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Habitat use, movement patterns, and home ranges of coaster brook trout in Nipigon Bay, Lake Superior

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Habitat Use, Movement Patterns, and Home Ranges of Coaster Brook Trout in Nipigon Bay, Lake Superior

by

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Graduate Program in Biology

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ABSTRACT

Coaster brook trout are one of two salmonine species native to Lake Superior. Abundant and widely distributed in Lake Superior a century ago, they have been reduced to a few remnant stocks due to exploitation and habitat loss. Twenty coaster brook trout, captured from Nipigon Bay, Lake Superior were surgically implanted with radio transmitters and were located from June 1999 to October 2000. Coaster brook trout locations were used to determine the characteristics of utilized lake habitat, identify streams and the critical habitat characteristics within them utilized for spawning, and establish home ranges and movement patterns on a daily and seasonal time scale. A total of 638 locations were obtained during the tracking period with 483 locations within Nipigon Bay and the remaining 155 within tributary streams. Coaster brook trout were located almost exclusively within the shallow nearshore areas of Nipigon Bay with 92% of locations in areas less than 7 m deep (mean depth = 3.4 m), and 94% less than 400 m from shore (mean distance to shore = 116.1 m). Coaster brook trout inhabited deeper areas (ANOVA, F=3.533, p=0.002) with steeper shoreline slopes (ANOVA, F=2.562, p=0.013) during July and August when the water temperature of shallow nearshore areas became higher than their tolerable limit. Following selected individuals for 24 hours revealed coaster brook trout utilized deeper areas during daylight hours and moved to extremely shallow nearshore areas during the night (ANOVA, F=3.187, p=0.02). Home range estimates for individual coaster brook trout using a 95% fixed kernel varied from less than 1 km to 185 sq. km. in size. Home range size was not correlated with the number of locations for the individual (r^2=0.046), or fork length (r^2=0.009). Tagged coaster brook trout began ascending streams during late summer in both 1999 and 2000. The mean residency time for brook trout in spawning tributary streams in 1999 was 46 days. Spawning occurred in early October with most tagged coaster brook trout returning to Lake Superior by mid-October. Four different streams were used by tagged coaster brook trout, with all brook trout entering streams exhibiting strong spawning site fidelity. Catchment size of spawning streams varied from 8.38 sq. km to 288.04 sq. km, but stream reach characteristics of spawning areas were similar, exhibiting a moderate gradient, riffle-pool complexes, coarse sands and gravels, and groundwater input. These results suggest that coaster brook trout utilize specific areas depending upon the time of year. Protection of these identified areas is critical to maintain these remnant natural stocks.

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This thesis is dedicated to my father, Richard Mucha who passed away shortly before this project started.

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Introduction

Similar to all organisms, fish utilize specific habitats and exhibit movement patterns driven by a myriad of physical, chemical, and biological factors (Moyle 1993). Prominent physical factors which contribute to the utilization of specific areas within an aquatic environment include temperature, light, water currents, and substrate. Chemical factors affecting the distribution of fish comprise oxygen, pH, and salinity. Predator-prey interactions and competition are foremost among biological factors affecting habitat use and movements of individuals. Successful management of a species or population relies heavily upon protecting those habitats which are critical to the success of the organism. Identification of critical habitat and an understanding of how it is used forms the foundation for sound management.

Brook trout are distinguished from other members of the genus *Salvelinus* by their large head, vivid colouration, and flat edged tail (Power 1980). Colour varies from olive green to brown with light green vermiculations, and red spots with blue halos. This colouration generally intensifies during the spawning season (Wilder 1952). The brook trout is indigenous to eastern North America and is particularly abundant within its native range in Ontario, Quebec, Newfoundland, New Brunswick, Nova Scotia, Maine, Vermont, New Hampshire, and upper New York (Power 1980). The native range also extends westward along the coast of Hudson Bay; borders the Great Lakes in Minnesota, Wisconsin, and Michigan; and extends south along the Appalachian mountains to Georgia (Power 1980). The original range of the brook trout has expanded through introductions to now include much of western North America, and to a lesser extent South America, New Zealand, Asia and Europe (Scott and Crossman 1973).

