140
3.50	80	76	4	9	67	63	4	8	147	139
3.75	80	73	7	7	68	62	6	6	148	135
4.00	75	75	0	7	70	64	6	4	145	139
4.25	72	71	1	5	71	67	4	3	143	138
4.50	72	72	0	5	67	67	0	3	139	139
4.75	63	60	3	5	61	56	5	3	124	116
5.00	40	41	0	3	43	43	0	1	83	84

Table 2.2: Estimates of tag detections for the Hurricane River stationary RFID system at different passing speeds based on recorded read range. PRNL, MI 2004.

	1 meters/second		**2 meters/second**		**3 meters/second**	
Antenna Point (m)	**Surface Reads**	**Bottom reads**	**Surface reads**	**Bottom reads**	**Surface Reads**	**Bottom reads**
0.00	7	6	3	3	2	2
0.25	10	8	5	4	3	3
0.50	10	9	5	5	3	3
0.75	11	10	5	5	4	3
1.00	10	10	5	5	3	3
1.25	11	9	5	5	4	3
1.50	11	9	5	4	4	3
1.75	11	9	5	5	4	3
2.00	11	10	5	5	4	3
2.25	11	10	5	5	4	3
2.50	11	10	6	5	4	3
2.75	11	10	6	5	4	3
3.00	11	10	5	5	4	3
3.25	11	10	5	5	4	3
3.50	10	10	5	5	3	3
3.75	10	9	5	5	3	3
4.00	10	10	5	5	3	3
4.25	10	10	5	5	3	3
4.50	10	10	5	5	3	3
4.75	9	8	4	4	3	3
5.00	6	6	3	3	2	2

Table 2.3: The maximum read range (cm) upstream and downstream of Sevenmile Creek RFID system taken at the water's surface and at stream bottom with the transponder perpendicular to the antenna plane. PRNL, MI 2004.

	Upstream range data				**Downstream range data**				**Total range**	
Antenna Point (m)	**Surface (cm)**	**Bottom (cm)**	**Difference (cm)**	**Depth (cm)**	**Surface (cm)**	**Bottom (cm)**	**Difference (cm)**	**Depth (cm)**	**Max range (cm)**	**Max range (cm)**
0.00	70	70	0	1	60	60	0	11	130	130
0.25	80	80	0	15	73	70	3	17	153	150
0.50	82	80	2	18	80	66	14	20	162	146
0.75	85	76	9	17	79	70	9	22	164	146
1.00	85	85	0	17	81	72	9	20	166	157
1.25	80	82	-2	15	82	77	5	23	162	159
1.50	80	79	1	15	81	73	8	24	161	152
1.75	83	78	5	17	84	77	7	20	167	155
2.00	80	78	2	17	81	71	10	15	161	149
2.25	83	83	0	21	82	65	17	20	165	148
2.50	79	70	9	23	77	69	8	18	156	139
2.75	79	79	0	27	79	50	29	20	158	129
3.00	79	73	6	24	83	78	5	16	162	151
3.25	76	74	2	22	81	78	3	16	157	152
3.50	74	65	9	18	82	70	12	18	156	135
3.75	66	60	6	14	67	62	5	12	133	122
4.00	46	32	14	6	60	53	7	14	106	85

Table 2.4: The maximum read range (cm) upstream and downstream of Sevenmile Creek RFID system measured at the water's surface and at stream bottom with the transponder parallel to the antenna plane. PRNL, MI 2004.

	Upstream range data				**Downstream range data**				**Total range**	
Antenna Point (m)	**Surface (cm)**	**Bottom (cm)**	**Difference (cm)**	**Depth (cm)**	**Surface (cm)**	**Bottom (cm)**	**Difference (cm)**	**Depth (cm)**	**Max range (cm)**	**Max range (cm)**
0.00	60	60	0	1	43	43	0	11	120	86
0.25	40	36	4	15	36	24	12	17	76	60
0.50	29	23	6	18	28	31	-3	20	52	59
0.75	36	30	6	17	15	28	-13	22	66	43
1.00	23	13	10	17	27	20	7	20	36	47
1.25	22	19	3	15	30	28	2	23	41	58
1.50	20	19	1	15	22	22	0	24	39	44
1.75	30	27	3	17	25	23	2	20	57	48
2.00	28	22	6	17	25	37	-12	15	50	62
2.25	25	30	-5	21	18	28	-10	20	55	46
2.50	22	29	-7	23	24	27	-3	18	51	51
2.75	23	30	-7	27	19	23	-4	20	53	42
3.00	31	40	-9	24	25	25	0	16	71	50
3.25	27	32	-5	22	23	31	-8	16	59	54
3.50	23	21	2	18	29	37	-8	18	44	66
3.75	41	28	13	14	51	53	-2	12	69	104
4.00	50	50	0	6	59	59	0	14	100	118

Table 2.5: Estimates of tag detections for the Sevenmile Creek stationary RFID system at different passing speeds (perpendicular tag orientation) based on recorded read range. PRNL, MI 2004.

	1 meter/second		**2 meters/second**		**3 meters/second**	
Antenna Points (m)	**Surface Reads**	**Bottom Reads**	**Surface reads**	**Bottom reads**	**Surface reads**	**Bottom reads**
0.00	9	9	5	5	3	3
0.25	11	11	5	5	4	4
0.50	11	10	6	5	4	3
0.75	11	10	6	5	4	3
1.00	12	11	6	5	4	4
1.25	11	11	6	6	4	4
1.50	11	11	6	5	4	4
1.75	12	11	6	5	4	4
2.00	11	10	6	5	4	3
2.25	12	10	6	5	4	3
2.50	11	10	5	5	4	3
2.75	11	9	6	5	4	3
3.00	11	11	6	5	4	4
3.25	11	11	5	5	4	4
3.50	11	9	5	5	4	3
3.75	9	9	5	4	3	3
4.00	7	6	4	3	2	2

Table 2.6: Estimates of tag detections for the Sevenmile Creek stationary RFID system at different passing speeds (parallel tag orientation) based on recorded read range. PRNL, MI 2004.

	1 meter/second		**2 meters/second**		**3 meters/second**	
Antenna Point (m)	**Surface Reads**	**Bottom reads**	**Surface reads**	**Bottom Reads**	**Surface reads**	**Bottom reads**
0.00	8	6	4	3	3	2
0.25	5	4	3	2	2	1
0.50	4	4	2	2	1	1
0.75	5	3	2	2	2	1
1.00	3	3	1	2	1	1
1.25	3	4	1	2	1	1
1.50	3	3	1	2	1	1
1.75	4	3	2	2	1	1
2.00	4	4	2	2	1	1
2.25	4	3	2	2	1	1
2.50	4	4	2	2	1	1
2.75	4	3	2	1	1	1
3.00	5	4	2	2	2	1
3.25	4	4	2	2	1	1
3.50	3	5	2	2	1	2
3.75	5	7	2	4	2	2
4.00	7	8	4	4	2	3

Table 2.7: The maximum read range upstream and downstream of the Mosquito River RFID system measured at the water's surface and at stream bottom. PRNL, MI 2004.

	Upstream range data				**Downstream range data**				**Total range**	
Antenna Point (m)	**Surface (cm)**	**Bottom (cm)**	**Difference (cm)**	**Depth (cm)**	**Surface (cm)**	**Bottom (cm)**	**Difference (cm)**	**Depth (cm)**	**Max range (cm)**	**Max range (cm)**
0.00	12	12	0	0	10	10	0	1	22	22
0.25	42	42	0	1	34	34	0	4	76	76
0.50	46	45	1	2	43	40	3	5	89	85
0.75	53	51	2	4	45	41	4	5	98	92
1.00	57	55	2	5	46	40	6	7	103	95
1.25	60	52	8	5	49	36	13	19	109	88
1.50	62	52	10	9	53	29	24	22	115	81
1.75	65	54	11	12	55	32	23	23	120	86
2.00	66	50	16	14	52	40	12	21	118	90
2.25	60	50	10	11	54	40	14	17	114	90
2.50	58	47	11	18	53	39	14	16	111	86
2.75	62	50	12	8	49	42	7	15	111	92
3.00	57	51	6	8	51	42	9	12	108	93
3.25	62	54	8	11	48	40	8	15	110	94
3.50	61	49	12	12	46	36	10	9	107	85
3.75	61	46	15	18	46	34	12	8	107	80
4.00	54	50	4	15	42	41	1	3	96	91
4.25	59	51	8	15	45	41	4	4	104	92
4.50	56	52	4	8	43	37	6	5	99	89
4.75	57	53	4	9	44	37	7	4	101	90
5.00	56	45	11	6	35	33	2	3	91	78
5.25	14	14	0	1	15	15	0	1	29	29

Table 2.8: Estimates of tag detections for the Mosquito River stationary RFID system at different passing speeds based on recorded read range. PRNL, MI 2004.

	1 meter/ second		**2 meters/ second**		**3 meters/ second**	
Antenna Point (m)	**Surface Reads**	**Bottom reads**	**Surface reads**	**Bottom reads**	**Surface reads**	Bottom reads
0.00	2	2	1	1	1	1
0.25	5	5	3	3	2	2
0.50	6	6	3	3	2	2
0.75	7	6	3	3	2	2
1.00	7	7	4	3	2	2
1.25	8	6	4	3	3	2
1.50	8	6	4	3	3	2
1.75	8	6	4	3	3	2
2.00	8	6	4	3	3	2
2.25	8	6	4	3	3	2
2.50	8	6	4	3	3	2
2.75	8	6	4	3	3	2
3.00	8	7	4	3	3	2
3.25	8	7	4	3	3	2
3.50	7	6	4	3	2	2
3.75	7	6	4	3	2	2
4.00	7	6	3	3	2	2
4.25	7	6	4	3	2	2
4.50	7	6	3	3	2	2
4.75	7	6	4	3	2	2
5.00	6	5	3	3	2	2
5.25	2	2	1	1	1	1

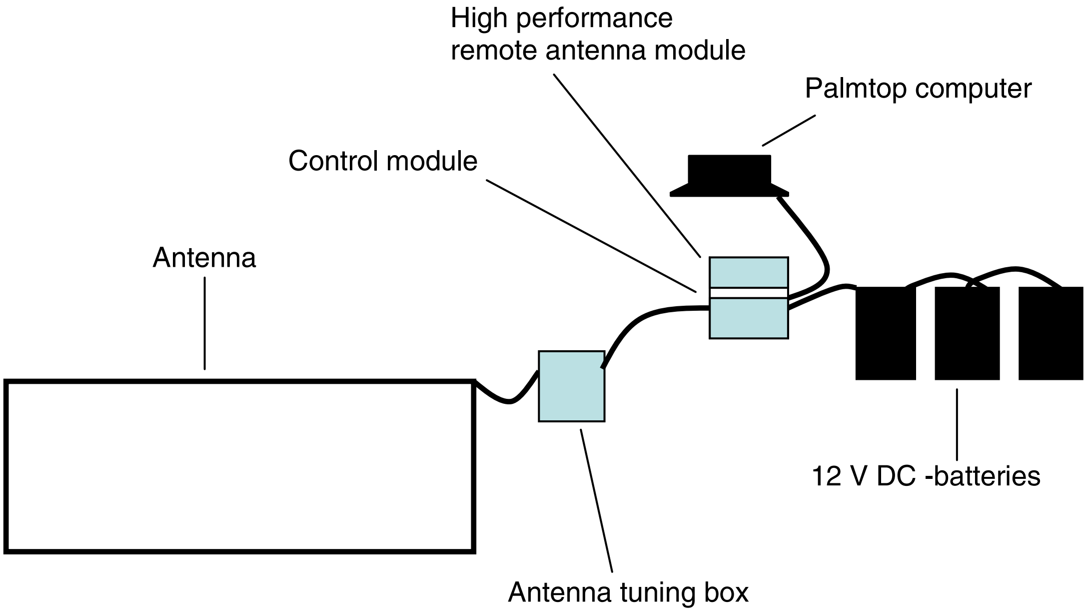


Figure 2.1: Layout diagram of RFID system with all components as placed in PRNL tributaries 2003-2004.

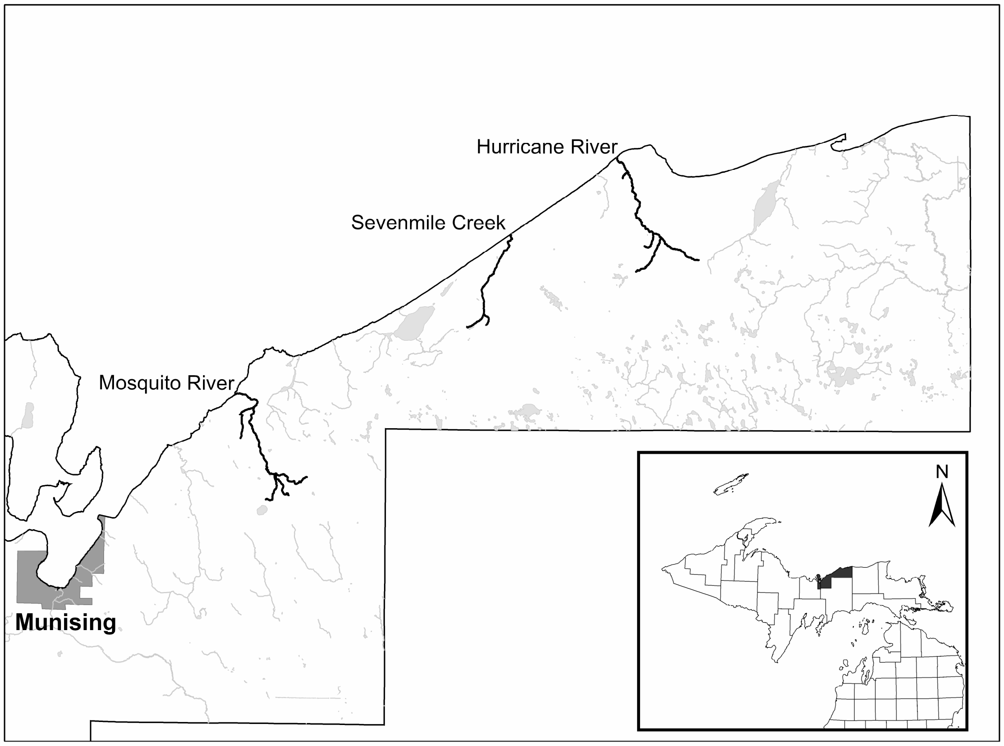


Figure 2.2: Location of the three principle study streams within Pictured Rocks National Lakeshore, MI 2003-2004.

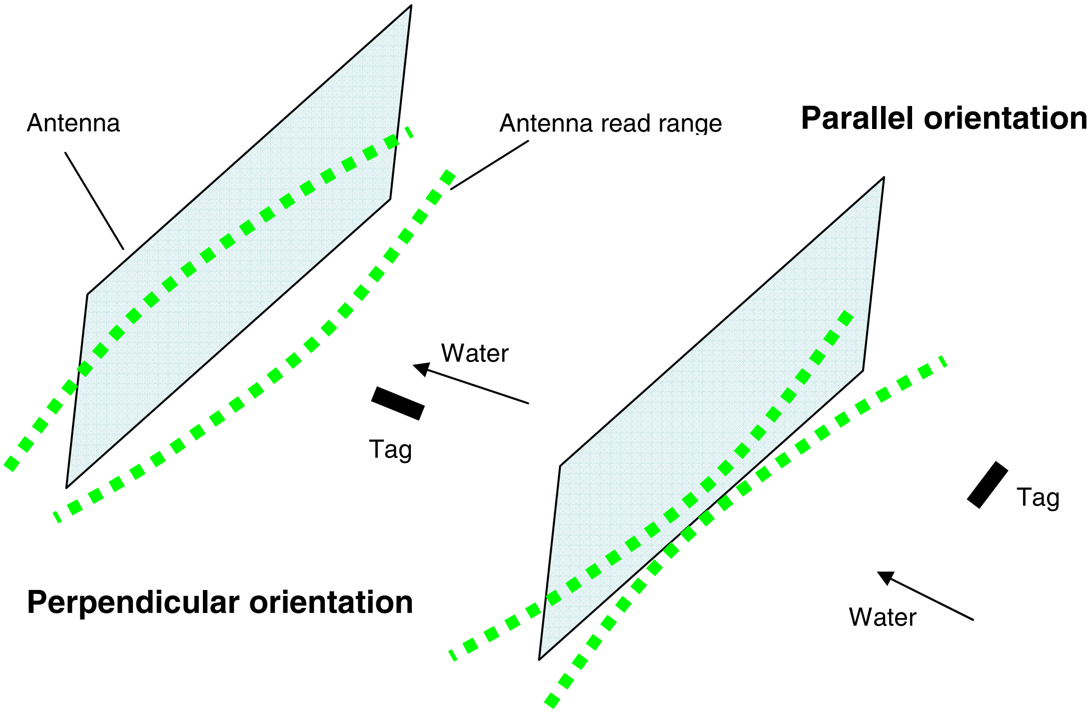


Figure 2.3: Antenna range configuration of RFID transponders (tag) approaching at two different orientations.

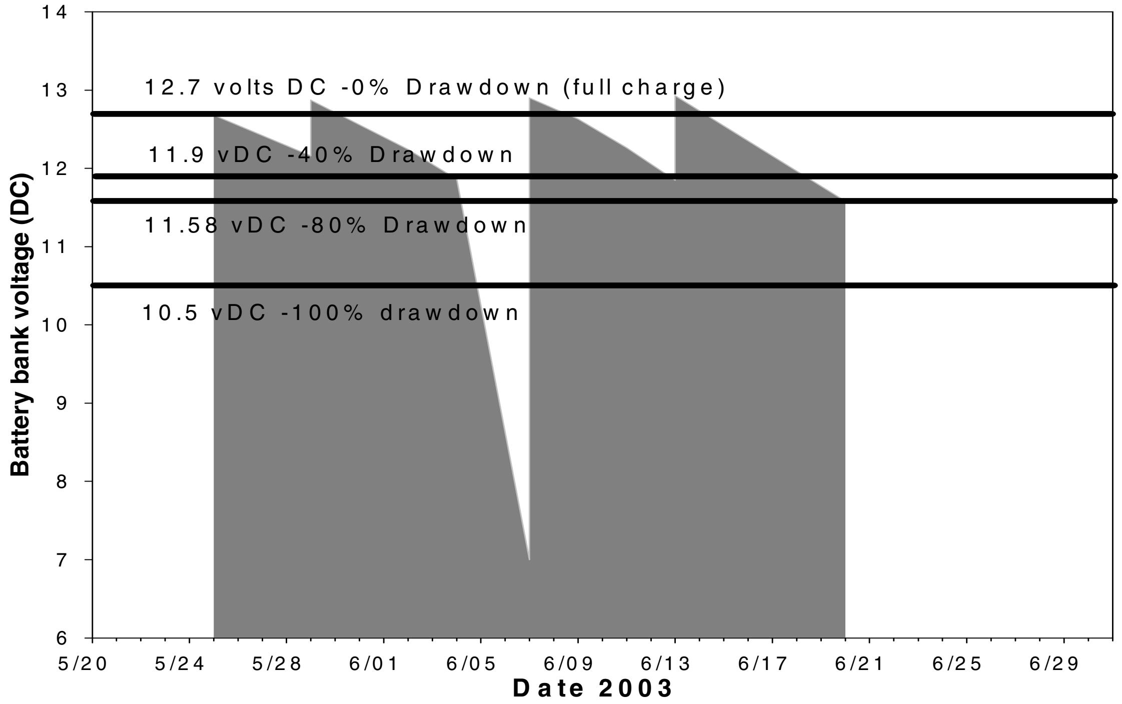


Figure 2.4: Hurricane River RFID system voltage loss between May 25, 2003 and June 27, 2003. PRNL, MI

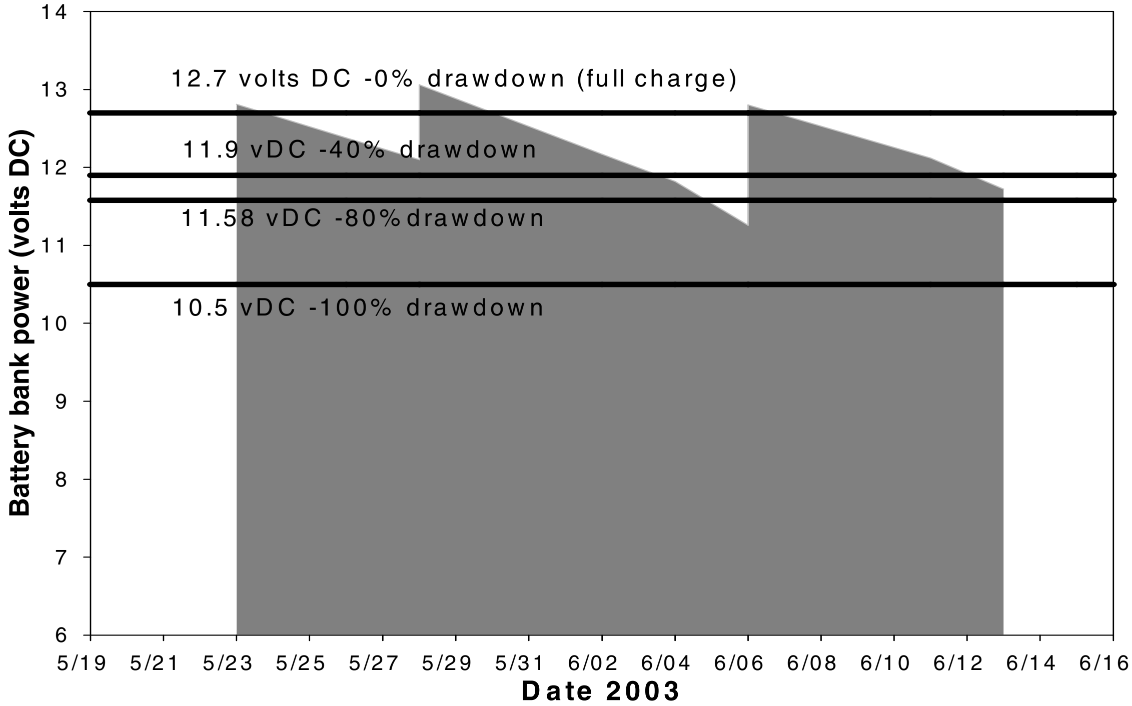


Figure 2.5: Mosquito River RFID system voltage loss between May 19, 2003 and June 15, 2003. PRNL, MI.