Throughout its range the brook trout exhibits considerable variation in life history strategies, reproduction, behaviour, and habitat preferences, but is generally a well-defined and stable species (Scott and Crossman 1973). Brook trout are generally small in size (22-30 cm total length) but can vary considerably due to local conditions and the onset of maturity (Scott and Crossman 1973). Males typically grow faster and attain a larger overall size than females regardless of local conditions or life history strategy (Scott and Crossman 1973). The largest brook trout on record is a 6.6 kg specimen taken from Ontario's Nipigon River. The life span of brook trout is generally short, with few individuals exceeding 5 years of age and none older than 8 years (McAfee 1966). Sexual maturity usually occurs at age 3 but commonly occurs as early as age 2 with rare cases showing maturity at the end of the first summer (Carlson and Hale 1973).

The brook trout occupies a wide variety of habitats throughout its range, being found in small streams, large freshwater lakes and rivers, estuaries, and saltwater. Brook trout habitats are generally clear, cool, and well-oxygenated waters with maximum temperatures less than 20°C (Scott and Crossman 1973). When water temperatures exceed the tolerable limit for brook trout they typically move to colder deeper areas (Baldwin 1948), or areas of groundwater refugia (Biro 1998).

Brook trout are fall spawners with the exact date varying according to latitude or elevation. Spawning may take place as early as August at higher latitudes and as late as December in the southern part of its Ontario range (Ricker 1932). Regardless of latitude or elevation, spawning is usually initiated when water temperatures drop below 10°C (Power 1966). Brook trout may migrate long distances to reach spawning areas (Naiman *et al.* 1987). Males generally arrive at spawning locations first and outnumber the females (Scott and Crossman 1973; Blanchfield and Ridgway 1997). A redd is excavated in the substrate by the female and eggs are deposited while the male fertilizes the eggs and defends the redd from other males. The female covers the eggs with gravel shortly after deposition and the redd is left unattended (Scott and Crossman 1973). Brook trout eggs range from 3.5-5.0 mm in diameter with the exact number of eggs positively correlated to the size of the female (Vladykov 1956). Fertilized eggs remain in the gravel over winter, hatching in early spring (Brasch *et al.* 1982). Gravel headwater streams are generally favoured as spawning sites for brook trout but they may also use the gravel shallows of lakes if local conditions are adequate (Ricker 1932). Brook trout in Lake Nipigon do not enter tributary streams to spawn but utilize gravel nearshore areas less than a meter in depth (Ricker 1932). Whether the spawning location is within a lake or stream, the exact site is usually an area influenced by upwelling groundwater (Witzel and MacCrimmon 1983; Curry and Noakes 1995; Blanchfield and Ridgway 1997). Brook trout redd site selection appears to be less influenced by substrate than the presence or absence of upwelling groundwater (Fraser 1982). This appears to be a behavioural adaptation to ensure the survival and development of eggs by providing an environment with a regulated temperature for developing embryos. Brook trout may not spawn every year after reaching maturity depending on the diet and overall health of the individual (Power 1966).

Brook trout populations commonly complete their lifecycle occupying solely a freshwater stream or lake environment. Exceptions to this strategy can be seen in anadromous populations of Canada's Atlantic coast and Hudson Bay, and potadromous populations of large freshwater lakes. Anadromous populations, known as "salters", use freshwater streams for spawning and the rearing of juveniles (White 1940; Naiman *et al.* 1987). Smolting generally occurs in the second or third spring following emergence. Adults return from saltwater in late summer or early fall to spawn (Dutil and Power 1980; Castonguay and Fitzgerald 1982; Wilder 1952; White 1940). After spawning is completed in the late fall anadromous brook trout overwinter in their freshwater streams to migrate again to saltwater in the following spring (Naiman *et al.* 1987). Anadromous brook trout are not taxonomically distinct from freshwater brook trout and genetically appear to be of the same stock (Wilder 1952). Both sea-run and resident brook trout often exist in the same streams. The reasons that some brook trout migrate and others do not are poorly understood (Jones *et al.* 1997; White 1940). Differences in life-history strategies may be linked to the metabolic efficiencies of individual brook trout (Morinville and Rasmussen 2003). Potadromous brook trout, referred to as "coasters", inhabit Lake Superior and differ from anadromous brook trout by smolting from a stream to a freshwater lake.

The diet of the brook trout is incredibly diverse, with the species being regarded as a generalist and opportunistic feeder. Brook trout diets range from small mammals to aquatic vegetation, but are almost always strictly carnivorous (Power 1966). More common items in the brook trout's diet include aquatic invertebrates, terrestrial insects, worms, molluscs, and fish (Brasch *et al.* 1982). The exact complement of a brook trout's diet is associated with the habitat in which it lives and ultimately governs the growth rate.