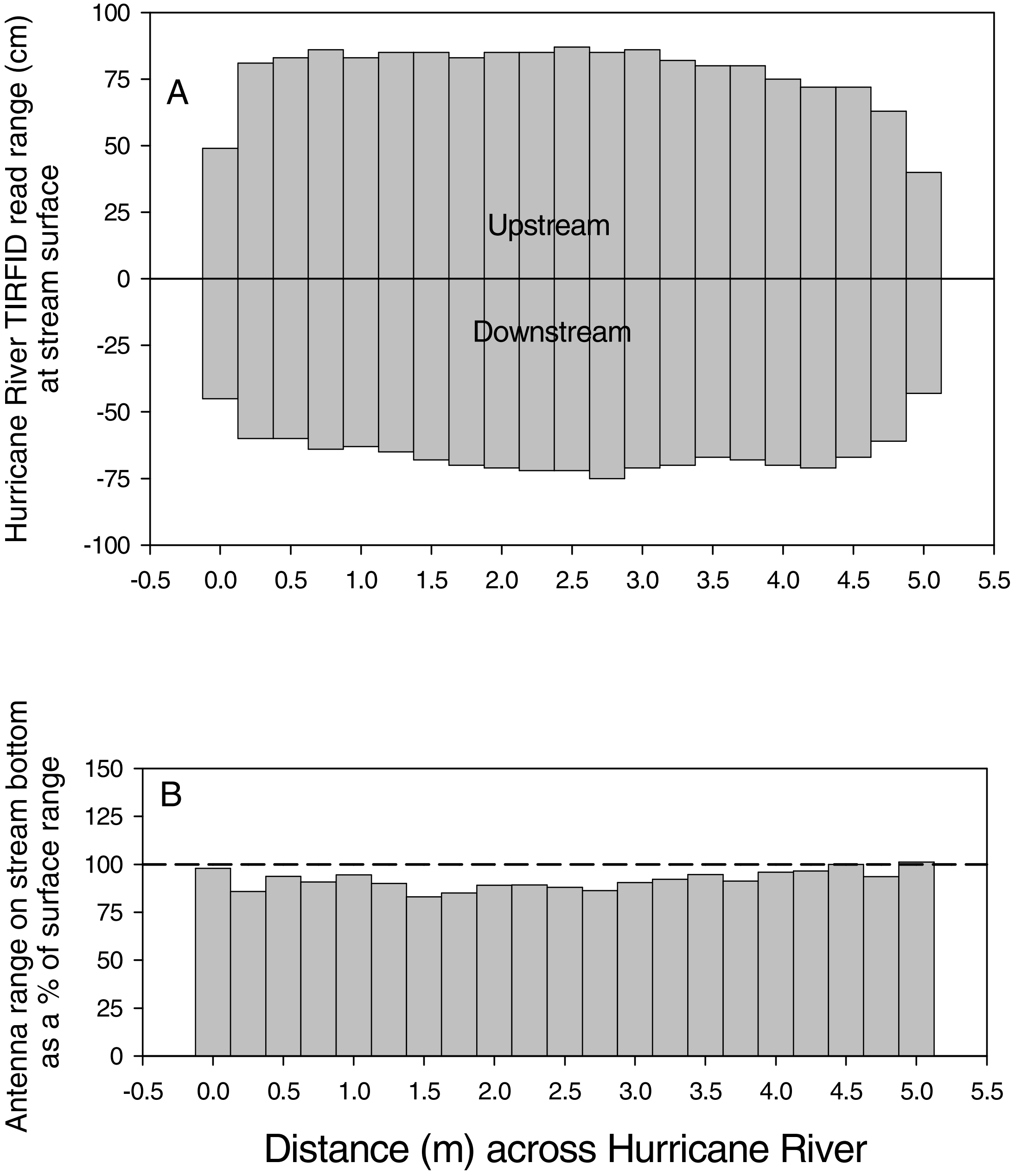


Figure 2.6: Hurricane River antenna read range (■) in centimeters at the water surface upstream and downstream from the antenna (▬) (A), as well as the bottom range (■) shown as a percentage of the surface range (— —) (B). PRNL, MI 2004.

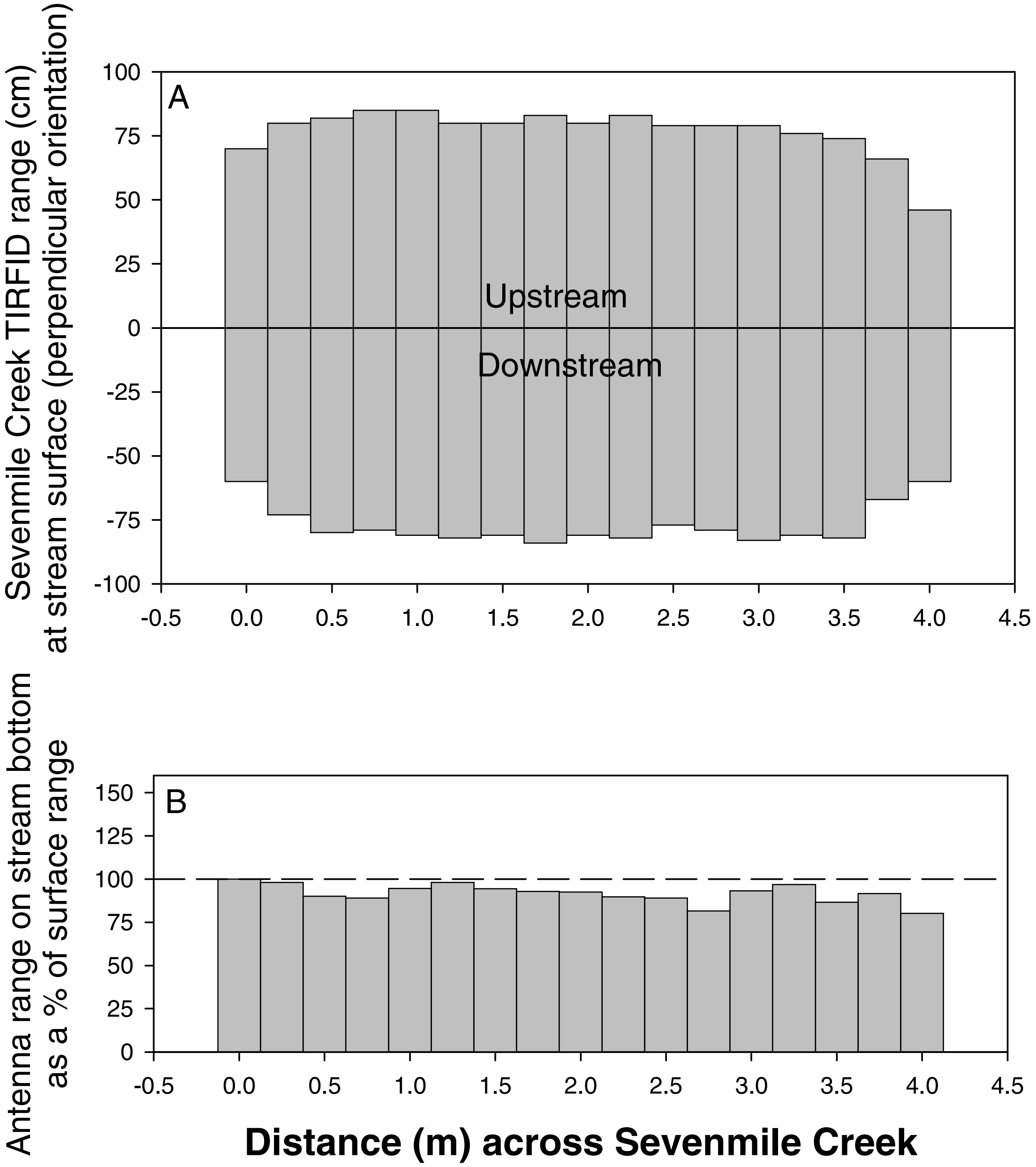


Figure 2.7: Sevenmile Creek RFID antenna read range (■) in centimeters (for tags perpendicular to the antenna) at the water surface upstream and downstream from the antenna (—) (A), as well as the bottom range (■) shown as a percentage of the surface range (– –) (B). PRNL, MI 2004.

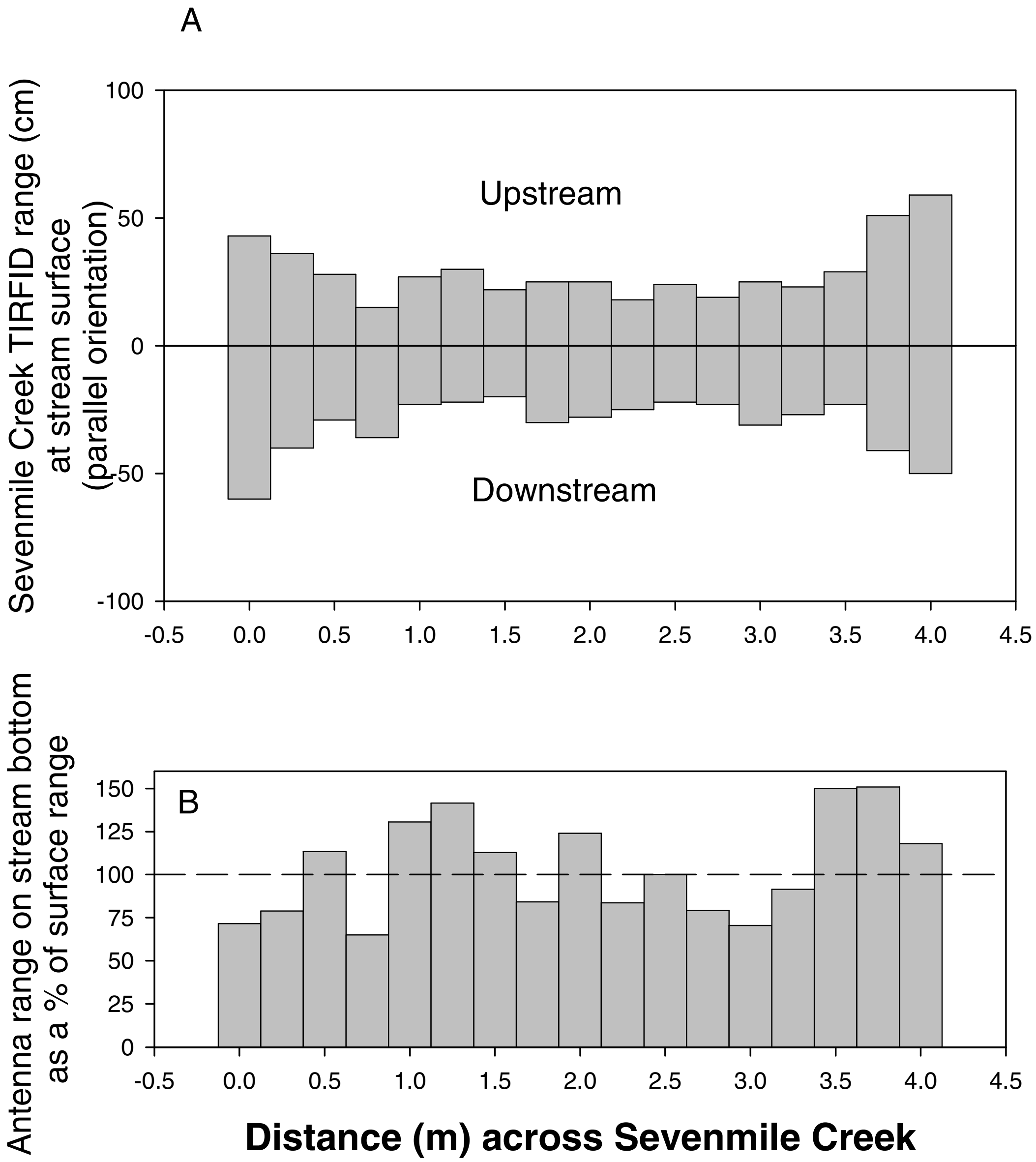


Figure 2.8: Sevenmile Creek RFID antenna read range (▨) in centimeters (for tags parallel to the antenna) at the water surface upstream and downstream from the antenna (—) (A), as well as the bottom range (▨) shown as a percentage of the surface range (– –) (B). PRNL, MI 2004.

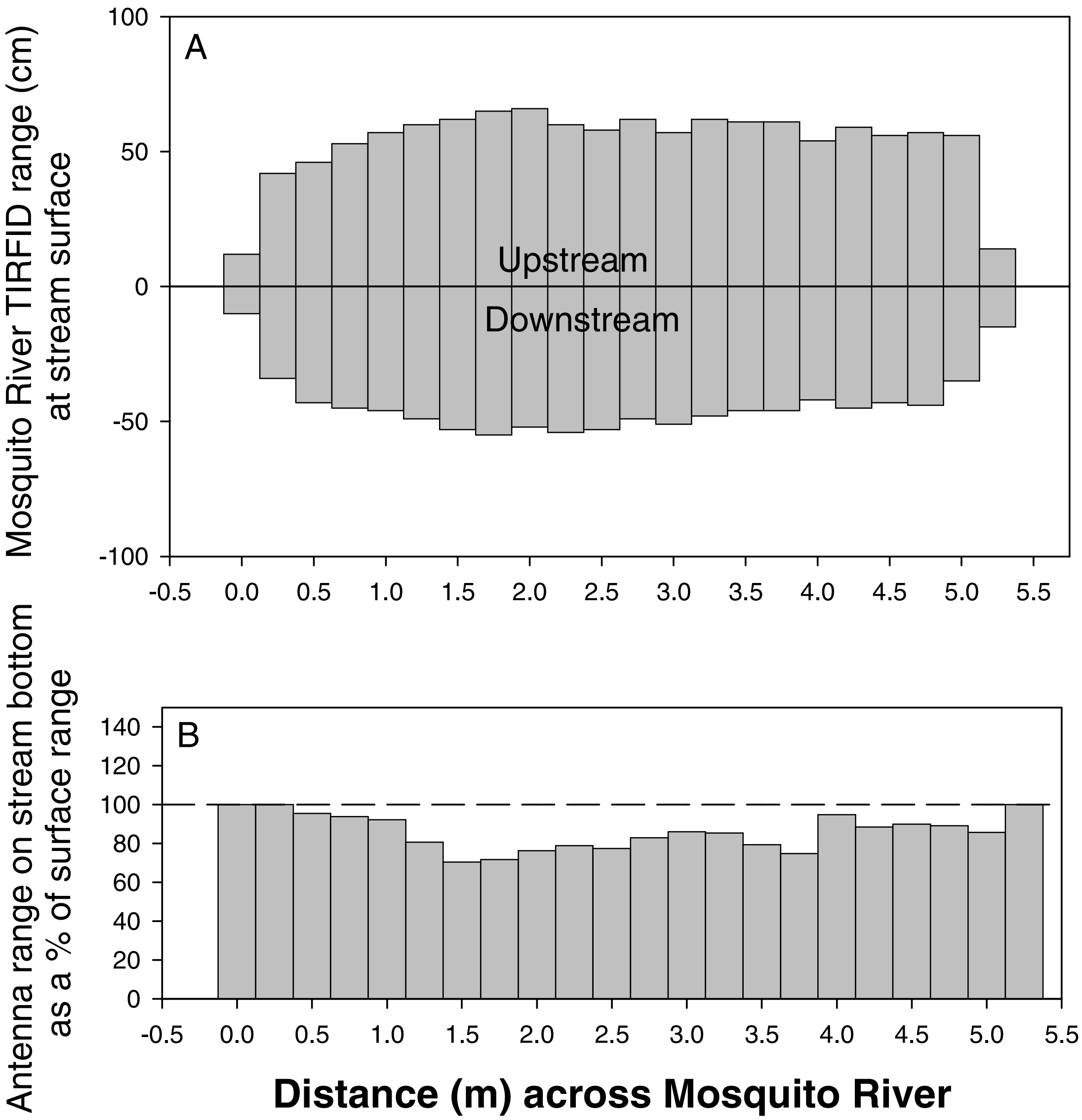


Figure 2.9: Mosquito River antenna read range (■) in centimeters at the water surface upstream and downstream from the antenna (▬) (A), as well as the bottom range (■) shown as a percentage of the surface range (– –) (B). PRNL, MI 2004.

CHAPTER 3: MIGRATORY TIMING IN TWO STRAINS OF BROOK TROUT (*SALVELINUS FONTINALIS)* IN THREE RIVERS IN PICTURED ROCKS NATIONAL LAKESHORE, MI.

CHAPTER SUMMARY

Three tributaries of Lake Superior in Pictured Rocks National Lakeshore (PRNL), MI are currently being stocked with brook trout (Salvelinus fontinalis) of Tobin Harbor (Isle Royale, MI) strain in an effort to restore migratory 'coaster' populations. Little is known about the biology of coasters including the timing of migratory movements between Lake Superior and river habitats. Using stationary RFID antenna systems and PIT tagging, the activity of both Tobin Harbor (TBH) and Pictured Rocks (PRNL) strain brook trout (N_{2003}=214, N_{2004}= 968), tagged near the mouth of these rivers from May to December 2003 and May to August 2004, was monitored. Increased activity of fish at the antennas was assumed to indicate migratory movement. Brook trout movements occurred in low numbers at all three tributaries with the majority of the activity occurring in late spring and fall of 2003 and spring of 2004. Movements of wild/feral fish were correlated with photoperiod differential (hours from the yearly mean; p=0.002) in 2003. Data from 2004 showed photoperiod differential to be correlated with hatchery (cc=-0.328, p=0.000) and feral TBH fish movements (cc=0.270, p= 0.002). Cumulative photoperiod and water temperature were also correlated with movement in Sevenmile Creek during 2004. In addition, some fish were detected at two different rivers, demonstrating movement between streams by brook trout.

INTRODUCTION

Migratory brook trout (*Salvelinus fontinalis*) populations have been documented in the scientific literature for many years. Weed (1934) described a sea-run form of brook trout found in Labrador, Canada. The migratory behavior of these brook trout, popularly known as salters, was documented in many other rivers in the following decades (Bigelow and Schroeder 1953, Smith and Saunders 1958, Montgomery et al 1990). Although all salters migrate to the ocean or brackish water, populations show different strategies. The sea-run brook trout of Quebec moved out of freshwater in the spring and spent the summer months in salt water before returning in the fall (Castonguay et al. 1982, Montgomery et al 1990). In contrast, the brook trout of Cape Cod, MA left freshwater streams in the fall and spent the winter months in salt water (Bigelow and Schroeder 1953). Between these two extremes lie populations such as those studied by Smith and Saunders (1958) where trout moved in and out of a small stream throughout the year.

Migration of brook trout is not restricted to those populations with access to the ocean. Several lake and stream populations of brook trout contain segments that are migratory and, like their sea-run counterparts, they display a wide variety of strategies. There are brook trout that live in lakes, but migrate to lake outlets for spawning (Josephson and Youngs 1996, Baril and Magnan 2002). Others live and spawn in lakes, but the juveniles migrate to stream outlets soon after hatching (Curry et al 1997). Many of Lake Superior's tributaries once held migrant brook trout. The fish were termed 'coasters' based on their habit of cruising in shallow water near the shoreline. More recent analyses have subdivided coasters based on life history patterns. Lacustrine coasters, like those of Tobin Harbor (Isle Royale, MI), live their entire lives within Lake

Superior, while adfluvial coasters, like those of the Salmon Trout River (MI) and Nipigon Bay (Ontario, Canada), migrate to the lake after living for a period of time in nursery tributaries (Dr. Casey Huckins, Michigan Technical University, personal communication 2002) Coaster brook trout were famous for reaching large sizes and were prized as a sport fish. According to Roosevelt (1865), by the 1800's coasters were already becoming rare in Lake Superior. By the mid-20th century they had nearly disappeared from Lake Superior tributaries. A few less exploited populations survived on the north shore of the lake, but those on the south shore did not fare as well. Only two natural populations on Isle Royale, MI and one in the Salmon Trout River, MI still exist in the U.S. waters of Lake Superior.

Since 1997, the U.S. Fish and Wildlife Service, the Michigan Department of Natural Resources (MI DNR) and the National Park Service have been attempting to restore coaster populations to three rivers located in Pictured Rocks National Lakeshore (PRNL; Alger County, MI). Stocking of hatchery-raised Tobin Harbor (coaster) strain brook trout occurred in 1997 and has continued annually since 2000. Additionally, new fishing regulations limiting creel and increasing legal size for the possession of brook trout have been set in Lake Superior and its tributaries in PRNL (Michigan Department of Natural Resources, 2005). However, recent attempts to restore coaster populations in PRNL may have been hampered by a lack of basic information. The ability to determine when fish will migrate is limited not only by the lack of scientific data on coasters, but also by the inherent variability found in brook trout migrations throughout their range. If timing of migration is unknown, then it is impossible to determine what factors are driving movements, making conservation potentially difficult. There also appear to be several possible cues that trigger movement in the species. Brook trout migrating to an estuary in Prince Edward Island, Canada exhibited a connection between movement, temperature, and changing water levels (Smith and Saunders 1958). Castonguay et al (1982) found a relationship between water temperature and upstream movement of anadromous brook trout. Montgomery et al. (1983) and Josephson and Youngs (1995) found that downstream movement of brook trout to estuarine waters occurred during decreasing flows soon after high water peaks during spring runoff. Movements of brook trout in the Moise River, Canada related to discharge in that returning adults appeared to move into the river with easier access provided by higher flows or tides (Montgomery et al 1990). Photoperiod is known to be an environmental cue in the upstream migration of salmonids (Thorpe 1989, Quinn and Adams 1996), but has not been well documented in the Salvelinus genus. McCormick and Naimen (1984) did observe anadromous male brook trout becoming less sea-water tolerant during the autumn photoperiod normally associated with spawning.

In PRNL, there are now at least two different strains of brook trout in the Mosquito River, Hurricane River, and Sevenmile Creek. These strains consist of the Tobin Harbor planted fish and the wild fish (defined as any local brook trout showing no fin clips and therefore determined to have been of local origin). The objective of this portion of the study was twofold: 1) To determine the seasonal timing of brook trout movements between stream habitats and Lake Superior and 2) to determine if photoperiod, water temperature, and rainfall influence the brook trout movements. Information regarding the migratory habits of brook trout potentially provides a window into the origins of anadromy in salmonid fishes. Charr, a relatively primitive migratory genus within Salmonidae, may be displaying migratory behavior ancestral to the anadromy that occurs in other genera such as Salmo and Oncorhynchus. Thus, determining the migratory timing of these brook trout is not only useful in determining how to manage coaster populations, but also as a way of examining the mechanisms that may have led to the evolution of anadromy in salmonids.

METHODS

Study Sites

Three study tributaries of Lake Superior in PRNL had Texas Instruments Radio Frequency Identification (RFID) systems installed near the river mouths. Each river has been designated by the National Park Service (NPS) and its partners as a target for coaster brook trout population restoration and has been stocked with Tobin Harbor (TBH) strain fingerlings, fall yearlings, or spring yearlings since 1997
(Lora Loope, National Parks Service, personal communication 2004). All three of these systems are thought to have once sustained coaster brook trout populations (Baker et al 1999).