Within Lake Superior, the brook trout is one of two native salmonine species. Brook trout inhabiting Lake Superior were aptly named "coasters" due to their predilection for near-shore areas. Presently the term "coaster" is used when referring to any brook trout that utilizes Lake Superior at some point within its lifecycle (Becker 1983). Coaster brook trout differ from other brook trout by attaining a larger average size, having a silver colouration with a lack of blue halos, and having a longer lifespan (Bent 1994).

Coaster brook trout were once ubiquitous throughout the near-shore waters of Lake Superior being absent only in areas of steep rocky cliffs and long sandy beaches (Shiras 1935). There were 109 documented streams that supported coaster brook trout spawning runs at some period within the last one hundred years with the actual number probably exceeding this figure (Newman and Dubois 1997). Through the late nineteenth and early twentieth century the coaster brook trout was a highly esteemed sportfish and was sought after in

Lake Superior's near-shore waters and tributary streams (Newman *et al.* 1999). The abundance of brook trout at this time provided an excellent fishery (Shiras 1935). These brook trout stocks were highly vulnerable to harvest due to their occupation of a narrow band of lake habitat and specific spawning habitats (Newman and Dubois 1997). Coaster brook trout were targeted and harvested with both an intense sportfishery and commercial fishery (Newman and Dubois 1997).

As the Lake Superior watershed was opened to both rail and road, formerly inaccessible coaster brook trout habitats became accessible. With increased settlement in these areas came landuse practices such as forestry, mining, and road development, as well as the introduction of non-native salmonids, all of which may have contributed to the decline of coaster brook trout numbers (Newman and Dubois 1997). Many of the tributary streams flowing into Lake Superior were channelized and equipped with splash dams for the driving of logs cut from headwater portions of these watersheds. The large masses of timber sent down these river systems scoured the banks and altered the instream habitat of these tributaries. The building of roads through the Lake Superior watershed also provided entry for anglers to previously inaccessible coaster brook trout waters (Newman and Dubois 1997).

At present, few stocks of coaster brook trout remain in Lake Superior and details regarding their abundance and distribution is limited (Slade 1994). Coaster brook trout are believed to be extirpated or at low population levels in most of their historic habitat (Newman and Dubois 1997). The populations that do exist today are located in relatively remote areas protected from large human populations, or are protected by private ownership (Newman *et al.* 1999). Current populations of coaster brook trout exist in Nipigon Bay along the north shore, around Isle Royale, and along Michigan's upper peninsula. Within these areas only a select few streams, most of which are tributaries of Nipigon Bay, have consistent spawning runs that support active fisheries (Newman and Dubois 1997). The only stream along Lake Superior's south shore to support a coaster brook trout population is Michigan's Salmon-trout River.

There has been a recent shift of interest and support for protection and restoration of native species in the Great Lakes (Busiahn 1990). Efforts have been hampered for restoration of the coaster brook trout by lack of understanding regarding this species' life history characteristics, habitat preferences, behaviour and its population status (Newman and Dubois 1997). To date, the published literature is very limited for the coaster brook trout with knowledge of its morphology, life history, and population structure yet to be described (Newman and Dubois 1997). Combining the limited knowledge of the coaster brook trout with information about inland freshwater brook trout and anadromous brook trout of the Atlantic Ocean and Hudson Bay thus far forms the basis for our understanding of the ecology of the coaster brook trout.

The movement patterns, habitat use, spawning behaviour, and the spatial extent of the habitat of coaster brook trout within the waters of Lake Superior are largely unknown and undocumented. The limited information presently available for the coaster brook trout does not satisfy the needs of fisheries managers trying to protect current coaster brook trout populations from further decline or restore those which have been extirpated (Newman *et al.* 1999). Decisions regarding land-use and harvesting regulations by fisheries managers cannot be determined until empirical knowledge regarding coaster brook trout movement and habitat utilization both within the lake and spawning tributaries is obtained. Although the lake habitat requirements of coaster brook trout are not clearly defined, the general ecological requirements can be derived from literature on other migratory and nonmigratory stocks.