The Hurricane River is the easternmost study river in PRNL (46^0 39’ 57.66” N, 86^0 10’ 3.76”W) (Figure 3.1). The Hurricane River is a second order tributary starting approximately 258 m above sea level and ending at Lake Superior (197 m above sea level). For the majority of its length, the Hurricane runs through mixed northern hardwoods. The mouth of the river is about 16.3 km west of Grand Marais, MI and 9.21 km from the next nearest rehabilitation river, Sevenmile Creek. The river has a waterfall (sloping approximately 2 m) 180 m from the mouth that may block upstream fish passage for part of the year. In addition to stocked TBH brook trout, there are also naturally occurring wild brook trout in this river. Other salmonids found in this river are splake (brook trout/lake trout hybrid) and naturalized populations of coho salmon

(*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*). Non-salmonid species occurring in this river include longnose dace (*Rhynichthys cataractae*), longnose suckers (*Catostomus catostomus*), spawning and juvenile burbot (*Lota lota*), and mottled sculpin (*Cottus bairdi*). The RFID antenna was set up 77 m from the mouth of the river using a walking trail bridge to support the wire loop. The river at this point, measured at low water in August 2002, was 6.5 m wide and 20 cm at its deepest point. For this study, the stationary RFID system was run from May 15, 2003 through Dec. 18, 2003, and April 24, 2004 through Aug. 31, 2004.

Sevenmile Creek is located toward the center of PRNL (46^0 37’ 16.28” N, 86^0 15’ 25.75”W), 9.21 km west from the Hurricane River and 24 km east of the Mosquito River (Figure 3.1). Sevenmile Creek runs approximately 7.1 km from Sevenmile Lake to Lake Superior with no apparent natural barriers to upstream migration except dams and impoundments created by beavers (*Castor canadensis*), which are not likely to be complete barriers to fish passage. Sevenmile Creek is also a second order stream, originating 282 m above sea level, running through mixed northern hardwoods to its mouth at Lake Superior. In addition to wild and TBH stocked brook trout, this system also maintains populations of steelhead, coho salmon, and pink salmon (*O. gorbuscha*). Occasionally splake and brown trout (*Salmo trutta*) are found near the mouth. Other species found in Sevenmile Creek during the study were longnose suckers, mottled sculpins, burbot, and longnose dace. The RFID system at this site is located anywhere from 92 to 189 m from Lake Superior as the river mouth continually shifts across the sand and gravel of a beach throughout the year. This system was put in place Sept. 26, 2003 and ran until Dec. 20, 2003 and from May 5, 2004 until Aug. 31, 2004.

The Mosquito River lies furthest west of the three study sites (46^0 31’ 33.86” N, 86^0 29’ 37.2”W). The river is located about 18.2 km east of Munising, MI and 24 km from Sevenmile Creek (Figure 3.1). The Mosquito is a third order tributary originating at 282 m above sea level at a waterfall which presents a barrier to further upstream migration. The river runs 3 km through mixed northern hardwoods to Lake Superior. Along with both hatchery and wild brook trout, this river is also inhabited by steelhead trout and some coho salmon. Splake are occasionally found in this system as well. Other species found include: mottled sculpin, central mudminnow (*Umbra limi*), brook stickleback (*Culaea inconstans*), blacknose dace (*Rhinichthys atratulus*), and the northern redbelly dace (*Phoxinus eos*). The RFID system is located at a walking path bridge over the river 135 m from the mouth. The PIT antenna ran from May 23 to Dec. 22 in 2003 and May 8 to August 31 in 2004.

All three of these rivers are open to fishing for salmonids although regulations were modified in 2002 to manage coasters. Because coasters are thought to delay spawning until a later age and greater size to maximize fecundity and competitive abilities (Hendry et al 2004), the harvest limits were set at 1 fish per day at a minimum length of 46 cm in 2002. In addition, the legal fishing season for brook trout in these systems was shortened to April 30 – July 31 instead of remaining open until September 31 as is normal for streams under MI DNR type 1 and 4 regulations (Michigan Department of Natural Resources, 2005). To further protect migrant brook trout, the legal length of brook trout in Lake Superior was set at 51 cm in MI waters, beginning in 2005 (Michigan Department of Natural Resources, 2005). Regulations for adjacent Lake Superior tributaries have not been altered.

Capture and tagging

2003

Between May and December 2003, brook trout were electrofished in each of the three study rivers and evaluated for PIT tagging. All fish larger than 100 mm and appearing in good health were weighed (g), measured (total length, TL, mm), sexed when possible, and then implanted with a 23 mm x 3.4 mm PIT tag (model: RI-TRP-RRHP, Texas Instruments, Dallas, TX). PIT tags were inserted into the body cavity through a scalpel incision on the left side of the fish just anterior to the pelvic fin. Each unique PIT tag was programmed with 2 codes; a river code denoting the river where the fish was tagged and an individual code allowing the identification of each tagged fish.

A total of 214 stream captured brook trout were PIT tagged in 2003 (Table 3.1) These fish were designated as TBH feral (fin clipped TBH brook trout found in streams after surviving at least 1 winter since stocking), or wild (trout with no discernable fin clip and therefore assumed to be stream reared). Wild was used in place of native due to the unknown genetic makeup of PRNL brook trout. Reproduction of native fish with previous brook trout stockings between 1920 and 1960 (Lora Loope, National Parks Service, personal communication 2004) as well as with TBH fish more recently stocked is a possibility in all of these streams. In 2003, it was believed that all TBH brook trout had been adipose fin clipped. Information released in April of 2004 revealed that some hatchery fish were right pectoral clipped only. This makes it possible that some fish designated as wild were actually TBH feral. Thus, all stream captured brook trout in 2003 were designated as wild/feral. In addition to electrofishing stream brook trout, 218 fall fingerlings (age 0 +, 83 mm mean TL) were tagged at the Iron River National Fish Hatchery, Iron River, WI on September 19, 2003 and stocked on September 26, 2003

(Table 3.1). The highest number of fall fingerlings were stocked in the Mosquito river (n=13 700), with Sevenmile Creek (n=12 500) and the Hurricane River (n=9 920) receiving fewer fish. These hatchery fish were not used in the 2003 analysis since fish in this group that moved between September - December were likely dispersing from high density stocking areas. However, they are relevant to the 2004 season.

2004

Brook trout in 2004 were designated as wild, feral, or hatchery. Fish designated as wild were still those without any fin clips. Feral fish also included those brook trout released in September 2003 along with all other previously released TBH brook trout. Hatchery fish consisted of 7 600 spring yearlings (age 1+) from the Genoa National Fish Hatchery, Genoa, WI. These fish were released below the first barrier near the mouth of the Hurricane River on April 29, 2004.

As in 2003, fish were tagged upon capture from electrofishing surveys or prior to stocking (in the case of some hatchery TBH fish). A greater tagging effort during this season led to some selectivity in tagging. A larger number of TBH hatchery spring yearlings were tagged in April and 2003 fall fingerling TBH trout were also commonly captured and tagged throughout the spring of 2004. Because of this, priority was given to tagging PRNL wild brook trout as well as TBH fall fingerling fish stocked prior to 2003 in an effort to attain a large sample for all three brook trout groups represented in PRNL. Between April 29, 2003 and August 31, 2004, 351 TBH spring yearling hatchery fish were captured and tagged. Also during this period, a total of 617 wild or feral fish were captured and tagged (222 of these brook trout were designated as feral and 395 as wild) (Table 3.2). Four previously tagged brook trout (2003) were either recaptured or detected bringing the total known number of tagged wild or feral fish to 621 in 2004.

In 2004, three adjacent streams, Sable Creek, Sullivan's Creek, and Miner's River were occasionally electroshocked (Figure 3.2). Brook trout were tagged in Sable Creek (10 wild or feral and 9 hatchery) and Miner's River (2 wild). No antennas were established in these streams, and resident and lake-run fish could not be verified except in cases where fish were recaptured or moved to rivers where PIT systems existed. Activity of these fish is described, but was not used in the 2004 statistical analysis.

Two laboratory studies to determine PIT tag retention in trout were conducted. In 2003, 14 splake had a PIT tag inserted and were observed for four months. In 2004, 46 TBH brook trout were electrofished from the Mosquito River. These fish were tagged and held from July 21, 2004 to October 11, 2005. In both groups there was no tag loss and no initial mortalities that might be associated with tagging stress.

Stream monitoring

To montior migratory timing and movement of the two strains of brook trout in PRNL, stationary PIT (passive integrated transponder) antennas were set up near the mouth of each river. Increased activity of brook trout at the mouths of rivers was used as an indication of brook trout movement to and from Lake Superior.

Each RFID station included a Series 2000 Control Module with RS232 interface (model RI-CTL-MB2A-02, Texas Instruments Dallas, TX 75234), series 2000 High Performance Remote Antenna RFM (model RI-RFM-008B-00 Texas Instruments Dallas, TX 75234), a Hewlett Packard palmtop computer data logger (HP 200LX) and three 12 volt DC Concord 97 amp/hr batteries (West Covina, CA 91790) enclosed in a weather-proof box. These were attached to an antenna tuning module (RI-ACC-008B, Texas Instruments Dallas, TX 75234) by twinaxial shielded cable (model EWN01A, Black Box Corporation, Lawrence PA 15055). The tuning module was in turn attached to an antenna loop constructed of 8 gauge OFHC multi-strand wire (Clearwater FL 33760) designed to encircle as much of a cross section of the river as possible without compromising read range (Figure 3.3). Each of these systems can run for approximately 8 days with a fully charged battery bank. Solar cells (Solar pro 225 w kit, ICP Global, Montreal, Canada) were added to these systems in 2004 in an effort to create longer runtimes between battery changes during the field season.

Any PIT tagged fish that crossed this antenna while it was running was detected and its tag identification number, the date, and time of movement were recorded. A portable handheld reader was constructed for locating previously tagged fish during electroshocking surveys as well as confirming tag numbers before inserting PIT tags in fish.

At several times during 2003 and 2004, one or more of the systems briefly lost power or become dismantled due to natural causes or vandalism. In these situations, passing fish were not detected and recorded. Additionally, in the event that one or more fish was in range of the antenna at the same time, it is possible for the signals to collide and only one or none of the tags would have been recorded. These issues make it impossible to determine direction of travel with one antenna and predict for certain if all moving fish have been detected. However, by observing fish detections occurring at the antennas, we can discern trends throughout the seasons as brook trout move to and from Lake Superior. This makes it possible to gather a picture of when brook trout are active in streams as well as when movement to and from the Lake is occurring.

Data Analysis

2003

Movements of brook trout in 2003 were examined as they occurred throughout the seasons. Brook trout activity timing was compared to season, photoperiod, water temperature, and rainfall using Spearman's correlations. Non-parametric correlations were used to accommodate the use of percentages (of total tagged) with lake-run and resident brook trout. Percentages were used because trout sample size continued to grow throughout the study period and it was important to prevent the appearance of greater activity in later months simply because more tagged fish were present.

Photoperiod was calculated as the deviation (in hours) from the yearly mean (photoperiod differential) as well as added cumulatively (light hours). Like stream temperatures, cumulative photoperiod as well as photoperiod against brook trout movement correlations was analyzed. In this case, however, all study rivers were combined as photoperiod was uniform across the region.

Stream temperature correlations were analyzed using additive water temperatures (cumulative daily average temperatures) as well as daily averages. Each stream was examined separately to account for differing daily average temperatures at each site. Correlations examined the combination of changing water temperature and increasing date on brook trout activity. Daily average water temperature correlations compare brook trout movement with changing water temperature only, disregarding date.

Rainfall amounts (cm) were obtained from the National Weather Service climatological station in Munising, MI. The amount of rainfall was pooled in one week blocks and compared to the brook trout detections that occurred in that week. This approach allowed for the examination of the effect of rainfall on brook trout movement even if the effect of rain on stream discharge was delayed by a few days.

Additionally, a Chi square-analysis was used to determine if there was a diel aspect to movements. Increased movements at night have been documented in the activities of ocean bound salmon smolts (Thorpe et al 1988), and Arctic charr (McCubbing et al 1998) as well as migrating brook trout (Smith and Saunders 1958). While diel timing may not necessarily be considered a cue of migration, its presence would show movement similarities between the brook trout of PRNL and those of previously studied salmonids.

2004

Analysis of 2004 data was similar to 2003 in that percentages of brook trout populations were used and Spearman correlations comparing movement timing and season, photoperiod, water temperature, and rainfall were conducted. Regression analysis comparing stream water temperatures was conducted for 2004 as well. Chi square tests determining if there were significant differences in diel movements were conducted for all trout and trout grouped by strain. Two important differences were that there were only spring and summer seasons and it was possible to discern and evaluate the movements of wild, feral, and hatchery brook trout.

One additional analysis comparing spring and summer movements between wild/feral brook trout was conducted with season to examine similarities and differences between the two years.

RESULTS

Movements

The movement of PIT tagged brook trout showed two periods of increased activity. The first was observed during spring when water temperatures and average daylight hours were increasing (Table 3.3). In the spring and summer of 2003, when only the Hurricane and Mosquito systems were operational, all of this activity occurred in the Hurricane River where 7 (23%) tagged individuals were detected (Figure 3.3). The first brook trout from the Mosquito River was not detected until summer. In 2004, the movements during the spring show activity in all three study rivers (Figures 3.4-3.6). PRNL wild and TBH feral fish were active in small numbers while TBH spring yearlings, stocked on April 29, provided a majority of the spring antenna activity at Sevenmile Creek (Figure 3.5). None of the TBH yearlings tagged and released at the mouth of the Hurricane River in April were detected moving upstream that spring.

Overall, the percentage of tagged PRNL wild and TBH feral fish detected was low in all three rivers. The timing of fish movements in 2003 was similar to the activity during the summer of 2004. In 2003, however, all of the spring activity occurred in the Hurricane River while in spring 2004, far fewer PRNL wild or TBH feral fish were captured below the falls (n_{2003}=30, n_{2004}=14). When not including the 30 brook trout tagged above the Hurricane River falls in the spring of 2004, the percentage of lake-run fish in the tagged populations was around 10% through June then dropped to 5% in July and August. This pattern of greater movement in spring is closer to what was seen during 2003. This decrease in wild and feral fish could be a consequence of adding 7600 larger spring yearling brook trout to the river system.

Brook trout were active during the summer months, but not to the degree that was seen in the spring and fall of 2003. A small number of fish were detected in July of 2003, but none in August (Figure 3.3). Similarly, in 2004, low levels of detection were recorded in July and August in all three rivers. The number of fish appeared to increasing from July to August in the Mosquito River and Sevenmile Creek, but when the percentage of fish moving is looked at, the movements appear to be proportionately similar in relation to the tagged population (Figures 3.5 and 3.6).

Autumn, when daylight hours and water temperatures are decreasing (table 3.3), proved to be the season where the greatest amount of movement occurred in 2003. Wild/feral brook trout were detected in each of the three rivers (although Sevenmile Creek was not available during spring and summer 2003) and the percentage of the tagged fish becoming lake-run increased in both the Mosquito and Hurricane Rivers (Figure 3.3). Fish in the Hurricane River included some that were tagged earlier in the year as well as unmarked fish previously not found in this river during earlier electrofishing surveys. Some of these fish were visibly spawning males and other fish, including one female captured in Sevenmile Creek, were ripe. The Mosquito River lake-run fish were all fish tagged upstream of Lake Superior and had been previously undetected. These fish gave all appearances of leaving Mosquito River during the fall season and moving into Lake Superior. This goes against conventional thought on coaster biology as they are believed to migrate up rivers as adults during the spawning season, not out as fall juveniles. However this trend was also observed in Elerslie Brook, Canada, where Smith and Saunders (1958) saw greater seaward movement of brook trout (seaward movement being analogous to movement to Lake Superior) in autumn than any other month. In addition to the wild/feral fish a number of TBH fall fingerlings were stocked in each of the three rivers (Table 3.1). Although these fish were not used in the 2003 analysis, they were important to the 2004 TBH feral tagging effort and analysis. Only in the Hurricane River were any of these fish detected in 2003 after stocking. Thirty-seven of the 74 tagged individuals (50%) were detected after being released due, no doubt, to the short stretch of river in which they were placed. These movements are most likely dispersal rather than migration.

Additional movements

In 2003 and 2004, several brook trout were captured that gave evidence of movement from one river to another via Lake Superior. Either brook trout tagged in one stream were detected at another antenna or TBH strain fish, having fin clips indicating which stream they had been stocked in, were captured in a different river. Movement of PIT tagged or fin clipped brook trout can be condensed into two categories, those moving from the Hurricane River, and those moving into Sevenmile Creek. Fish moving from the Hurricane River to Sevenmile Creek were placed into the latter category. Brook trout moving from the Hurricane River were found, detected, or reported in the Mosquito and Sable Rivers as well as Sullivan's and Beaver Creek (Figure 3.7**).** Those fish moving through Lake Superior to Sevenmile Creek came from both the Mosquito and Hurricane Rivers (Figure 3.7**).** None of the fish tagged at Sevenmile Creek were found elsewhere during the study. These brook trout provide absolute proof of movement into Lake Superior and by the present definition these fish are coasters.

The average tagged brook trout in 2003 was 152 mm, while in 2004 wild fish averaged 151 mm and feral fish 122 mm. Migratory brook trout were slightly larger, the wild/feral fish of 2003 averaging 160 mm. In 2004 wild migratory fish averaged 157 mm and feral fish 115 mm.

Photoperiod

In 2003, there was a significant negative correlation between brook trout activity and photoperiod differential (hours difference from the yearly mean) (cc=-0.153, p=0.022) (Figure 3.8). No significant correlation (cc=0.053, p=0.431) was found between the cumulative light hours between May 15 and December 18, 2003 and brook trout activity.

The 2004 photoperiod data showed no significant correlation between wild brook trout movement and photoperiod differential (p=0.790) or cumulative light hours (p=0.711) from May through August 31 2004. Correlations in both photoperiod differential (Figure 3.9) and cumulative light hours in 2004 occurred with feral brook trout (Figure 3.10). The photoperiod hours from the yearly mean was negative (cc=-0.181, p=0.044), while photoperiod hours from the yearly mean and feral brook trout movement was positively correlated (cc=0.270, p=0.002).

No correlation existed between spring yearling brook trout and photoperiod differential (cc=0.071, p=0.429) but a significant negative correlation was seen with cumulative light hours (cc=-0.328, p=0.000) (Figure 3.10).

Water temperature

During 2003, there was no correlation between average daily temperature or additive daily temperature in the Hurricane River (p=0.090, 0.958), the Mosquito River (p=0.626, 0.509), or Sevenmile Creek (p=0.344, 0.202). The two periods of greatest movement had different daily temperature averages. The average daily stream temperature during June for the Hurricane and Mosquito Rivers were 13.1^{o}C ± 1.6^{o}C and 13.3^{o}C ± 1.7^{o}C respectively, while the average daily temperature in October for the

Hurricane, Mosquito, and Sevenmile Creek were 7.2°C ± 0.8 °C, 7.5°C ± 1.5 °C, 7.6°C ± 1.6 °C (Table 3.3)

In 2004, significant correlations involving water temperature were only found in Sevenmile Creek. Wild fish activity correlated with average daily water temperature suggesting greater movement at lower daily average temperatures (cc=-0.248, p=0.006) (Figure 3.11). There was no correlation between wild fish activity and additive daily water temperature. As with photoperiod, feral fish activity correlated with additive daily water temperature (cc=0.213, p=0.020) (Figure 3.12), but not with average temperature. When wild and feral fish were combined as in 2003, a correlation was present with average daily photoperiod (cc=-0.226,p=0.013), similar to the wild fish correlation where most of the movement in these two groups occurred.

Spring yearling trout activity correlated with both daily average water temperature (cc=-0.260, p=0.004) (Figure 3.11) and additive daily water temperature (cc=-0.376, p=0.000) (Figure 3.12) showing that most activity of these fish occurred at lower temperatures early in the year.

Rainfall

When weekly movements were compared with weekly rainfall, no significant correlations were detected during 2003 (cc=0.136, p=0.450) or 2004 (cc=0.073, p=0.772).

Diel timing

Overall, greater numbers of brook trout moved at night than during the day (p=.011). When separated into wild/feral fish and spring hatchery fish in 2004, however, there were no significant differences in diel movement among the hatchery or wild/feral stream fish diel activity.

DISCUSSION

Observed movements

There was a bimodal distribution of brook trout movement occurred in 2003 (Figure 3.13). Each stream had a movement pattern that differed from the others in timing and overall intensity. Lastly, tributaries of Lake Superior are not necessarily habitat islands where brook trout reside; these fish use the lake as well as adjacent tributaries.

The bimodal distribution of brook trout movement in 2003 shows a pattern from spring to fall with increased in fish movement during June and October. Several brook trout studies have found brook trout moving downstream during spring and returning later in the fall to spawn (Smith and Saunders 1958, Castonguay et al 1983, Montgomery et al 1990, Morinville and Rasmussen 2003, Theriault and Dodson 2003). The size of brook trout moving in PRNL is similar to juvenile trout on the east coast that are captured moving downstream to estuarine waters. Other than the TBH feral fish of 2004, a majority of which came from the 2003 fall fingerling stocking, the average movement lengths were similar to those found by Smith and Saunders (1958), where the average length of migrant fish in Elerslie Brook, Prince Edward Island Canada was 168 mm, and those of the Moise River, Canada where the average size of out migration brook trout was > 150 mm (Naimen et al 1987). However, some populations show brook trout activity similar to that within PRNL where brook trout move in greater numbers during spring and fall, but also show continuous movement throughout the year. Smith and Saunders (1958) found this to be true in Prince Edward Island where they saw movement in brook trout populations exhibiting characteristics of both dispersal and migration. Data from 2004 are difficult to include due to the unknown effect of adding the TBH hatchery fish as well as not knowing what the distribution of movement would be like with the addition of fall. The 2004 data does show movement in all months with greater movement in spring and a decrease in summer (Figure 3.14). Brook trout tagged during the fall season appear to be mature adults although it cannot be confirmed that they are homing to natal streams. It is entirely possible that these fish are simply untagged returning brook trout that were not captured and tagged previously, or it could be that brook trout in PRNL do not show a great affinity for natal streams and may simply move up any potential spawning tributary during the fall season. Information on brook trout homing suggests that some brook trout display a greater ability to home than others. The brook trout of Lake St. Michel, Quebec showed imperfect or underdeveloped homing with low percentages of fish returning (<10%) (Baril and Magnan 2002), while the fish of Matamek Lake, Quebec reviewed in Power (1980), and those of the St. Jean River, Quebec (Castonguay et al 1982) showed a high degree of homing. These patterns offer a regional view of how brook trout are using Lake Superior and adjacent tributaries, but each river also differs from the other in the intensity and in aspects of the timing.