Brook trout have general ecological constraints and requirements, which limits their distribution regardless of whether they inhabit streams, freshwater lakes, or saltwater. Brook trout require cold, clear, well-oxygenated waters, with their distribution being limited at both local and regional scales according to these factors. The temperature preference for brook trout lies between 14 and 19°C, their upper lethal temperature is 25°C (Fry *et al.* 1946). The open waters of Lake Superior rarely exceed the temperature preference of brook trout, but shallow, sheltered embayments such as Nipigon Bay will have surface temperatures above the preferred ranged.

Salmonids will typically remain within their temperature preference if waters in that range exist (Reynolds and Casterlin 1979). Numerous strategies are exhibited by salmonids to remain in their preferred temperature range throughout the year. Brown trout in Lake Ontario inhabit shallow inshore waters during spring but move offshore to deeper waters associated with the thermocline in early summer when water temperatures exceed 18°C (Haynes and Nettles 1983). Brown trout in Box Canyon Reservoir, Washington left the main basin for cooler tributaries when water temperatures reached 20°C (Garrett and Bennett 1995). Brook trout in small lakes will move from shallow nearshore areas to occupy significantly deeper habitat during summer (Baldwin 1948; Lackey 1970). If deeper waters are not available to brook trout as a temperature refugia then individuals will compete for cooler areas caused from groundwater seepage (Biro 1998). Sea-run brook trout rarely occur in areas deeper than 3 m during their summer residence in saltwater (White 1940); most likely due to water temperatures not exceeding their preferred range.

Brook trout will select areas providing protection from predators while allowing for foraging opportunities (Power 1980; Cunjak and Green 1983). Cover habitat in lakes is generally in the form of large woody debris, aquatic vegetation, large boulders, shoals, saddles, and drop-off areas. Lake resident brook trout are most often associated with bottom structure in comparison with the remainder of the water column (Flick and Webster 1962; Chapman 1966; Lackey 1970).

Although brook trout are generally considered stream spawners, it is not uncommon for brook trout populations to be supported solely through lake shoal spawning. Lack of suitable substrate and groundwater seepage is the limiting factor on natural reproducing brook trout in lakes (Fraser 1985). Brook trout have spawned successfully in lakes in groundwater seepage areas without suitable substrate (Fraser 1982).

Details regarding coaster brook trout movements and ranges within their lake habitat are also necessary for the protection and enhancement of this species. Presently, very little documented information regarding coaster brook trout movements and ranges is available. Sea-run brook trout were found to remain close to the estuary and nearshore areas of their natal stream (Bigelow and Welsh 1925; White 1940; Naiman *et al.* 1987). Mark-recapture techniques using gillnets found sea-run brook trout to travel no further than 7-10 km from their natal stream estuary (Dutil and Power 1980). Maximum linear range for a re-introduced population of brook trout in Lake Superior was relatively small, averaging 6.06 km (Newman *et al.* 1999). Knowledge of coaster brook trout movements are limited to a single study of reintroduced coasters to Minnesota's shoreline. The study suggests that brook trout are more active and move greater distances during the night, often assembling in social groups of 2 to 10 individuals to feed (Newman *et al.* 1999). Other salmonids are also more active at night, moving inshore at night to feed (Haynes and Nettles 1983).

Numerous factors contribute to determining which streams will support brook trout. These same factors may also influence the densities of brook trout produced in these systems. Streams used for spawning require instream nursery areas with maximum summer temperatures of less than 25°C (Meisner 1990). Water temperature is the single most important factor limiting brook trout distribution in streams (MacCrimmon and Campbell 1969). Water temperature within a fluvial system is controlled by numerous factors other than climate and local air temperature regime. Groundwater input to a stream provides stability to the flow and is much cooler than surface run-off water during the summer months. The amount of groundwater contributed to a stream is a function of the surficial geology of the watershed (Freeze and Cherry 1979). Brook trout distribution along their southern range is limited to streams with surficial geological deposits, which are conducive to groundwater transmission (Portt and King 1989). If groundwater is not sufficient to maintain stream temperature within a tolerable limit for brook trout, then localized areas of groundwater input are often used as refugia (Gibson 1966; Bowlby and Roff, 1986). Basin scale attributes which influence the temperature of a stream include basin size, link number (number of first order tributaries), mean slope, proportion of standing water within watershed, and proportion of forested area within watershed (Lewis *et al.* 2000).

Stream spawning salmonids select discrete areas within their natal stream to spawn based on variables such as water depth, water velocity, and substrate size (Knapp and Preisler 1999). These factors are often correlated, and alone cannot effectively explain the selection of spawning sites by salmonids, any models predicting spawning sites solely on these factors are generally poor (Knapp and Preisler 1999). Other factors important to the selection of spawning sites by salmonids include nearby cover (Reiser and Bjornn 1979) and the presence of groundwater (Witzel and MacCrimmon 1983). Cover provides fish with both protection from predators and shade. Cover types include overhanging vegetation, undercut banks, submerged vegetation, woody debris, boulders, or depth. Cover is critical for migratory fish that enter small streams months before they spawn (Reiser and Bjornn 1979). Given the choice between two similar spawning areas, one with cover and one without, salmonids will almost always choose the one with cover (Reiser and Bjornn 1979; Witzel and MacCrimmon 1983).

Groundwater has been identified as an important component of spawning areas of salmonids, including brook trout (Curry and Noakes 1995), sockeye salmon (*Oncorhynchus nerka*) (Lorenz and Eiler 1989), arctic char (*Salvelinus alpinus*) (Cunjak and Power 1986), brown trout (*Salmo trutta*) (Hansen 1975), and rainbow trout (*Oncorhynchus mykiss*) (Sowden and Power 1985). In areas of the Canadian shield, brook trout spawn exclusively in distinct groundwater discharge areas (Curry and Noakes 1995). Groundwater provides incubating eggs an environment of constant temperature and protection from frazil (fine spicules of ice formed in supercooled, turbulent water) and anchor ice throughout the winter months. In the selection of redd sites, substrate composition is secondary to presence of groundwater seepage (Witzel and MacCrimmon 1983). Brook trout have been observed to spawn in groundwater upwelling areas regardless of the substrate, including spawning over waterlogged woody debris (Fraser 1982). In comparison with other salmonids, brook trout tend to spawn in areas of lower velocity and at shallower depths (Witzel and MacCrimmon 1983).

Details regarding both the timing and movement patterns of the coaster brook trout within their spawning stream are limited. Movements of anadromous brook trout into their natal streams generally coincide with temperature, discharge, lunar, and tidal cues. Sea-run brook trout ascend rivers from late June to August depending on latitude (White 1941; Dutil and Power 1980; Castonguay and Fitzgerald 1982). Anadromous brook trout can migrate up to 50 km upstream to spawn (Naiman *et al.* 1987) but this distance is generally shorter due to the presence of migratory barriers (Dutil and Power 1980). Upstream movements of anadromous brook trout are generally nocturnal (Castonguay *et al.* 1982). Sea-run brook trout tagged in their natal stream have been recaptured in nearby streams but numbers are generally low and straying does not appear to be prevalent (Castonguay *et al.* 1982; White 1941). Brook trout will spawn from early September to early December depending on latitude (Scott and Crossman 1973) with peak spawning occurring between 6-8°C (Witzel and MacCrimmon 1983). Anadromous brook trout generally overwinter within their natal stream after spawning has been completed (Dutil and Power 1980; White 1941; Montgomery *et al.* 1990). Bigelow and Welsh (1925) observed anadromous brook trout returning to saltwater in November after spawning. Migration to sea generally occurs from April to early June (White 1942; Montgomery *et al.* 1990).

Underwater biotelemetry has enabled the monitoring of locations, behaviours, and physiology of aquatic animals. Biotelemetry involves attaching a device which relays information via radio or ultrasonic signals. This allows for the monitoring of animals that are not visible to us, and can be done without influencing the behaviour or health of the individual (Winter 1996). Biotelemetry allows for more information gathering than other techniques such as mark-recapture (Winter 1996). Numerous studies have used biotelemetry to gain insight into the behaviour of both fresh and saltwater fish species. Devices which emit signals are called transmitters and differ from transponders which only return a signal in response to one. Transmitters produce a signal by inducing a high frequency vibration (Millspaugh and Marzluff 2001). Radio signals are received using a variety of antennas held above water. A receiver unit, attached to the antennae transfers the signal to a form that is audible or displayed on a digital screen. This setup allows animals to be located using a variety of methods, including boats, aircraft, automobiles, or on foot. Most transmitters are encapsulated in wax, epoxy, urethane, or acrylic (Winter 1996). Transmitters are inactive until turned on by activating a magnetic reed switch usually done by removing an external battery (Winter 1996).