The Hurricane River contains the shortest stretch of river from a barrier (partial) to Lake Superior and yet it displayed the greatest amount of activity in 2003. Because this river was such a short stretch, the continuous discovery of untagged fish indicates there was movement from either Lake Superior or downward from upstream reaches. Small numbers of fish do appear to move down the falls, and there is also evidence that brook trout are moving in from the lake. Brook trout tagged in the Hurricane River have been either recovered or detected at three other tributaries within the park. Whether the Hurricane River is actually their natal stream, or if this is a temporary stop where they were captured is difficult to determine. While some fish may have been returning from previous excursions to Lake Superior, they were captured and tagged within the stream and are then listed as a Hurricane River fish. Other fish were tagged and made repeated approaches to the antenna exhibiting a propensity for moving in and out of Lake Superior several times during the study period.

The distribution of Hurricane River fish mimics the overall trend, however, the Mosquito River has a different activity pattern. In 2003, all brook trout were tagged above the antenna and below the barrier falls. The first detection occurred on July 13, 2003 when a single fish was detected. No fish were detected in August, but movement increased in September and October and then decreased again in November. Based on the data collected, it appears that the brook trout of the Mosquito River are active mainly during the fall months with no substantial spring movement, unlike the other streams. Additionally, while all fish at the Mosquito River were tagged upstream of the antenna, these moving fish may be working their way downstream toward the lake instead of upstream toward spawning grounds as would be expected of migratory salmonids during the spawning season. Without directionality at the mouth of the stream this cannot be verified. Subsequent electrofishing surveys conducted between Lake Superior and the Mosquito RFID system failed to reveal that any of these fish are simply residing in this shallow, shelf rock area.

Sevenmile Creek's system monitoring was only conducted through the fall of 2003 and spring/summer of 2004 and therefore it is more difficult to detect trends that are visible in other streams. What was observed during this period is similar to the PRNL system as a whole. There were low numbers of active fish at virtually all times of the year, with increases during spring and fall. Summer appears to be a season where fewer fish are active around the mouths of the rivers. The most notable feature of the

Sevenmile Creek data set is that brook trout tagged in the Mosquito and Hurricane Rivers were detected here, although none of the fish tagged in Sevenmile Creek have been detected elsewhere. It is impossible to determine if these fish moved from their natal streams to Sevenmile Creek or possibly returned after a period of time spent in Lake Superior and adjacent tributaries. Additional movements of tagged fish might be able to shed light on the origin of these fish, it should not take attention away from these movements. These movements give absolute confirmation that wild and naturalized brook trout are moving out into the lake and in some cases making use of other tributaries of Lake Superior. These are not hatchery fish stocked in high density that are dispersing outward as a necessity, but brook trout that have successfully managed to survive at least one winter in PRNL.

Brook trout across their range show a wide degree of plasticity in life history strategies (Power 1980). Even populations with migrant individuals differ in age of migration, size at migration, distance, timing, and the number or percent of the population that is migratory. Curry et al (2002) concluded that migratory behavior in brook trout is not fixed as it is in some other salmonids and therefore a greater variety in anadromous tactics is displayed. The Tobin Harbor strain of brook trout is lacustrine, spending life within Lake Superior. With this strain of brook trout being planted into PRNL, it is interesting to see these fish acclimating and acting in a very similar way to those wild brook trout already inhabiting these streams. These observations lead to questions as to whether or not the stream environment creates the type of coaster we may be seeing on the southern coast of Lake Superior as opposed to the previous idea that a specialized strain of brook trout made up a migratory component of the stream.

Environmental Factors

Photoperiod is the environmental factor that was most related to brook trout activity in PRNL. In 2003, when the study period ran from mid May through mid December, photoperiod differential was the only environmental factor examined that correlated with brook trout movement in PRNL. The correlation between photoperiod differential and the percentage of brook trout moving suggest that as the number of daylight hours increases from May through December, i.e. into mid-summer, there is decreased movement. While the lack of a correlation between cumulative light hours and brook trout movement initially suggested that this correlation was not related to date, the graphical representation of brook trout movement in 2003 showed a bimodal curve with peaks in June and October. Perhaps these two peaks early and late in the season nullified the effect of date.

In the shortened 2004 season, photoperiod was only considered during spring and summer. For the spring and summer seasons in 2004, correlations existed with photoperiod and hatchery TBH as well as photoperiod and feral TBH movements. A significant negative correlation existed with photoperiod differential and hatchery TBH brook trout (stocked on April 29, 2004) showing greater movements of fish in the spring after stocking and then less activity into the summer. While initially this may appear to be seasonal activity, it is more likely that it is dispersal. All of these brook trout (7600) were stocked into the Hurricane River below the waterfall, a stretch of only a 180 m. The initial burst of activity was probably due to density dependent dispersal, as all of these fish could not possibly coexist in this small stretch, rather than an instant reaction to photoperiod. The interaction of photoperiod and trout movements would be more substantial if this behavior continues in subsequent years after a year of stream or lake habitation.

The other significant correlation involving photoperiod in 2004 was with feral TBH brook trout. A negative correlation with photoperiod differential showed a decrease in movement in relation to increasing day length. On the other hand, these fish also showed a positive correlation with cumulative light hours which points to increased activity with advancing date. These two correlations suggest an increase in movement with the decreasing daylight hours in late summer into fall.

That there was no correlation between photoperiod and wild brook trout movement is contrary to the results from 2003. This could be due to the lack of a fall season or simply to a different year producing different reactions of the fish within streams. Another possibility is the introduction of the hatchery TBH fish into the Hurricane River. All of the spring movement in 2003 came from the Hurricane River and the introduction of these large yearlings may have affected the movements of the generally smaller wild and feral fish in the river.

Photoperiod is a documented cue in the migration of adult and juvenile salmonids. Water temperatures may be an essential factor in spawning times and conditions but can be irregular, shifting annually, making it a less reliable cue than photoperiod. Beecham and Murray (1988) found that pink salmon responded to both water temperature and photoperiod and suggested that both may play a role in migration and maturation. As early as the 1950's studies were conducted using controlled light situations to advance maturity in brook trout by as much as three months (Hazard and Eddy 1951, Corson 1955). Other salmonids exposed to shorter light regimes well before natural spawning periods have also been known to become mature earlier than those in natural conditions

(Combs et al 1959, Johnson 1984). Sockeye salmon (*O. nerka*) use photoperiod as a means of determining optimal stream conditions at spawning sites when beginning upstream migrations (Quinn and Adams 1996). McCormick and Naimen (1985) found that maturing male brook trout showed decreased salinity tolerance during the autumn photoperiod associated with spawning time.

A majority of the brook trout in PRNL are likely to be juveniles (although some of the fish captured in autumn are mature) and therefore photoperiod cues that apply to adults or maturing adults beginning spawning runs may not necessarily affect immature fish in the same way. Photoperiod is known to affect the growth and smoltification of Atlantic salmon parr (Saunders et al 1985, Saunders et al 1989, Saunders and Harmon 1990) and therefore it is possible that brook trout in Lake Superior are also cueing in on changes in daylight hours for the initiation of movement even as juveniles. Whether this activity is migration or seasonal dispersal is difficult to determine based on available data, but it does appear that photoperiod is plays role and should be examined more closely when regarding brook trout movements.

Rainfall, as a determinant for discharge, provided no correlations with brook trout activity in 2003 or 2004. A closer look at stream levels and discharge might provide further insight into discharge as an environmental cue, the amount of rainfall in the area does not appear to be a significant factor in PRNL. Neither average water temperature nor additive daily water temperature influenced movements in 2003. Water temperature did correlate with stream temperature and movement during spring and summer season of 2004 at Sevenmile Creek.. The hatchery TBH brook trout activity correlated negatively with additive daily water temperature and mean daily water temperatures. This, as in the case of photoperiod, is more likely due to stocking date and dispersal.

Wild brook trout activity in Sevenmile Creek correlated with average stream temperatures, showing decreasing movements with increasing temperatures. While this trend was not seen here in 2003, it was similar to the general seasonal trend of increased movement in spring, when the temperatures were lower, exhibited by fish in PRNL. When wild and feral fish were combined, as in 2003, they mimicked the pattern shown by wild fish. That only 8 feral TBH fish had moved by the end of August 2004 and therefore made up a very small portion of migrating fish might have affected these results. These feral fish showed a positive correlation when compared to additive daily water temperature (i.e. increased movement from spring to summer). This is odd in that the majority of these fish are juvenile and movement of juvenile coasters is generally thought to occur early in the year not during mid summer, although this pattern may be similar to that seen in the Mosquito River fish.

It is interesting that stream temperatures only appeared to be correlated to movements in Sevenmile Creek. It may be due to the unique qualities that the creek possesses not observed in the Hurricane and Mosquito rivers. Sevenmile Creek has a stable flow regime coupled with high variability in water temperatures (Stephan Rybzinski, personal communication 2004), possibly due to beaver activity slowing and impounding water upstream. Perhaps high variation in water temperature has created a situation where fish are more responsive to increases in temperature.

Small numbers of brook trout inhabiting three of Lake Superior's tributaries in PRNL move into the lake during spring, summer, and fall. Although both PRNL wild and TBH stocked brook trout populations each have individuals that move into Lake Superior, the majority of these fish from both strains are small (generally > 180 mm) and are most likely juveniles. Tagged fish have been detected leaving one river and entering another, which suggests that brook trout are using the tributaries and the shoreline habitat and are not isolated in riverine habitat islands. Movements of brook trout to and from Lake Superior are greatest in the spring and autumn and are correlated with increasing and decreasing seasonal photoperiod hours. Other environmental factors (water temperature and rainfall) did not correlate with PRNL brook trout movements although water temperature may have a role in the movements of fish in Sevenmile Creek where the local hydrodynamics create different stream conditions than other tributaries.

Table 3.1: The 2003 PRNL wild/feral and TBH fall fingerling tagging record showing the number of brook trout tagged by month, river, and total.

2003 Strain	River	May	June	July	Aug	Sept	Oct	Nov	Totals
2003 wild/TBH feral	**hur**	12	18	8	19	1	19	0	77
	mos	11	54	0	10	0	4	10	89
	svn					0	34	14	48
	totals	23	72	8	29	1	57	24	214
2003 Fall fingerling TBH strain	**hur**					74	0	0	74
	mos					89	0	0	89
	svn					69	0	0	69
	totals					232	0	0	232
totals		23	72	8	29	233	57	24	446

Table 3.2: The 2004 PRNL wild, TBH feral and hatchery tagging record showing the number of brook trout tagged by month, river, strain, and total.

2004 Strain	River	April	May	June	July	August	Totals
2004 TBH spring yearlings	**Hur**	278	3	14	0	0	295
	Mos	0	0	0	0	0	0
	Svn	0	19	19	0	18	56
	Totals	278	22	33	0	18	351
PRNL wild brook trout	**Hur**	0	4	43	34	7	88
	Mos	0	4	27	43	22	96
	Svn	0	39	52	48	72	211
	Totals	0	47	122	125	101	395
TBH feral brook trout	**Hur**	0	0	2	0	0	2
	Mos	0	7	72	0	45	124
	Svn	0	4	58	6	28	96
	Totals	0	11	132	6	73	222
Total	**all rivers**	278	80	287	131	192	968

Table 3.3: The monthly averages of daylight hours and water temperatures (^{0}C) for the three study streams in PRNL during the 2003 and 2004 study period.

			Monthly Avg Stream Temps					
Year	**Avg. Monthly Daylight hrs**	**SE**	**Hur**	**SE**	**Mos**	**SE**	**Svn**	**SE**
May-03	14.96	0.59	11.69	1.28	12.95	2.23		
Jun-03	15.73	0.29	13.11	1.61	13.26	1.66		
Jul-03	15.40	0.51	15.13	1.25	15.57	1.33		
Aug-03	14.17	0.66	15.68	1.33	16.56	1.33		
Sep-03	12.59	0.69	12.91	1.57	13.41	1.62		
Oct-03	10.94	0.69	7.23	0.81	7.48	1.50	7.60	1.57
Nov-03	9.47	0.60	3.20	1.28	2.55	1.22	2.82	1.34
Dec-03	8.67	0.30	0.52		0.21	0.55	1.47	0.94
Apr-04	13.57	0.68	3.65	1.26			5.83	1.21
May-04	14.99	0.60	9.06	1.58	10.97	1.45	11.11	1.56
Jun-04	15.74	0.28	12.72	1.42	13.54	1.43	15.76	1.63
Jul-04	15.38	0.52	14.20	1.39	15.02	1.40	15.91	1.56
Aug-04	14.14	0.67	13.68	1.31	14.47	1.33	15.14	1.44

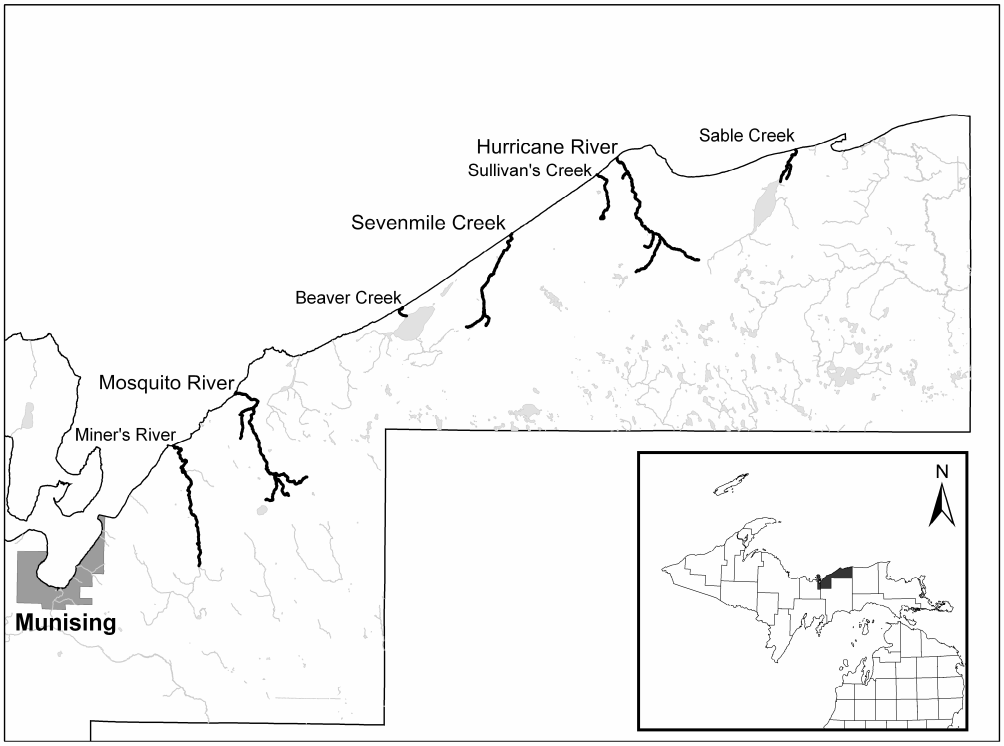


Figure 3.1: The location of the three principle study streams and five adjacent streams located within Pictured Rocks National Lakeshore, MI 2003-2004.

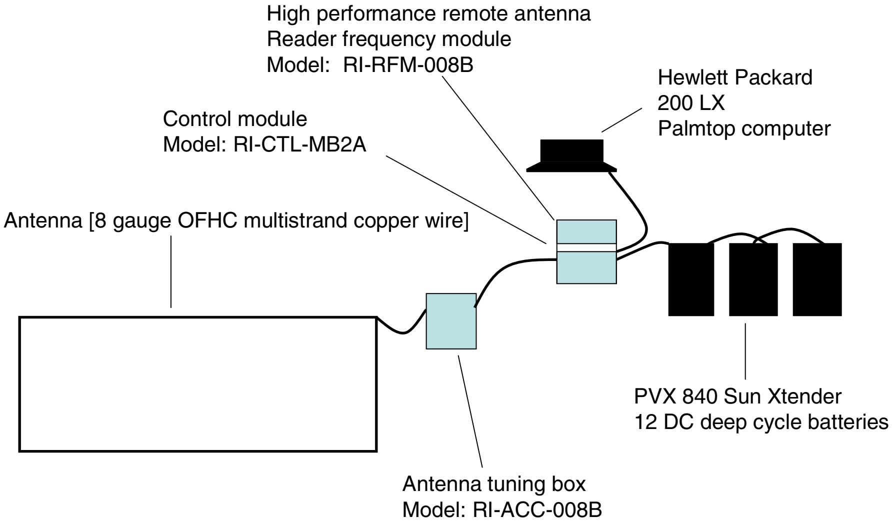


Figure 3.2: Layout diagram of RFID system as placed in PRNL tributaries 2003-2004.

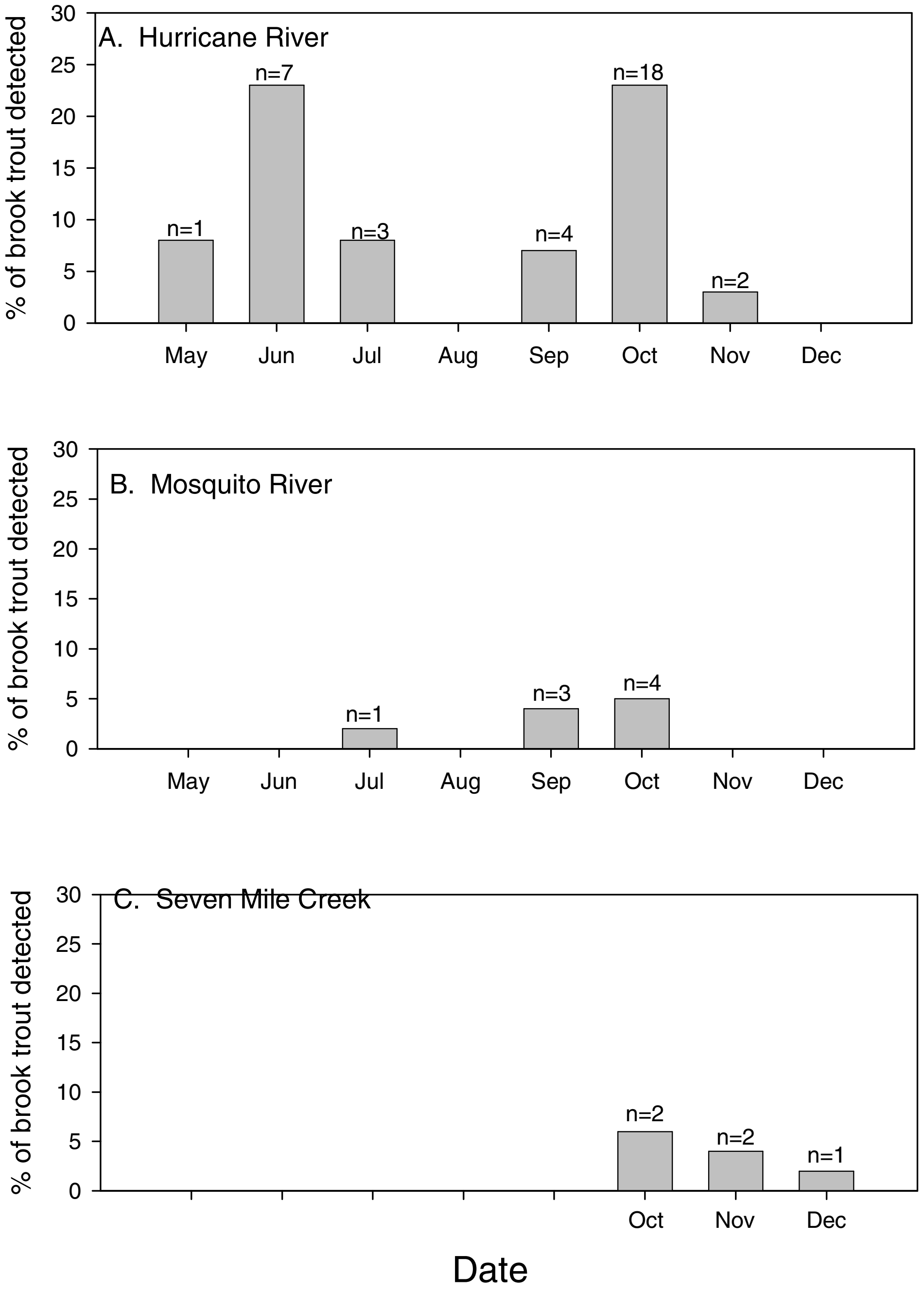
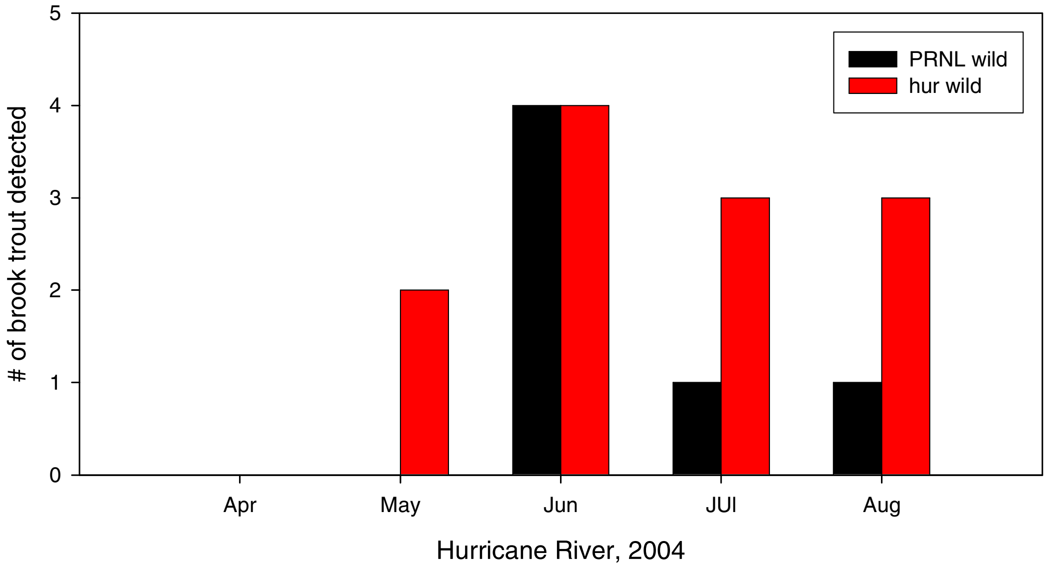


Figure 3.3: Percentage of PIT tagged wild/feral brook trout detected at an antenna array during 2003. PRNL, MI.



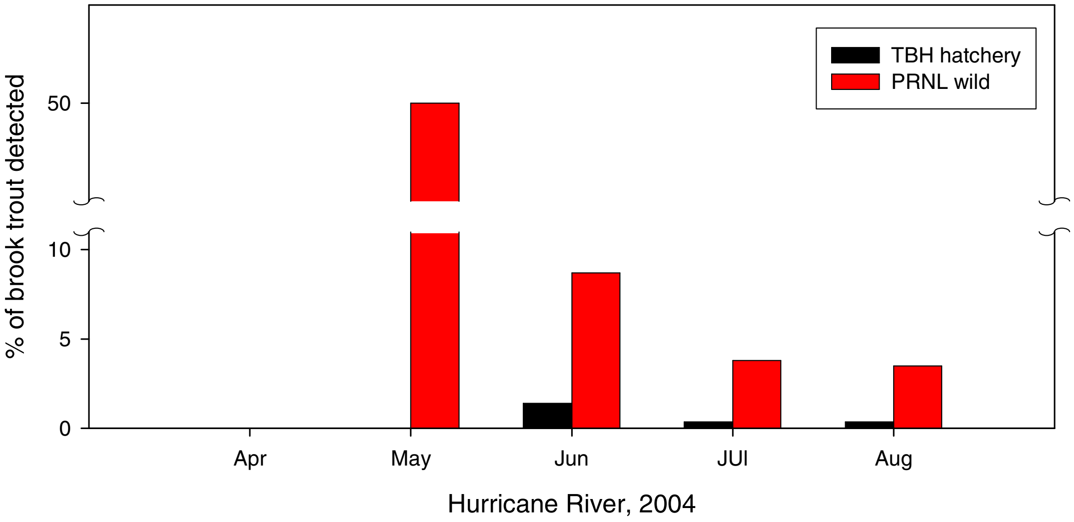
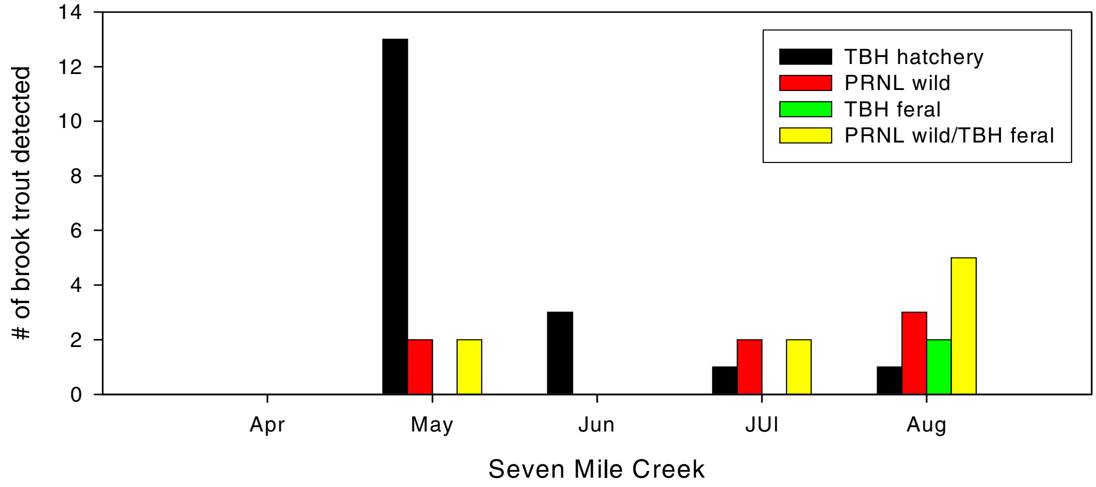


Figure 3.4: Movements of brook trout in the Hurricane River (2004) broken down by strains and separated by number of fish moving as well as percentage of the river's tagged population moving. PRNL, MI.



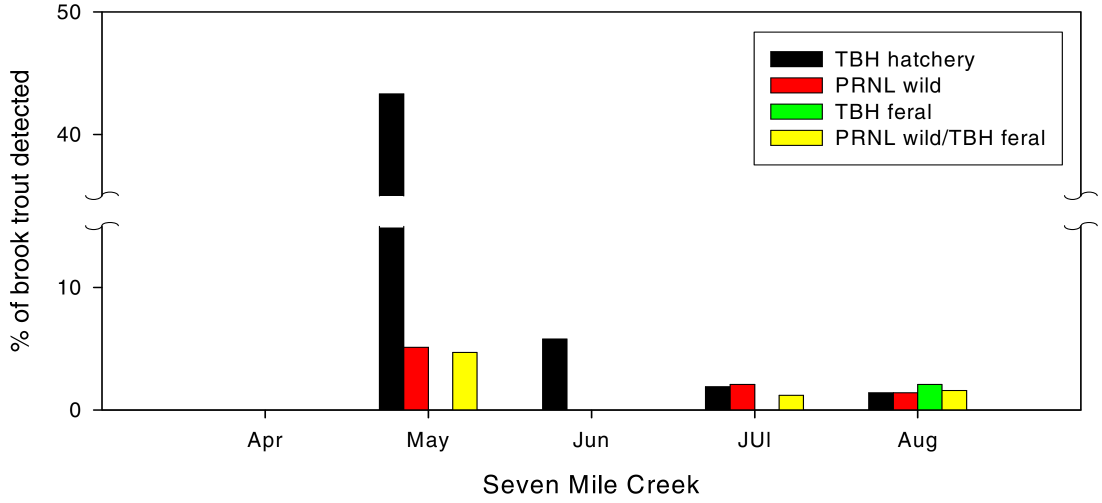


Figure 3.5: Movements of brook trout in Sevenmile Creek (2004) broken down by strains and separated by number of fish moving as well as percentage of the river's tagged population moving. PRNL, MI.

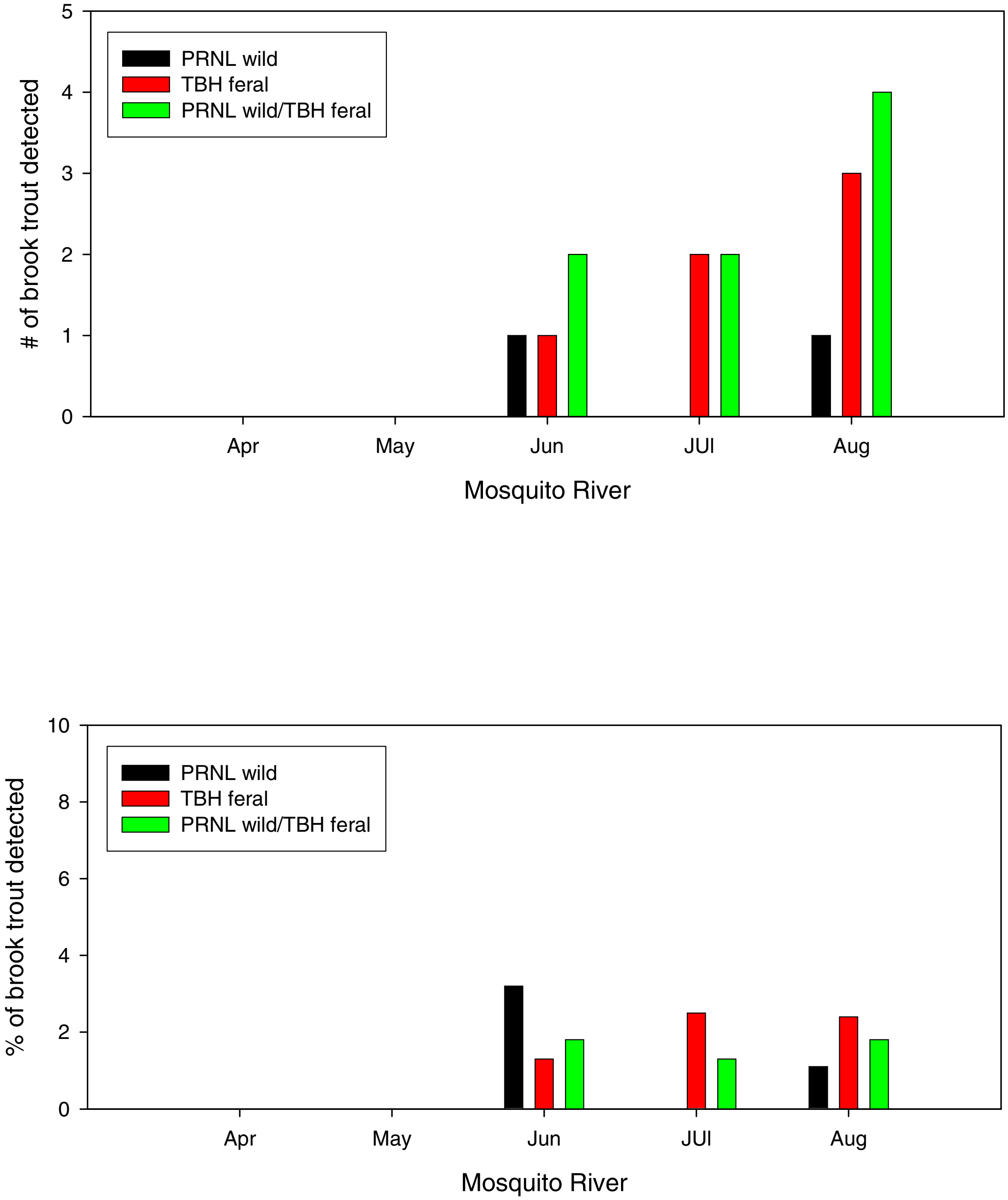


Figure 3.6: Movements of brook trout in the Mosquito River (2004) broken down by strains and separated by number of fish moving as well as percentage of the river's population moving. PRNL, MI.

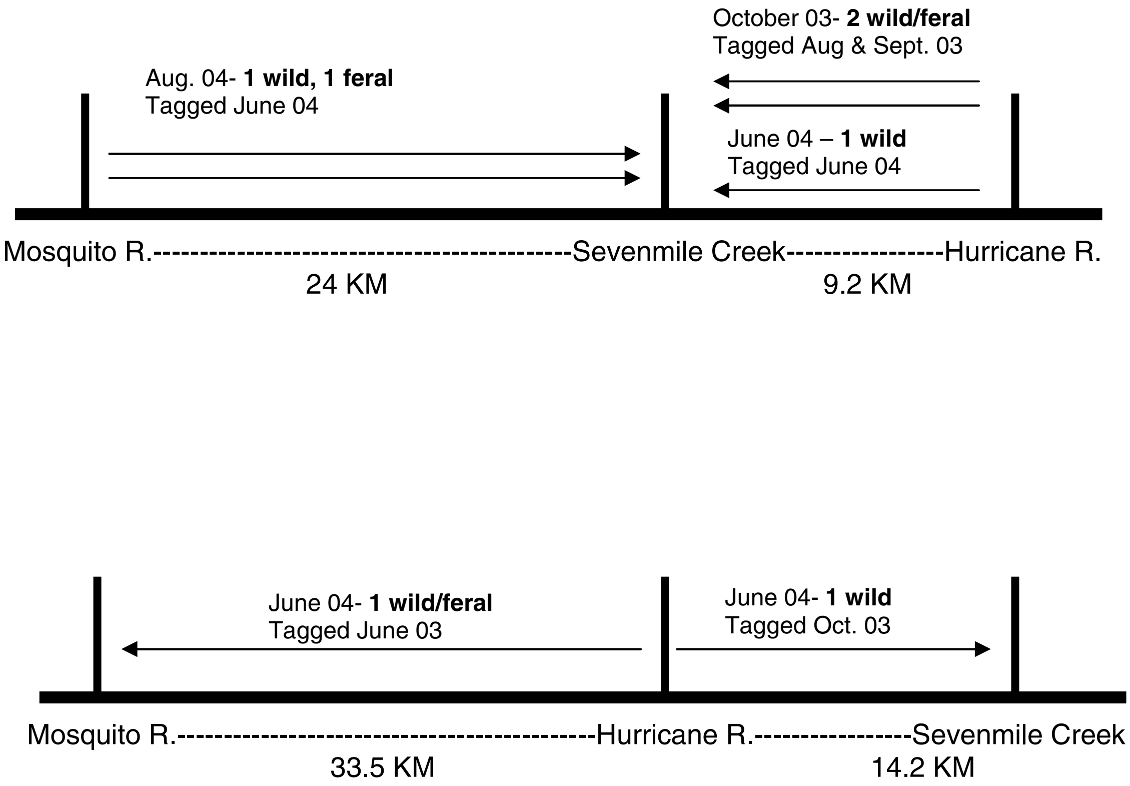


Figure 3.7: Movements of PIT tagged brook trout through Lake Superior from one river to another. PRNL, MI 2003-2004.

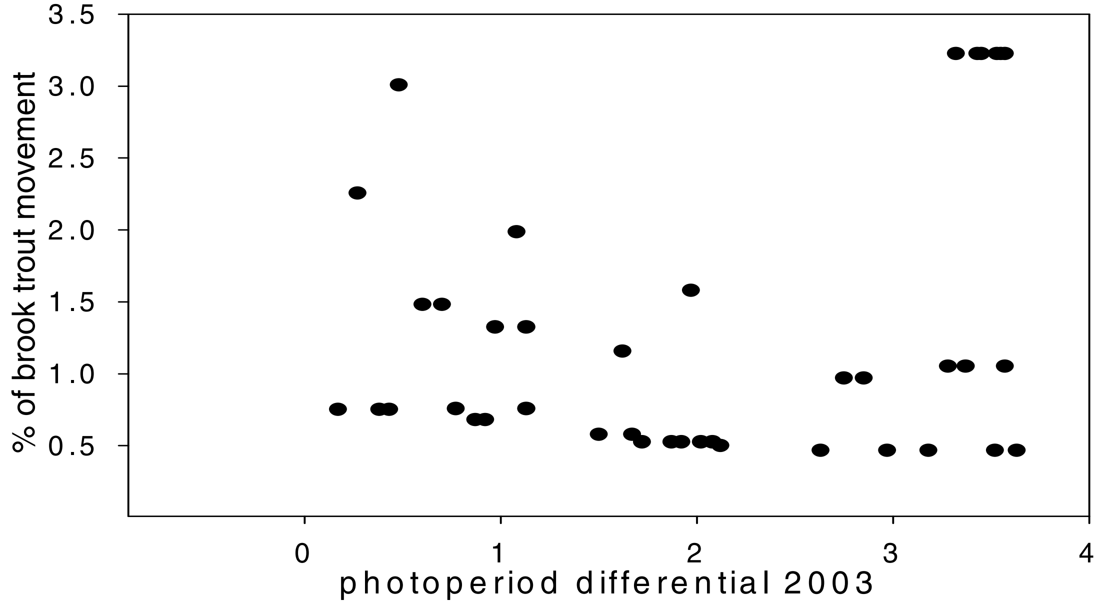


Figure 3.8: Photoperiod differential alongside the daily percentage of wild/feral brook trout detected during 2003. A significant negative correlation between the two existed. (p=0.022, cc=-0.153). PRNL, MI.

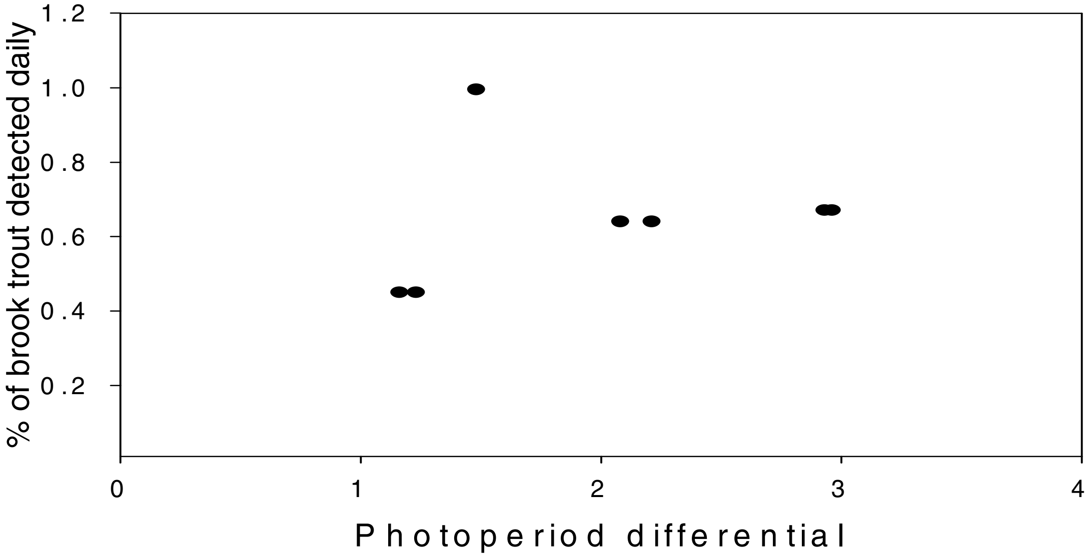


Figure 3.9: The photoperiod differential plotted against the daily percentage of TBH feral fish (2004) showing a negative correlation (p=0.044, cc=-0.181). PRNL, MI.

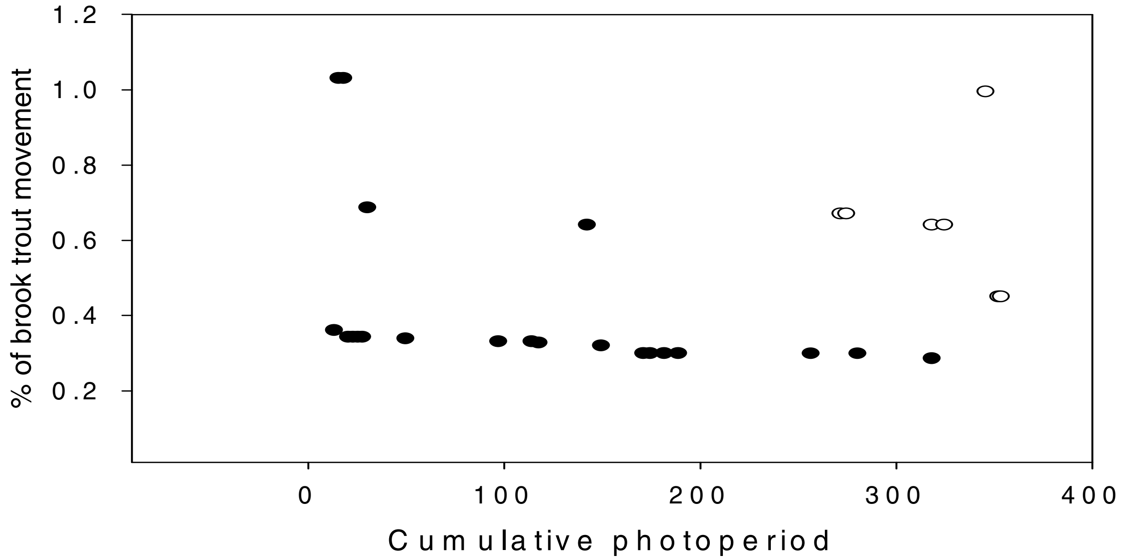


Figure 3.10: The daily percentage of TBH hatchery brook trout [●] and TBH feral brook trout [○] correlated with cumulative mean light hours. TBH hatchery fish showed a negative correlation (p=0.00, cc=-0.328) while TBH feral showed a positive (p=0.00, cc=0.270). PRNL, MI 2004.

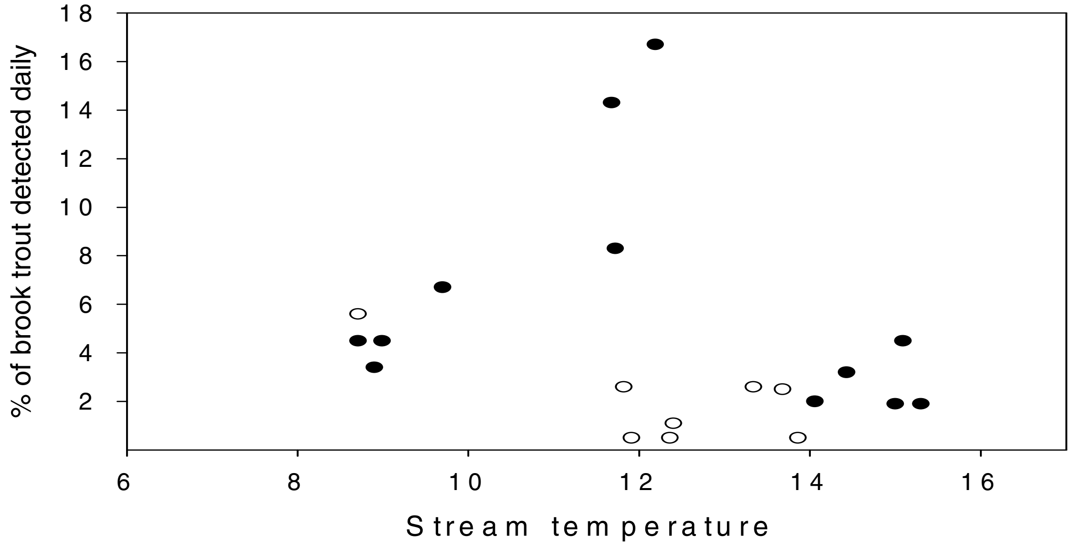


Figure 3.11: The average daily temperature (^{0}C) in Sevenmile Creek, 2004 compared with the percentage of tagged wild brook trout [○] and TBH hatchery brook trout [●] detected daily provided two significant correlations. Wild fish showed a negative correlation (p=0.01, cc=-0.248) as did TBH hatchery trout (p=0.00, cc=-0.260). PRNL, MI.