Radiotelemetry is well-suited for shallow, low conductivity, freshwater or turbulent water (Winter 1996). Radio antennas do not require contact with the water and therefore can be used to search large areas to find highly mobile species. Because signal strength decreases almost exponentially with the depth of the organism, radiotelemetry is not well-suited for monitoring species inhabiting deep areas (Winter 1996).

Transmitters may be attached to aquatic organisms externally, by stomach insertion, or surgical implantation (Winter 1996). The best method depends on the species being investigated, time of year, and the objectives of the project. External attachment is quick and has a shorter recovery period but may cause balance and drag issues (Winter 1996). Internal tags can be stomach inserted or surgically implanted. Stomach insertion is quicker and less difficult, but may rupture the esophagus or be regurgitated by the organism (Winter 1996). Surgical implantation is not difficult but requires extensive planning for anaesthetic use and suturing. Although rare, some species exhibit transintestinal expulsion of the transmitter, and mortality rates associated with this process are generally higher (Winter 1996).

My overall goal was to evaluate habitat use and movement patterns of coaster brook trout using biotelemetry. The first objective of this study was to identify the type of lake habitat used by coaster brook trout and to determine when it is used. More precisely, at what depths and distances from shore are coaster brook trout located, and does the depth and distance to shore for coaster brook trout vary either seasonally or diurnally. The second objective was to examine movement patterns displayed by coaster brook trout at various time scales. This included the calculation of both home range and maximum range values for coaster brook trout within Lake Superior. I also examined the distances moved by coaster brook trout both between and within days, and determined whether these values differed seasonally. The third objective was to identify basin scale attributes of coaster brook trout spawning streams, and reach scale attributes of discrete coaster brook trout spawning areas. The fourth objective was to examine the movement patterns displayed by coaster brook trout during their stream residency as adults, including stream residency time, dates of ascending and descending, and instream directional movements.

Methods

Study Area

Nipigon Bay lies entirely within Ontario and forms the most northerly portion of Lake Superior. Numerous tributaries feed into Nipigon Bay including the Nipigon River, Lake Superior's single largest inflow of water. Nipigon Bay is enclosed by the Black Bay Peninsula to the west, and St. Ignace, Simpson, and numerous other small islands to the south (Figure 1). Water is exchanged between the open waters of Lake Superior and Nipigon Bay through the Nipigon Straits, Moffat Straits, Simpson Channel, and Wilson Channel. Nipigon Bay spans nearly 55 km east to west. Within Nipigon Bay there are four large islands, La Grange, Vert, Burnt, and Outan, as well as several smaller islands. Nipigon Bay and its islands constitute over 200 km of shoreline.

Although Nipigon Bay has a maximum depth of 138 meters, approximately one third of this area is productive shallow water habitat of less than 10 meters. Nipigon Bay is at least partially frozen over for the months of January through April. During this time, and in summer, Nipigon Bay becomes stratified. Although open water surface temperatures for Lake Superior rarely exceed 14° C, the abundant shallow nearshore waters of Lake Superior can reach 25° C. Due to its productivity, Nipigon Bay is host to healthy populations of numerous top predator fish other than brook trout. These species include lake trout, rainbow trout, coho, chinook, and pink salmon. At present, the eastern half of Nipigon Bay supports a commercial fishery for whitefish and lake

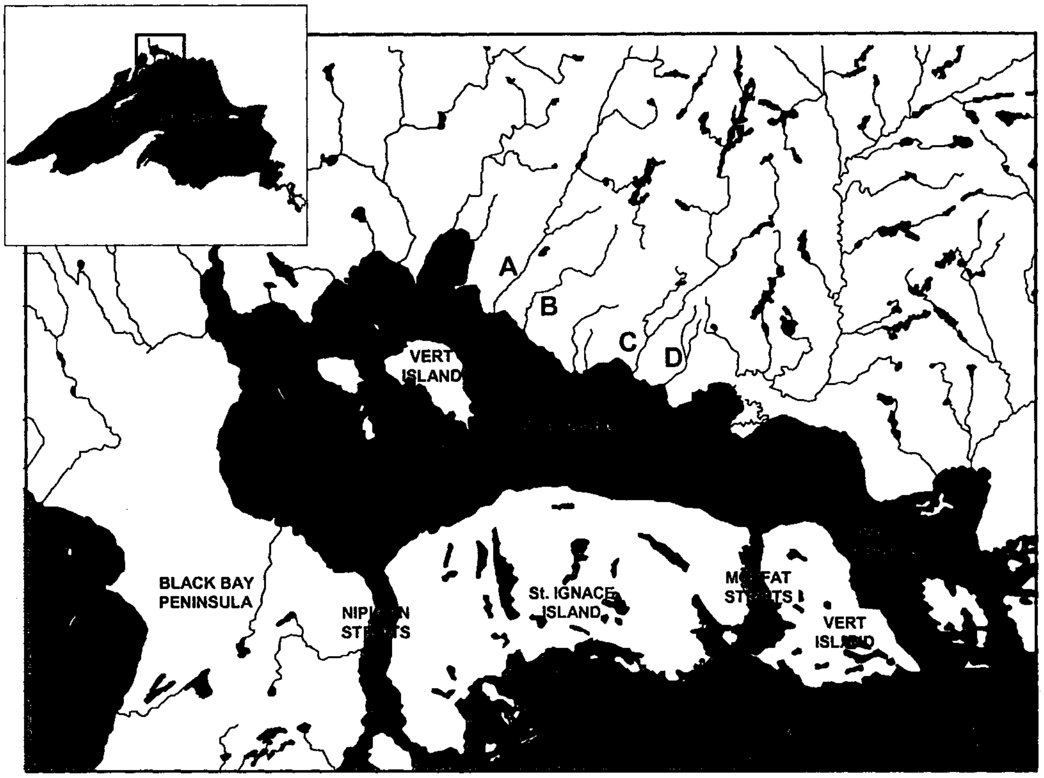

Figure 1: Map of study area illustrating Nipigon Bay's placement within Lake Superior and streams utilized by tagged coaster brook trout.

A – Jackpine River
B – Dublin Creek
C – Cypress River
D – Little Cypress River

trout. The western half, which is primarily shallow does not have any commercial fishing (J. Black, OMNR pers. comm.).

Transmitter Implantation Methods

From May 20 until June 2 1999, 20 brook trout were captured by angling in numerous areas throughout Nipigon Bay. Brook trout implanted with a radio transmitter ranged from 35.9 to 52.9 cm in length and 634 to 2223 g in weight (Table 1).

Brook trout were anaesthetized in an 18 l clove oil bath (tricane methane sulfonate (MS 222)) a common fish anesthetic could not be used due to Canadian regulations prohibiting the use of chemical anesthetics on fish that could potentially be eaten). The clove oil bath consisted of 13.5 ml of clove oil solution mixed with 18 l of lake water. The clove oil solution consisted of 1 part 100% eugenol to 10 parts 100% ethanol (Anderson *et al.* 1997). Brook trout were placed in the clove oil bath and were not removed until the fish lost equilibrium and became unresponsive to pinching of their pelvic fins. Once removed from the clove oil bath, fish were placed on a surgical trough where the gills were irrigated with clove oil bath water sprayed from a 1 l bottle. A 4 cm incision, large enough to insert the transmitter, was made just anterior to the left pelvic fin. After the incision was made, a 14-gauge hypodermic needle was inserted 1 cm caudal to the incision until visible from the incision. The transmitter's antenna was then inserted through the tip of the hypodermic

Table 1: Summary of coaster brook trout capture dates, transmitter frequencies, size attributes, and number of locations.

Brook Trout ID Number	Date Tagged	Transmitter Frequency	Transmitter Code	Fork Length (mm)	Depth (mm)	Width (mm)	Weight (g)	No. of Locations
1	20-May-99	151.510	*	501	116	56	1515	52
2	21-May-99	151.540	*	412	82	42	820	23
3	21-May-99	151.550	*	385	75	39	690	28
4	26-May-99	151.570	*	400	79	46	810	58
5	26-May-99	151.610	*	376	73	39	710	7
6	27-May-99	151.640	*	359	69	38	634	7
7	28-May-99	151.650	*	385	82	44	845	6
8	26-May-99	149.400	51	470	103	49	1319	42
9	28-May-99	149.400	55	446	91	51	1180	36
10	27-May-99	149.420	51	522	106	57	1543	27
11	21-May-99	149.420	53	419	89	42	945	73
12	27-May-99	149.420	54	529	130	68	2223	35
13	28-May-99	149.420	55	410	91	47	935	53
14	01-Jun-99	149.420	56	516	117	51	1685	22
15	21-May-99	149.420	58	456	112	47	1085	18
16	28-May-99	149.700	70	479	106	56	1535	9
17	21-May-99	149.700	71	506	116	49	1701	10
18	27-May-99	149.700	73	480	102	49	1363	29
19	28-May-99	149.700	74	486	101	56	1620	55
20	20-May-99	149.700	75	426	105	57	1238	48