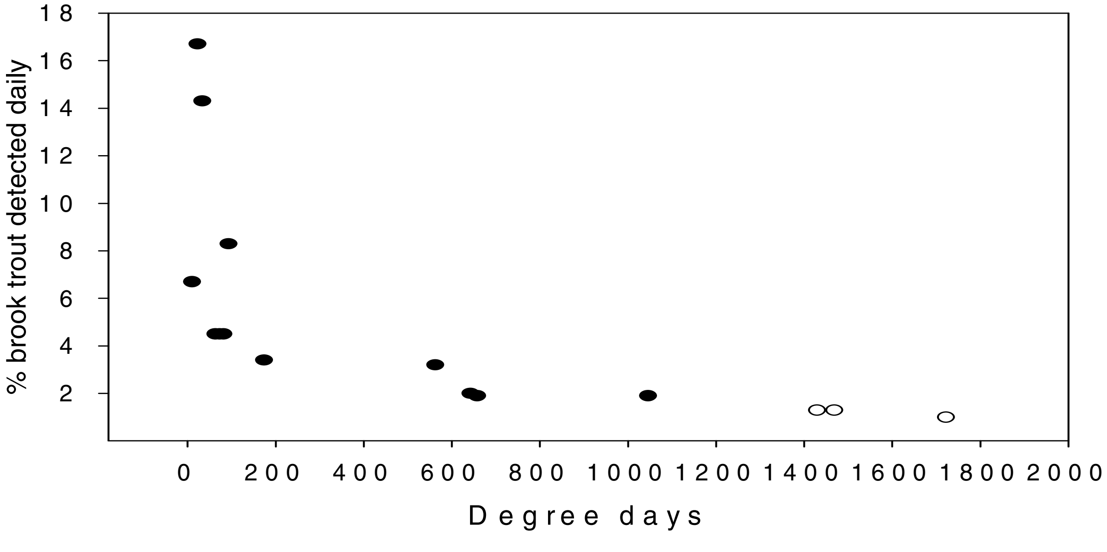


Figure 3.12: Additive daily water temperature (^{0}C) in Sevenmile Creek, 2004 showed significant correlations with the percentage of TBH hatchery brook trout [●] (p=0.00, cc=-0.376) and TBH feral brook trout [○] (p=0.02, cc=-0.213) detected daily. PRNL, MI

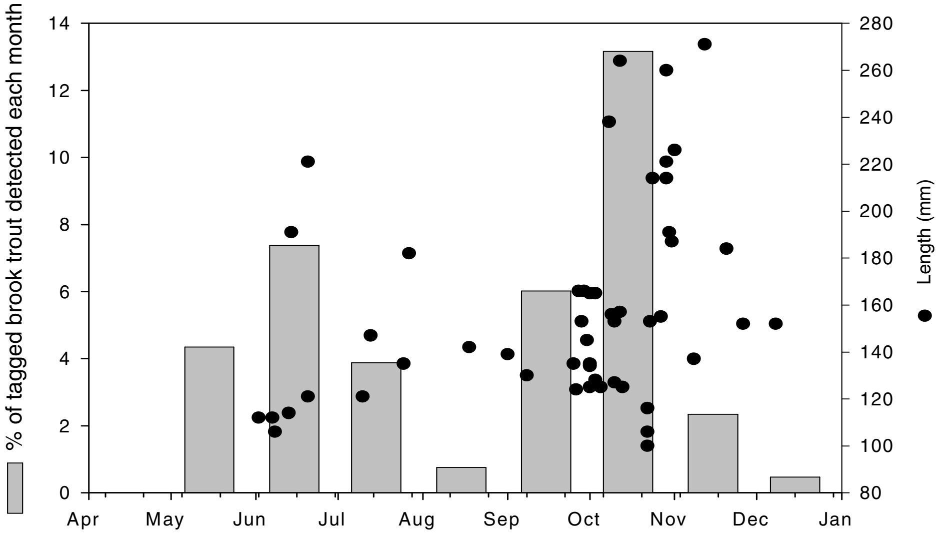


Figure 3.13: Percentage of tagged brook trout detected each month (2003) along with the individual marks of each fish moving designated by their length at time of capture. PRNL, MI

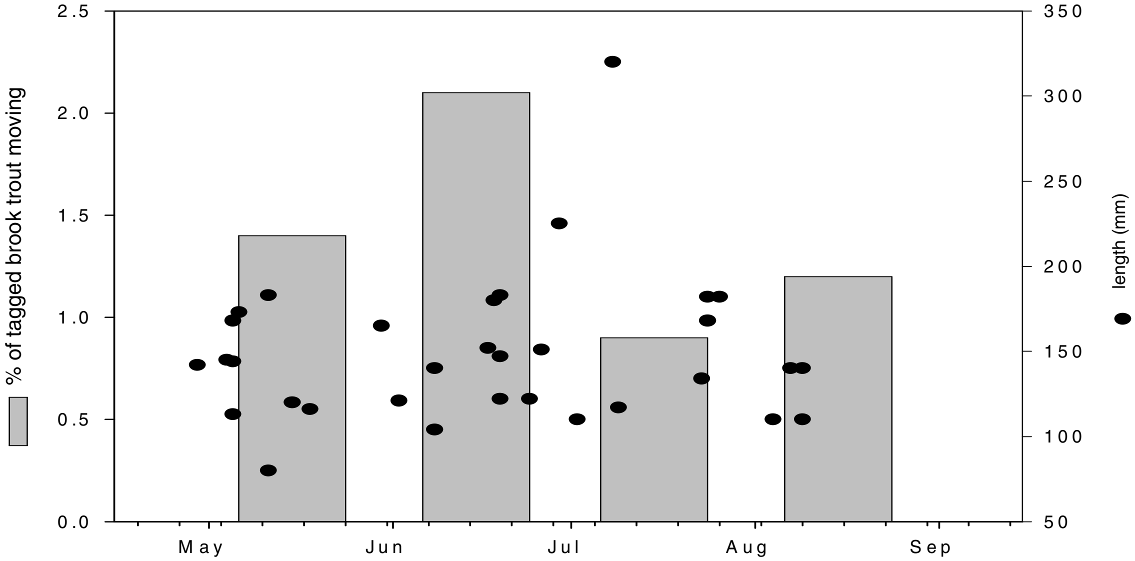


Figure 3.14: Percentage of tagged wild/feral brook trout detected each month (2004) along with individual marks of each fish moving designated by their length at time of capture. PRNL, MI.

CHAPTER 4: A COMPARISON OF CONDITION AND SIZE OF MIGRATORY AND RESIDENT BROOK TROUT (*SALVELINUS FONTINALIS*) IN PICTURED ROCKS NATIONAL LAKESHORE, MI.

CHAPTER SUMMARY

Since 1996, efforts have been made to restore coaster brook trout to tributaries on the south shore of Lake Superior. Brook trout fingerlings and yearlings of Tobin Harbor strain have been stocked in rivers within Pictured Rocks National Lakeshore. Physical condition of brook trout at the season of capture was used to determine if there is a relationship between movement to the lake and a trout's relative nutritional status. Condition factor (K), relative weight (W_r), and length were considered for fish captured during spring, summer, and fall in 2003 (n=214) and for spring and summer 2004 (n=968) for PIT tagged brook trout. Brook trout condition was significantly lower during the fall of 2003 ($p<0.000$). In 2004, condition of wild fish improved while that of TBH feral and hatchery fish decreased ($p<0.000$); lake run brook trout condition increased significantly from spring to summer ($p_k=0.023$, $p_{W_r}<0.032$). These data suggest that there may be differences in metabolic rates or competitive capabilities between migrant and resident brook trout as well as the two different strains.

INTRODUCTION

In tributaries to freshwater lakes or the ocean, some salmonid populations consist of both resident and anadromous forms, a situation known as partial migration (Doucette et al 1999, Genevieve and Rasmussen 2003). It is generally accepted that environmental cues such as photoperiod, water temperature, and discharge are proximate cues for the onset of migration, it is often more difficult to determine which individuals within these populations will adopt a migratory life history. Growth and size are two physical traits that may provide information on whether fish will migrate, but they can be misleading as well. Theriault and Dodson (2003) found that in the Sainte-Marguerite River, Quebec Canada, although there was no difference between the size of age 1+ resident and migrant brook trout (*Salvelinus fontinalis*), at 2+ larger brook trout tended to remain resident while slower growing fish undertook migration to the ocean. These findings suggest that growth or size alone may not be enough to predict migratory individuals and that there may be a particular size and developmental stage combination that impacts life history strategy.

Metabolic rate and the ability to maximize growth and condition in a given habitat are two potential factors that could lead to the migration of select individuals within a population. Anadromous brook trout in Quebec, Canada had higher metabolic rates and lower growth efficiencies than residents (Morinville and Rasmussen 2003). Essentially, these migrants consumed more food and grew less from that consumption than resident fish in the same system. Brown trout (*Salmo trutta*) from an anadromous population in Norway were similar in that migrants maintained higher metabolic rates than residents and may have been unable to capitalize on limited food supplies in freshwater (Forseth et al. 1999). Migrant Arctic charr (*Salvelinus alpinus*) from an oligotrophic lake in Sweden had significantly lower condition factors than residents (Naslund et al 1993). Those authors thought that migrants were unable to compete for food resources with other charr in the lake as opposed to having a faster metabolic rate than residents. The results, however, appear similar to the studies involving different growth rates among migrants and residents. In all cases, future migrants showed an inability to maximize potential in their riverine habitat.

While these data suggest that metabolic rate and competitive ability are key factors in determining which individuals within a partial anadromous population will migrate, size can be an essential aspect as well. This is especially true for those species in the genus Salvelinus which show a less derived form of anadromy than other salmonid genera such as Oncorhynchus and Salmo. Smaller, slower growing age 1+ brook trout in the Sainte-Marguerite River waited an extra year before migrating towards the highly productive estuaries, providing support for the idea of a 'threshold size' for migration in brook trout (Theriault and Dodson 2003, Lenormand et al 2004). These studies support previous findings showing size dependent survival of ocean migrating brook trout where a fish's ability to osmoregulate increases with length (McCormick and Naiman 1984). Size appears to be an important factor in freshwater-to-saltwater migrations of brook trout, it is unclear if there is a threshold size for brook trout migrating within freshwater as greater size would provide no advantage for fish moving between waters with similar salinities. However, brook trout like the coasters of Lake Superior were known for being migratory and for being much larger as adults than their stream-resident counterparts (Baker et al. 1999), which suggests size may be an issue in freshwater migrations as well. Because so little is known about coasters, it is difficult to determine what role body size plays in becoming migratory for freshwater brook trout. While salinity is not a size barrier for these fish, there could be one involving food resources. The above average growth of brook trout in McGee Lake, WI was in part due to their predominantly piscivorous diet (Hunt and Niermeyer 1984). However, fish must attain a certain size to become effective piscivores. East and Magnan (1991) found that brook trout less than

250 mm in length were less effective in fish predation than larger fish. Other studies also have shown that piscivory increases with predator body size (Campbell 1979, Fraser 1981). Thus in freshwater systems, size can not be ruled out as a factor in the determination of a migratory life history.

The first objective of this study was to examine length differences to determine if there was a threshold size for coasters migrating to Lake Superior. The role of length as a determinant is somewhat limited as age of the fish is unknown. Length can be used, however, to determine if there is a significant difference between size in migrant and resident brook trout in PRNL, and therefore suggest a potential critical size at migration. This critical size could be displayed through larger fish migrating to Lake Superior and, if these fish become piscivorous, larger fish returning to spawning grounds in late summer and autumn.

The second objective was to examine the condition factor/relative weight and length of migrant and resident brook trout within PRNL to determine if there might be metabolic or competitive factors that determine which fish will become migrants. If migrants display greater metabolic rates like the salters in Quebec, or are less able to compete with fish as seen with Arctic charr in Norway, they may exhibit a significantly lower condition factor or relative weight than resident fish better adapted to the constraints of stream habitats.

METHODS

Brook trout from three Lake Superior tributaries located in Pictured Rocks National Lakeshore, MI were used in this study. The rivers, located from west to east, were Mosquito River, Sevenmile Creek, and the Hurricane River (Figure 4.1). These three systems contain wild brook trout populations and have also been stocked with fall fingerlings and/or spring yearlings of Tobin Harbor Isle Royale, MI strain (TBH) in an attempt to restore coaster brook trout to this region of the south shore of Lake Superior. Stocking of these hatchery fish occurred in 1996 and 2000-2004 (Table 4.1).

For another portion of this study, stationary RFID (radio frequency identification) systems were placed near the mouth of each of these systems to detect passive integrated transponder (PIT) tagged fish moving to or from Lake Superior in order to determine the timing of brook trout movements. Brook trout were either tagged from electrofishing surveys in these streams or prior to stocking.

Brook trout PIT tagged for movement analysis also were measured (total length mm) and weighed (g) from which a condition factor (K) and relative weight (W_r) (Hyatt and Hubert 2001) were calculated. Both K and W_r are indices of fish stockiness, or how well they are accumulating and utilizing resources in their habitat. All fish tagged during May-June were considered spring tagged fish and movements of these fish, regardless of season, were analyzed based on their spring condition. All fish tagged during July and August were summer fish, and those tagged from September through November were fall fish. Previously-stocked Tobin Harbor brook trout were identifiable by fin clips that had been administered at the hatchery before release.

The brook trout tagged in 2003 (Table 2.2) were categorized as wild/feral and TBH fall fingerlings. Feral brook trout were fin-clipped fish (and therefore of TBH ancestry) that have survived at least one winter in a PRNL stream. During hatchery stocking, two sets of fall fingerlings released previously in the Mosquito River (2001) and Sevenmile Creek (2002) were pectoral-fin clipped only. Only adipose-clipped fish were identified during 2003 and pectoral-fin clipped fish could have been misidentified as wild. Therefore, all non-adipose-fin-clipped fish were grouped into a wild/feral category. These fall fingerlings were not used in the 2003 K and W_r analysis, because they were stocked in the fall and could not be compared to the wild/feral fish tagged earlier in that year as their K and W_r were related to their hatchery residency and not necessarily indicative of their migratory potential.

In 2004, a total of 968 brook trout were tagged (Table 4.3) and were placed into three different categories; TBH hatchery (2004 spring yearlings), TBH feral (all previously released TBH strain fish), and wild PRNL brook trout. Four brook trout from 2003 detected at antennas in 2004 also were included in these analyses.

Length-frequency distributions with fish grouped into 20 mm size intervals were constructed for 2003 and 2004. Univariate ANOVAs were used to compare length and season/behavior for wild/feral fish in 2003 and 2004 to determine if movement to Lake Superior might be size dependent.

Condition factor and relative weight were calculated for all PIT tagged fish. Condition factor, which examines the length/weight relationship between fish, was determined by: $K= W/(L^3) \times 100$ (Neilsen and Johnson 1983) where W is the weight in grams and L is the total length in cm. Relative weight was calculated as: $W_r= W/W_s$ (Neilsen and Johnson 1983) where W is the weight (g) and W_s ($\log_{10} W_{s} = -5.186 + 3.103 \log_{10} TL$) is the standard weight for North American brook trout of the same length (Hyatt and Hubert 2001). Relative weight and condition factor are both indices of how heavy or stocky a fish is. This heaviness is, in turn, an indicator of how well a fish is able to grow and accumulate resources in its present habitat. The condition factor compares individuals against others within the same data set. Relative weight examines the general condition of fish by comparing it to standards for a species throughout its range.

Condition factor is autocorrelated with length and is best used for fish of similar lengths (Neilsen and Johnson 1983). Relative weight nullifies the effects of length, but it is dependent on standard weights determined for this species and in this case has been determined for fish over 120 mm (Hyatt and Hubert 2001). Both K and W_s were used as a safeguard against any bias that might occur from these limitations.

All statistical analyses were run with SPSS 13.0. Univariate ANOVAs were run using K and W_r as dependent variables. In 2003, the grouping factors were season and behavior. Behavior was determined based on data from the stationary RFID system. Tagged fish detected at an antenna were characterized as moving towards or from the lake. These moving fish were referred to as 'migrant' while those remaining undetected are listed as residents. Due to the inability to determine the K and W_r of a fish at the time/season of movement, season was based on the time of capture and tagging. Fish that were tagged during May and June were termed spring fish, those tagged during July and August were summer fish, and those tagged during September through November were fall fish.

For 2004, univariate ANOVAs were run for K and W_s with the grouping factors; behavior, season, and strain. Behavior was based on the same qualifications used in 2003. Season was restricted to spring and summer as only data through August 2004 was considered. Strain was based on three different categories although two categories are of the same Tobin Harbor lineage. Strains 1 and 3 referred to the 2004 TBH spring yearlings and TBH feral fish, respectively, while strain 2 was designated for the PRNL wild fish tagged during 2004.

Equal variances were determined for 2003 and 2004 data sets using Levene's test. Non parametric Kruskal Wallis test and non parametric t-tests were substituted in the event of unequal variance. Where applicable, Tukey's tests were run as post hoc analysis on ANOVA results.

RESULTS

Length distribution

2003

The length distribution pattern for wild/feral brook trout (> 100 mm) captured in 2003 shows a population with a large number of fish between 99-159 mm (n=139) and smaller groupings consisting of fish between 160-220 mm(n=59) and fish greater than 220 mm (n=16) (Figure 4.2). The mean length of migratory brook trout (m=166 mm) was not significantly different from resident fish (mean = 151mm) (p=0.055). Although the migrant and resident fish were similar in length during the spring and summer, those designated as migrant had a length (mean = 193mm) that was significantly larger (p=0.014) in the fall season than the resident fish (mean = 160mm) (Figure 4.3). There was a significant difference for the length by season interaction (p=0.001) which is likely due to growth of all brook trout throughout the summer. No significant effect was found for the interaction of season and behavior (p=0.240).

2004

The 2004 brook trout were divided into three different classifications for length distribution (Figure 4.4). The 2004 distribution for wild brook trout showed the majority of the fish were from 100 to 159 mm (Figure 4.4). Feral brook trout were mostly below 139 mm, with few in the larger length classes. Only 39 feral fish were captured between 140-219 mm, as opposed to 242 wild fish (Figure 2.4) In addition, only four feral fish over 220 mm were captured (16 wild). The distribution of TBH hatchery spring yearlings tagged ranged from 120 to 299 mm; a wide range of lengths for 1+ brook trout. There was a large number of these hatchery fish in the 200-299 mm range (n=227), which is a length class in which far fewer wild and feral fish were seen in 2003 (n=28) and 2004 (n=42) (Figures 4.2 & 4.4).

A significant difference in length was found between strains ($p<0.001$), where a large difference in mean length can be seen between the TBH hatchery fish and the wild and feral trout. There was also a difference in the length of fish when separated by season ($p<0.000$). This effect appears to be a result of tagging many large fish in the spring (TBH hatchery) and many smaller fish in the summer (PRNL wild and TBH feral).

Condition factor (K) and Relative weight (W_r)

Of the PIT tagged brook trout in 2003 (n=214), forty two were detected at an antenna and therefore considered moving fish. The numbers of fish tagged by season were: 95 spring, 39 summer, and 80 fall. K ($p<0.001$) and W_r ($p<0.001$) of fall-season fish differed from spring and summer fish (Figure 4.5). Fall-season brook trout had a lower condition than those captured in other seasons, which suggest that fish had been spawning. No significant differences were observed with behavior or the behavior/season interaction when using K and W_r as dependent variables. These results show a change in the general condition of brook trout over the different seasons, but no difference between the migratory or resident fish or the two behaviors from spring to summer. K and W_r were highest in the spring, declined slightly into the summer and then sharply from summer to fall.

The PIT tagged brook trout of 2004 (n=968) were grouped by behavior and season as in 2003 and also by strain. Through August 31, brook trout detected at an antenna system were determined to be lake-run. The seasonal tally included 645 fish tagged in the spring and 323 tagged during the summer. The different strains tagged included the TBH spring yearlings (n=351) and the wild/feral (n=617). A univariate ANOVA that compared wild and feral strains showed differences between both K (p=0.003) and W_r (p=0.003) with the strain x season interaction. For this reason, all three groups (wild, TBH feral, and TBH hatchery) were separated out during the K and W_r comparisons.

In univariate ANOVAs using K as the dependent variable; significant differences were found among strain, strain x season interaction, and season x behavior interaction. Among strains (p=0.00) (Figure 4.6) significant differences in K were found in all three categories with wild PRNL strain fish highest, TBH feral moderate, and TBH hatchery lowest. In strain x season (p=0.00) (Figure 4.7), TBH hatchery and feral fish declined in condition while PRNL fish showed a slight increase over time. The season x behavior (p=0.023) (Figure 4.8) showed lake-run fish having a lower K than resident fish during the spring, but a greater K during the summer. No significant differences were found in K with season (p=0.810), behavior (p=0.930), or strain x behavior (p=0.786). Similar results were found when using W_r as the dependent variable. Strain (p=0.000) (Figure 4.6), strain x season (p=0.000) (Figure 4.7), and season x behavior (p=0.032) (Figure 4.8) all presented similar differences as seen in the K data analysis, while season (p=0.667), behavior (p=0.963), and strain x behavior (p=0.820) showed no differences.

While post hoc analysis of the K x strain interaction showed significant differences (<0.05) between all three trout categories, in the W_r analysis significant differences were found between wild and feral (p=0.001) and wild and TBH hatchery (p=0.001) but not between feral and TBH hatchery (p=0.253) (Figure 2.6).

Within the season x strain interaction, a significant difference was found within K (p=0.003) and W_r (p=0.003) in the wild/feral comparison, but not in the wild/TBH hatchery or TBH hatchery/TBH feral comparisons.

DISCUSSION

Length Distribution

Overall, despite a difference in numbers and strain categories, the two length frequencies show similar trends in wild and feral fish size distribution during 2003 and 2004. Larger numbers of small fish dominated the populations with far fewer larger fish. Michigan Department of Natural Resources regulations that increased the length of legal brook trout in each of these streams to 46 cm were established in 2002. Additionally, the legal length limit on brook trout caught in Lake Superior was changed from 25.4 cm to 50.8 cm in 2005. It will be important to see if these restrictions result in an increase in the number of larger fish present in these systems. While it appears that size does not play a significant role in movement to and from Lake Superior for these brook trout, the mean length of moving fish was consistently larger in both 2003 and 2004. Perhaps a greater number of larger fish present, a potential result of decreased angler mortality, will provide more individuals moving between lake and stream habitats.

Larger fish would be better prepared to take advantage of Lake Superior's food supply. East and Magnan (1991) found that the number of fish found in stomachs of brook trout increased with body size and that brook trout began using fish more extensively as a prey base when they reached 200-250 mm in size. Although the mean length of migrants in PRNL was 160 mm in 2003 and 173 mm in 2004, below the minimum of 200-250 mm, brook trout may still be able to prosper in a lacustrine habitat by using the areas where Lake Superior and the tributaries meet or by moving in and out of the tributary intermittently. With more brook trout approaching the threshold size range of 200 mm, fish may become a larger part of their diet. Fish as a food source might also provide better growth and subsequently produce larger brook trout (Hunt and Niermeyer 1984). The spring yearling TBH brook trout were stocked at larger sizes (many over 250 mm) and many went into Lake Superior and other streams located within PRNL. This outpouring of fish into Lake Superior is most likely dispersal caused by placing 7,600 larger brook trout in a 200-meter stretch of stream with a barrier upstream and Lake Superior downstream. Regardless of the method by which these fish entered the lake, it is interesting to note that many are of a size where they should be able to adequately use fish as a prey base (as well as avoid becoming part of another piscivore's prey base) and may be able to successfully survive and grow as coasters.

Condition factor (K) and Relative weight (W_r)

Seasonal changes of brook trout condition were similar during spring and summer in both 2003 and 2004 (PRNL wild and TBH feral fish combined). In both years, brook trout had greater K in the spring (May and June) and lower in the summer months (July and August). Power (1980) noted that slow-growing brook trout populations completed their annual growth by mid July. Perhaps this trend is caused by feeding opportunities occurring in the spring of which brook trout are able to take advantage, allowing them to add mass earlier in the year. One explanation for the increased spring condition could be the occurrence of migratory fish found in the PRNL region of Lake Superior. All three of these study rivers, along with all of the adjacent streams, have naturalized runs of *O. mykiss* beginning in April and ending in early June. The Hurricane River and Sevenmile Creek also have sizable longnose sucker (*Catostomus catostomus*) runs from late May through mid June. In some instances, brook trout captured during these times have regurgitated steelhead eggs and they have also been observed actively taking loose eggs behind actively spawning steelhead (personal observation). Perhaps this influx of a highly nutritious, fatty food early in the year made it possible for these brook trout to substantially improve their K before the summer season during these two years.

When separating the PRNL strain, TBH hatchery and feral strain fish in 2004, there was a different trend in K from spring to summer. Both TBH hatchery and feral brook trout had higher mean K during spring than in the summer. In contrast, PRNL wild brook trout had higher mean K in the summer. The TBH feral fish initially had a higher mean K than the wild fish, while the TBH hatchery fish began with a much lower mean condition than either feral or wild fish.

The lower K and W_r of these spring yearlings was perplexing. These fish came directly from a hatchery with a constant supply of food which should have propagated brook trout with at least comparable condition to those in the wild. Interestingly, this trend of declining condition into the summer was mirrored by the TBH feral fish captured but not the wild fish. These data present more evidence for physiological (i.e. metabolic) differences between PRNL and TBH strains. Sreenivasin (2006) found that Tobin Harbor strain brook trout displayed physiological traits suggesting greater metabolic rates than wild PRNL fish. TBH brook trout, from a coaster strain, with a higher metabolism would be analogous to ocean migratory brook trout of Canada (Morinville and Rasmussen 2003). If this is the case, it is possible that the wild fish with slower metabolic rates, and therefore lower energy demands, are able to meet nutritional needs while feral TBH trout, with higher metabolic demands, cannot even though the same food resources are available to each. In this situation, brook trout unable to meet nutritional needs within the stream may become migratory (Morinville and Rasmussen 2003). It is also possible that the TBH feral fish have lower conditions from their first winter as stream fish. The majority of the TBH feral fish captured in 2004 were from the previous year's stocking (September 2003) and perhaps this uniform age structure as well as 2003-2004 being their first year in the wild affected their K and W_r through a decreased ability to compete and capture food.

The analyses using K and W_r in 2003 and 2004 also show potential for metabolic and/or competitive differences between lake run and resident fish. While not statistically different, lake run brook trout displayed a greater mean K and W_r during the spring and summer seasons in 2003. In 2004, migrant brook trout condition was less than that of resident fish during the spring, but greater during summer. This could be due to metabolic differences or competitive differences within the two types of brook trout. A higher metabolic rate would be advantageous to brook trout during times of high food availability. Conversely, stream residents with lower metabolic rates might not be able to take full advantage of high food availability, but would be better equipped for survival in streams when resources are less abundant.

In 2004, a significant difference was found in the season/behavior analysis, with lake-run brook trout having a lower K than resident fish in the spring and a higher K in the summer. This is different than in 2003, where the lake-run fish having slightly higher K during spring and summer, and then dropping to equal or slightly less than that of resident fish during the spawning season. Perhaps in 2003 conditions allowed for a greater availability of resources in the spring allowing fish with greater metabolic rates the chance to improve condition earlier. It is possible that migrant fish with lower K/W_r in the spring of 2004 were the ones that, whether due to metabolic rate or inability to compete for resources, moved to the lake. In the same light, those fish tagged in the summer might have been fish using Lake Superior that had already benefited from this move.

The results of this chapter point to some differences in size and condition that discriminate between the two strains of brook trout. Whether these metabolic differences are due to the TBH brook trout being from a known coaster strain, or if these are differences in two populations of brook trout that have evolved based on the environment and conditions endemic to each area is yet unknown. However, it appears that even when TBH and PRNL fish are analyzed together, those fish determined to be lake-run are showing trends that point towards there being a difference in condition between them and resident fish. Based on this, it seems that in each strain there may be some brook trout displaying characteristics that may lead to becoming a coaster.

Table 4.1: The stocking record of Tobin Harbor strain brook trout in PRNL (1997-2005) showing the month, age, and number of fish stocked as well as the rivers into which that year's stocking were divided.

Year	Month	Age	Total stocked	Locations
1997	June	0+	5 860	Hurricane & Mosquito R.
2000	May	1+	25 000	Hurricane R., Mosquito R., Sevenmile Cr.
2000	October	0+	28 130	Hurricane R., Mosquito R., Sevenmile Cr.
2001	October	0+	27 650	Hurricane R.*, Mosquito R., Sevenmile Cr.
2002	September	0+	27 000	Hurricane R.*, Mosquito R**., Sevenmile Cr.
2003	September	0+	36 120	Hurricane R., Mosquito R., Sevenmile Cr.
2004	April	1+	7 500	Hurricane R.
2005	April	1+	7 500	Hurricane R.

* Brook trout in Hurricane River stocked above falls ant Hurricane R. truck trail.

† Brook trout in Mosquito River stocked above falls.

Table 4.2: Numbers of brook trout tagged in PRNL during 2003 organized by strain, month, and river.

2003									
Strain	**River**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Totals**
2003 wild/TBH feral	**Hur**	12	18	8	19	1	19	0	77
	Mos	11	54	0	10	0	4	10	89
	Svn					0	34	14	48
	Totals	23	72	8	29	1	57	24	214
2003 Fall fingerling TBH strain	**Hur**					74	0	0	74
	Mos					89	0	0	89
	Svn					69	0	0	69
	Totals					232	0	0	232
totals		23	72	8	29	233	57	24	446

Table 4.3: Numbers of brook trout tagged in PRNL during 2004 organized by strain, month, and river.

2004							
Strain	**River**	**April**	**May**	**June**	**July**	**August**	**Totals**
2004 TBH spring yearlings	**Hur**	278	3	14	0	0	295
	Mos	0	0	0	0	0	0
	Svn	0	19	19	0	18	56
	totals	278	22	33	0	18	351
PRNL wild brook trout	**Hur**	0	4	43	34	7	88
	Mos	0	4	27	43	22	96
	Svn	0	39	52	48	72	211
	totals	0	47	122	125	101	395
TBH feral brook trout	**Hur**	0	0	2	0	0	2
	Mos	0	7	72	0	45	124
	Svn	0	4	58	6	28	96
	totals	0	11	132	6	73	222
Total	**all rivers**	278	80	287	131	192	968

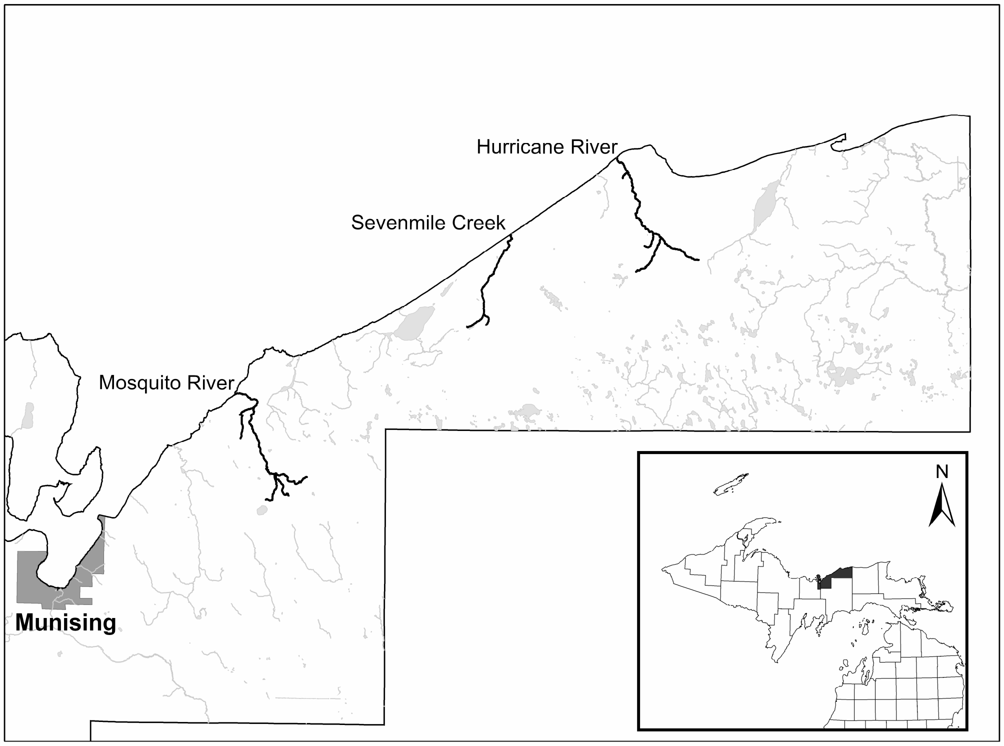


Figure 4.1: Location of the three principle study streams within Pictured Rocks National Lakeshore, MI 2003-2004.

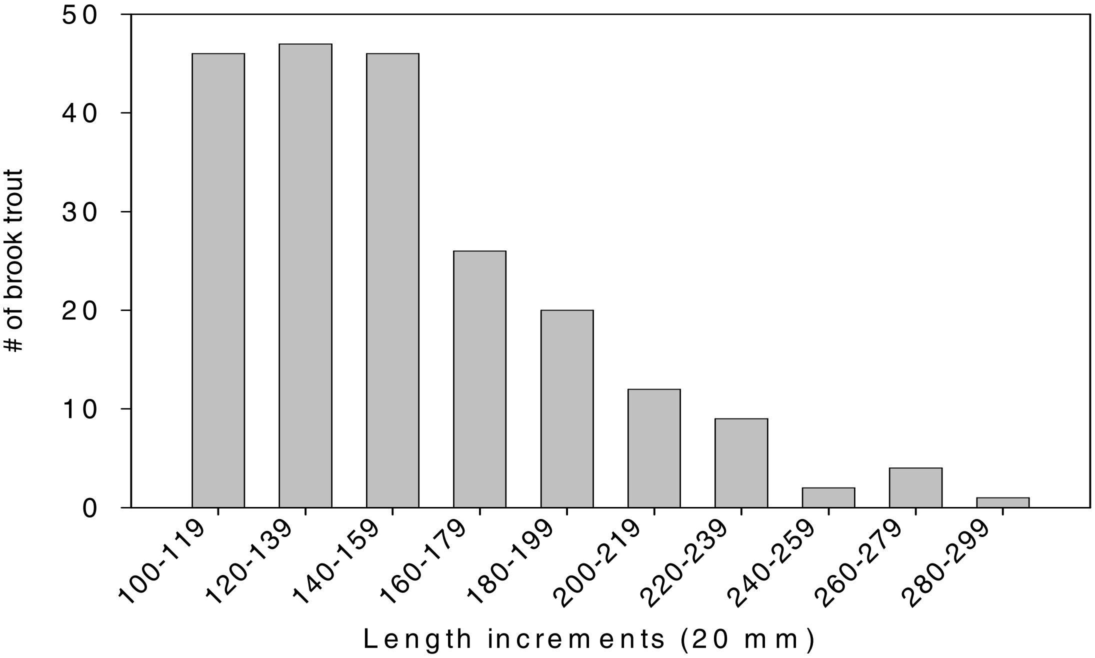


Figure 4.2: Length distribution of all brook trout PIT tagged over 100 mm in three PRNL, MI rivers May – November 2003 (n=214).

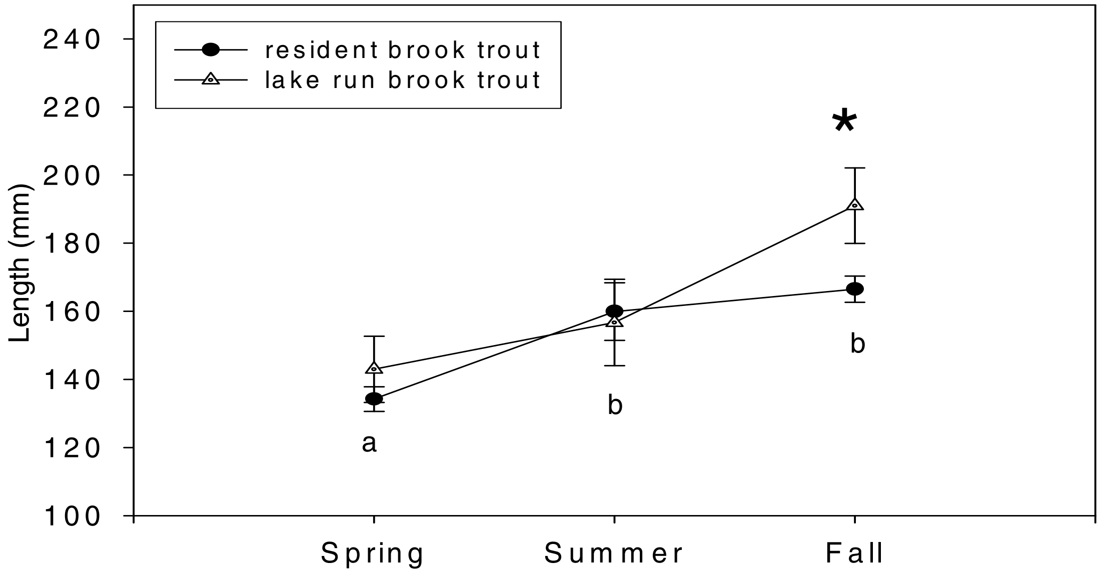


Figure 4.3: Mean length difference over three seasons between resident (n=172) and lake run brook trout (n=42). During the fall season lake-run fish were significantly larger than resident (*) [p=0.014]. Overall, brook trout were significantly larger in the fall and summer (b) than in spring (a) [p<0.001]. PRNL, MI 2004.

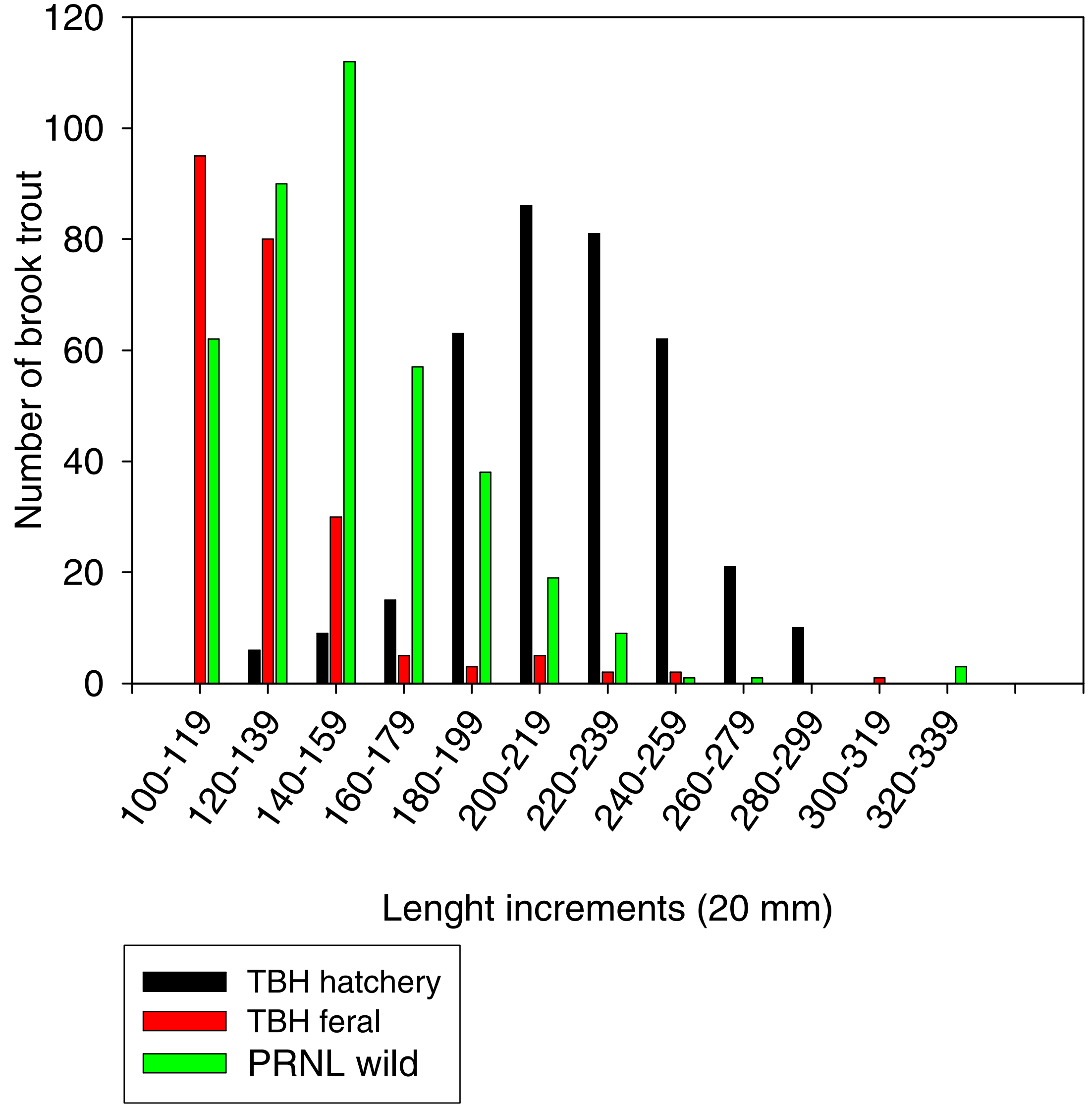


Figure 4.4: Length distribution of PIT tagged TBH hatchery, TBH feral, and PRNL wild brook trout in three PRNL streams in 2004 (n=968). PRNL, MI.

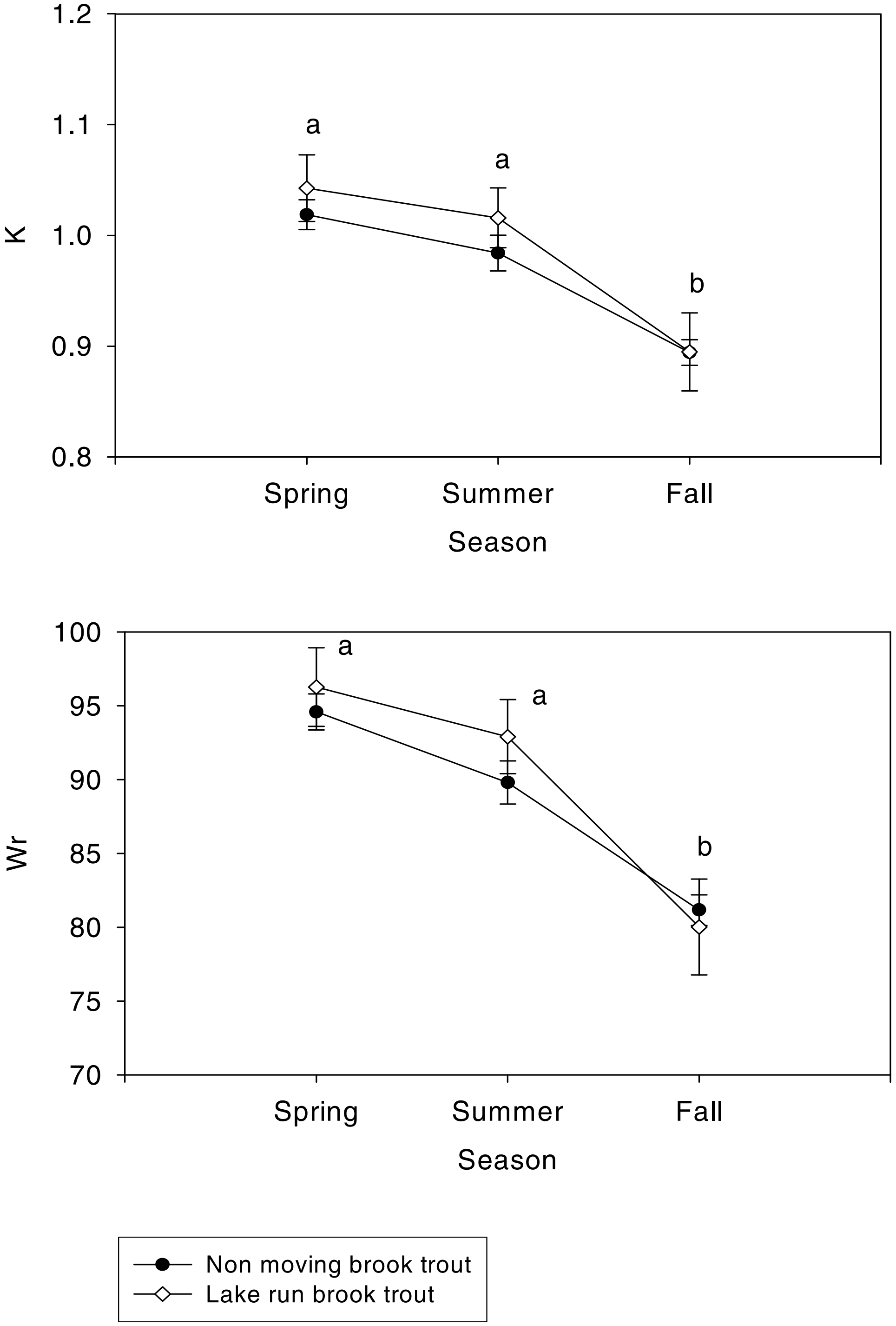


Figure 4.5: Mean seasonal condition factor (K) and relative weight (W_r) of lake run (n=42) and resident (n=172) PIT tagged brook trout (n=214) in PRNL, MI 2003. Fall condition (b) was significantly lower than spring and summer (a) [p<0.000].

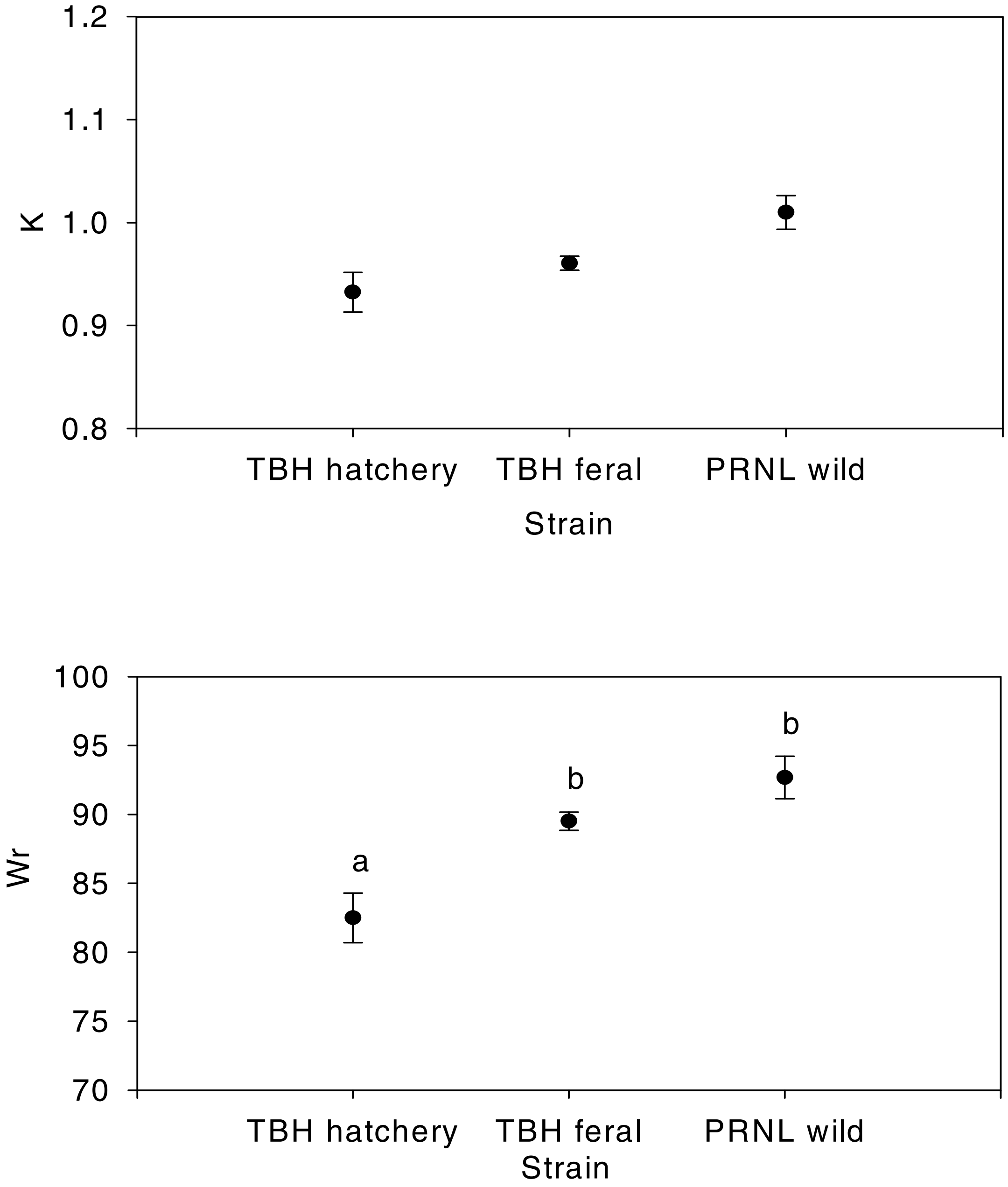


Figure 4.6: Mean condition factor (K) and mean relative weight (W_r) between brook trout strains in 2004 (n=926). While all strains differed significantly in condition (K) the significant difference in relative weight (W_r) was between TBH hatchery (a) and TBH feral strains and PRNL wild (b) [$p<0.000$]. PRNL, MI.

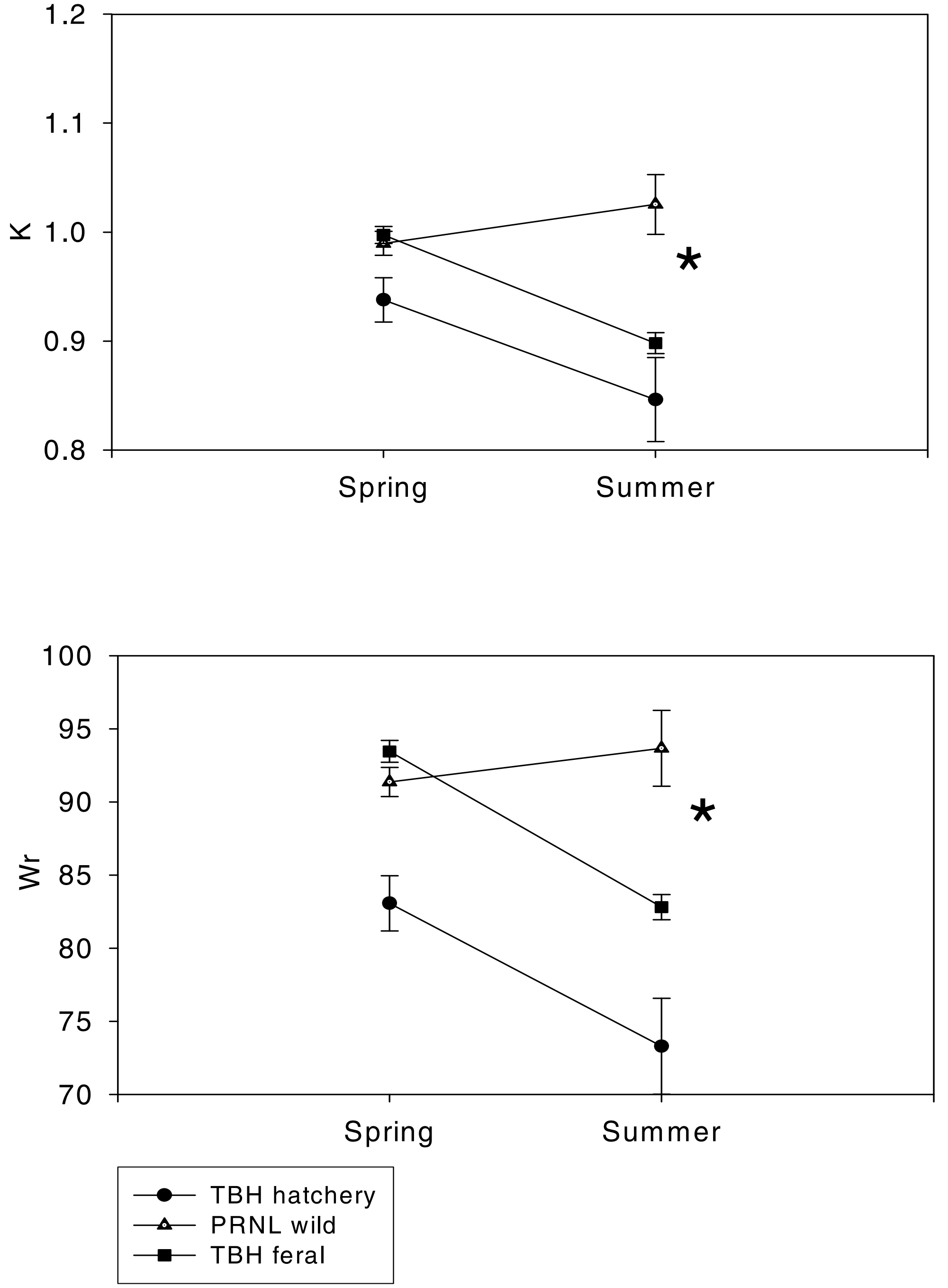


Figure 4.7: Mean condition factor (K) and relative weight (W_r) of PRNL wild (n=392) and, TBH feral (n=221) and hatchery brook trout (n=313) tagged in PRNL, MI 2004. Condition and relative weight were significant for the wild and TBH feral interaction from spring to summer (*) [p=0.003, 0.003].

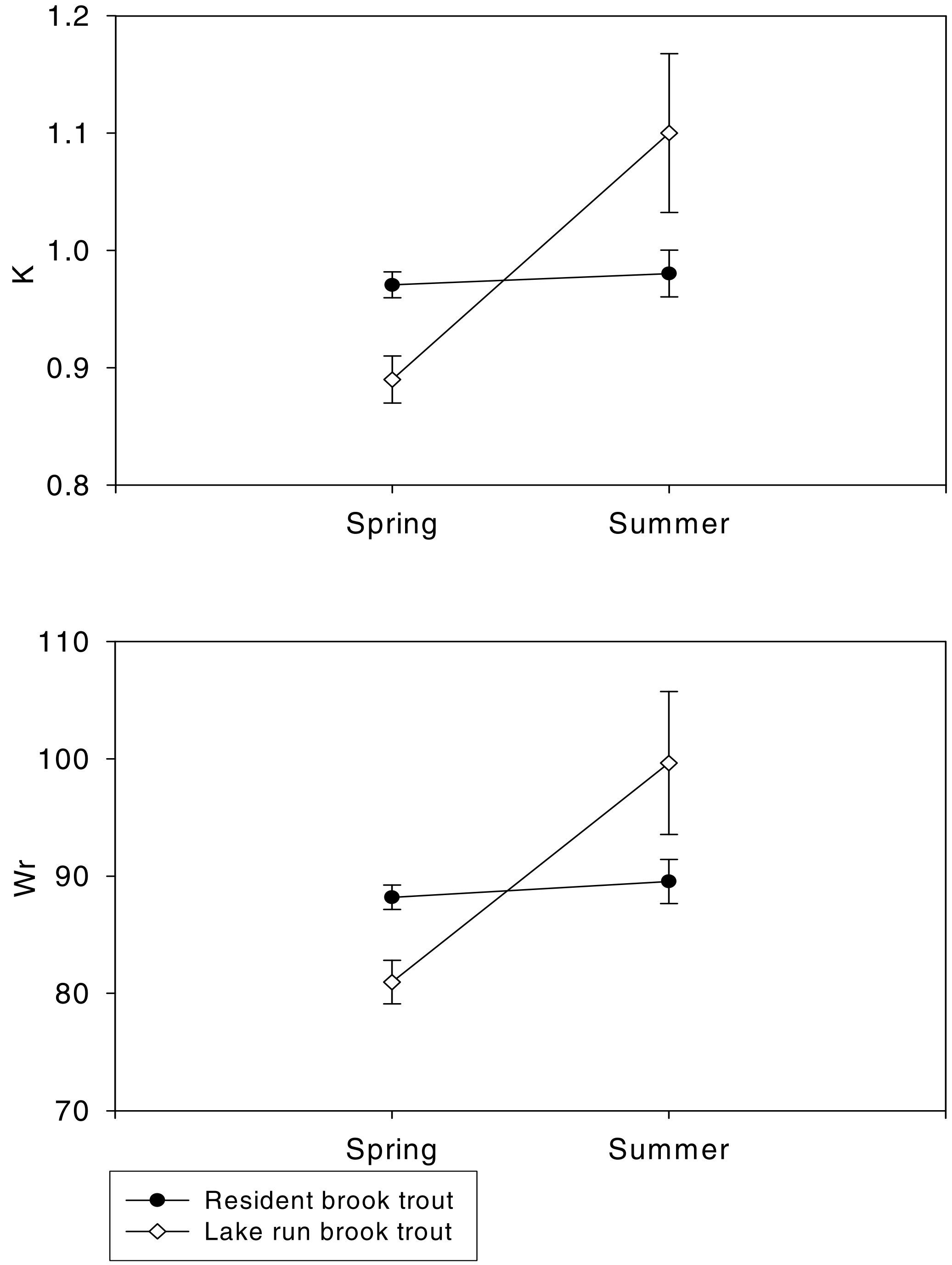


Figure 4.8: Mean condition factor (K) [p=0.023] and relative weight (W_r) [p=0.032] during spring and summer of 2004 between lake run (n=42) and resident brook trout (n=884). Lake run fish initially showed lower condition but were on average significantly higher by summer. PRNL, MI

CHAPTER 5: CONCLUSIONS

The majority of migratory brook trout were lost to Lake Superior's tributaries due to exploitation and habitat destruction by the early part of the 20th century. Recent efforts to restore coaster brook trout to regions of the south shore of Lake Superior have led to the stocking of TBH strain brook trout in three rivers in PRNL. In an effort to examine the migratory timing and selected environmental cues to movement, stationary RFID antennas were positioned near the mouths of these three rivers to detect PIT tagged brook trout moving to and from Lake Superior. Additionally, brook trout condition was measured prior to tagging to determine if it was a factor in migrant behavior.

It appears that RFID systems can be an effective method of monitoring tagged fish within remote streams and rivers. Once a system is put in place it provides continuous 24 hr monitoring without blocking up or downstream movements the way a weir or nets might do. PIT systems, after the initial tagging, allow less handling of fish as they can be monitored without recapture.

The main concerns in using a RFID system in remote locations are centered around two themes; power supply and antenna size. Antenna size, also a concern in less remote locations, affects the read range of the system. A large antenna (> 6 m) using the materials in this study can create gaps in the coverage across the stream or even reduce the effective read range of the system to the point where fish moving in fast water might be missed. The most limiting factor in remote locations of PRNL is the ability to supply power continuously to the RFID system. All of the decisions necessary to choose the proper power supply (number of batteries and supplemental power sources) depend on the location that is being used. It should be noted that the further a site is from vehicle access, the more important it is to select a compromise between power longevity and ease of transport. Ultimately, a supplemental power supply (i.e. solar) may be the best option for prolonging system run time.

Brook trout were most active in the spring and fall during 2003 and during the spring of 2004, although activity occurred during all months that the systems were running. The majority of brook trout movement was in the Hurricane River in 2003. The addition of TBH hatchery strain, as well as separately evaluating the wild and feral brook trout, complicated the analysis of these rivers in 2004. Overall, movement was still highest in spring rather than summer, but percent activity was much less than in 2003. There was not really a strong differentiation in the spring and summer movements as in 2003. Far fewer fish were found below the falls in the Hurricane River which might have had an effect on seasonal movements as all of the 2003 spring activity data is from this river. It could be that the addition of larger TBH hatchery fish created a less hospitable environment for smaller wild and feral fish moving down the Hurricane River or in from Lake Superior at this site.

Overall it appears that low numbers of small wild and feral TBH brook trout, most under 180 mm, use Lake Superior and within this number there are a few that move to other tributaries. Restrictions on brook trout harvesting and an increase in legal harvest length may result in an overall increase in the size of these brook trout in the future. This activity throughout the year by smaller brook trout is thus far more similar to the movements found in Elerslie Brook salters (Smith and Saunders 1958) than any of the other migrant brook trout studies. The similarity in wild and TBH feral fish (a lacustrine stock) behavior in these PRNL streams suggests that environmental conditions may be an important factor in the behavior of brook trout in these streams.

Movements of tagged brook trout were correlated with photoperiod differential in 2003. In 2004, when looking at only TBH feral and hatchery fish during the shortened spring and summer field season, there was a correlation with photoperiod and movement. Photoperiod is used by many species of salmonids as a cue for out migrations as well as those returning on spawning runs, and its use by brook trout as an environmental cue for movement and spawning is not necessarily unusual.

Interestingly, the two other environmental factors documented as cues for migration, rainfall (substitute for discharge) and stream temperature, do not appear to play a larger role in these seasonal movements. Stream temperature did play a role during the shortened 2004 season, but only in Seven Mile Creek. While all of these data is based on a small amount of movement, it may be that water temperature plays a permissive role in brook trout movements that is more noticeable in Seven Mile Creek with its unique hydraulic qualities.

Although we can see that small numbers of brook trout, both PRNL wild and TBH strain, are using Lake Superior at some level, and that their movements are correlated to photoperiod (and perhaps water temperature to a lesser degree), it is less clear which individuals will move to the lake and which will remain resident. Recently, both size and metabolic rate have been found to be determinates in brook trout migration to estuaries (McCormick and Naiman 1984, McCormick and Naiman 1985, Lenormand et al 2004). When examining the transient and resident brook trout in PRNL, no significant difference in length was discovered. However, in 2003, when spring, summer, and fall seasons were examined, there was a greater mean length of lake-run fish relative to resident fish and this trend is more clearly seen in the greater length of moving fish relative to resident fish in the fall of 2003. In saltwater scenarios, the greater size at migration is an advantage as larger brook trout will be better able to adapt to the shift in salinities. While salinity is not an issue in fresh water, it is possible that there is a different size selective factor (such as ability to successfully capture prey) that may affect lake migrations. Greater size would be an advantage in that larger brook trout are better able to use a fish prey base (East and Magnan 2001). Using fish as a prey base might also create greater growth rates (Hunt and Niermeyer 1984). Given these two possibilities, it seems reasonable that migrant fish would be larger than residents and perhaps continued research coupled with the recent change in regulations for brook trout in Lake Superior will show this.

Condition factor and relative weight were used to determine the success of brook trout within PRNL compared to others within this population as well as throughout the range. There were no significant differences in K and W_r during 2003 that would indicate either of these factors played a role in determining whether or not to move to the lake. In 2004, K and W_r of lake-run brook trout began lower than resident fish in the spring but were higher later in the summer, suggesting that fish using the lake may have initially been at a disadvantage, but that they were able to increase their K and W_r to levels that were greater than resident fish. One of the explanations for this is that lake-run fish may have greater metabolic rates, leaving them unable to compete in resource-poor environments where resident fish, with lower metabolic rates, can thrive. Perhaps in Lake Superior, these fish are able to take advantage of a little used environment or a more nutritious food resource (fish) that allows them to fully realize their metabolic potential.

When examining the K and W_r between strains, there is perhaps more evidence for metabolic differences in PRNL. THB strains in 2004 decreased from spring to summer while PRNL strains increased. While this does not take into account migrant or resident groups, it does suggest that perhaps the TBH fish (which are considered a coaster strain) have greater metabolic rates than PRNL fish in general, which might make them more likely to adopt a migratory lifestyle than other brook trout. A previous study has shown physiological differences in TBH fish that indicate they do exhibit higher metabolic rates than PRNL fish (Sreenivasin 2006).

Brook trout can be monitored using RFID technology in PRNL for at least three seasons of the year. Within this spring to fall time period, we see an increase in migrant activity in the spring, when water temperatures and daylight hours are increasing, and fall, when water temperatures and daylight hours are decreasing. Photoperiod is the only environmental cue that appears to correlate with the movement of brook trout in PRNL, although water temperatures may also play a role. Brook trout condition, due to metabolic or competitive differences, shows potential differences in lake-run and resident fish as well as between the PRNL and TBH strains.

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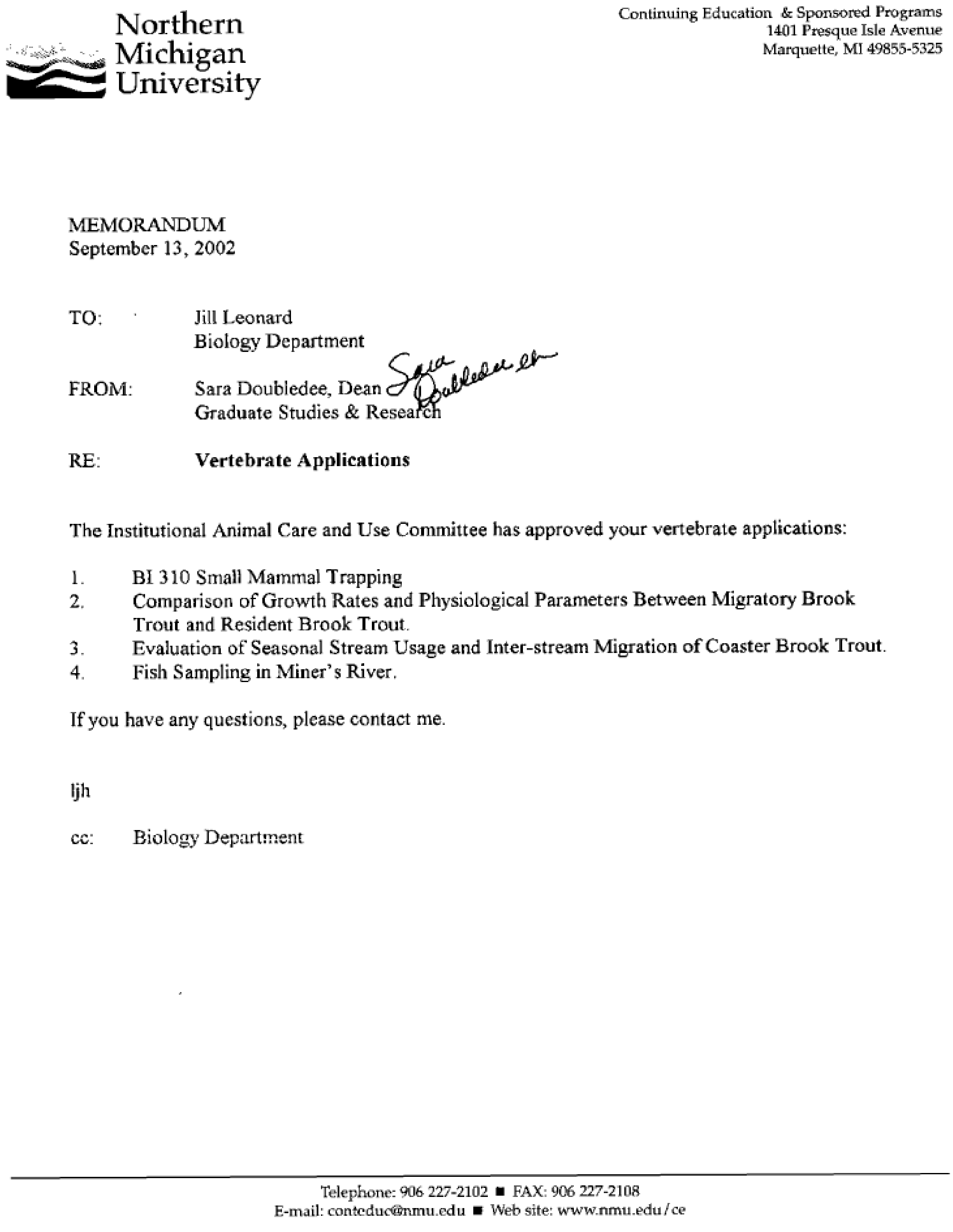
APPENDIX

APPENDIX



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MEMORANDUM
September 13, 2002

TO: Jill Leonard
Biology Department

FROM: Sara Doubledee, Dean Sara Doubledee
Graduate Studies & Research

RE: **Vertebrate Applications**

The Institutional Animal Care and Use Committee has approved your vertebrate applications:

1. BI 310 Small Mammal Trapping
2. Comparison of Growth Rates and Physiological Parameters Between Migratory Brook Trout and Resident Brook Trout.
3. Evaluation of Seasonal Stream Usage and Inter-stream Migration of Coaster Brook Trout.
4. Fish Sampling in Miner's River.

If you have any questions, please contact me.

ljh

cc: Biology Department

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