* not coded

needle and threaded through. This allowed the antennae to have an exit hole separate from the incision to alleviate abrasion caused by movement of the antennae within the incision. After the antennae was fully threaded through and the transmitter inserted into the body cavity, the incision was closed with 2 or 3 sutures. The suture needles used were #2-0 with non-dissolving thread. Before the start of the last suture, the gills were wetted with lake water instead of water from the clove oil bath to begin to revive the fish. After all sutures had been completed, 3 cc of liquamyacin were injected into the body cavity, and iodine was applied to the outside of the incision (Ross and Kleiner 1982). Following surgery, all brook trout were fixed with two floy anchor tags with an identifying six digit code, measured for total length, width, and depth, and weighed. Total surgery time lasted three to four minutes before fish were placed into a recovery tank with circulating water. Brook trout were held in the recovery tank for 45 minutes before being released to ensure complete recovery from the surgery, although the fish generally righted themselves after 5 minutes in the recovery tank. All fish were released within 100 m of their original capture point.

Radiotransmitters used for this study were of two different sizes and programming. All transmitters were obtained from Lotek Engineering (Newmarket, Ontario). The first style of transmitter was used in 13 brook trout. These transmitters had a minimum operational lifespan of 575 days, were operational for 24 hours a day, and operated on the frequencies 149.400, 149.420, and 149.700 MHz, they measured 16 mm by 51 mm, weighed 18 g, and required a fish of minimum weight 900 g, as transmitter weight should not exceed 2% of the weight of the fish (Winter 1996). The second type of transmitter was used in 7 brook trout. These transmitters had a minimum operational lifespan of 375 days, were operational from 9:00 AM to 9:00 PM, operated on the frequencies 151.510, 151.540, 151.550, 151.570, 151.610, 151.640, and 151.650 MHz, their size was 11 mm by 49 mm, they weighed 9 g, and required a fish of minimum weight 450 g.

Telemetry Tracking Methods

Tracking began on June 15 1999, two weeks after the final transmitter had been implanted. This two week period was necessary as tagged fish often exhibit erratic or abnormal behaviour directly following the tagging procedure (Mesing and Wicker 1986). Tracking was done from a boat using a Lotek SRX 400A receiver and a 3 element Yagi antennae. During boat tracking the Yagi antennae was attached to an eight foot length of PVC pipe mounted on the bow of the boat. Between the first week of September and the third week of October tracking was done on foot along stream banks. Boat tracking resumed until the second week of December. Unsafe ice conditions did not allow for tracking during the months of January and February. ATVs were used for tracking in the month of March. Ice conditions were once again unstable in April and tracking was suspended. Boat tracking resumed in May and continued until the first week of September when streams were once again tracked on foot until the end of October.

Tagged brook trout were located as often as time and weather conditions allowed. Tracking in Nipigon Bay was primarily done in the nearshore areas along Superior's northshore and proximate islands. For each day tracking, location, time, surface water temperature, air temperature, and lake surface conditions were recorded at the beginning and end of each day. Tracking was generally limited to between 9:00 AM and 9:00 PM when all transmitters were active. Brook trout with transmitters operational for all hours of the day were selected for 24 hour tracking. This was accomplished by locating an individual brook trout at 4 hour intervals for a 24 hour period. Tracking by boat was done at low speeds, generally less than 5 km/h with the receiver continuously scanning all frequencies. Radiotagged brook trout could generally be detected at distances up to 500 m, with that distance decreasing with the depth of the fish. While determining the location of a tagged fish, the gain (receiver sensitivity) was decreased as we moved closer to the fish until the strongest signal was obtained from the lowest gain. The accuracy of the location of a tagged fish could generally be determined to be within 3 m, this was confirmed with visual observations on occasion. At each fish location, a depth reading to the nearest 0.1 meter was taken with a Humminbird 200 depth sounder, and a distance to shore reading to the nearest meter was taken with a Bushnell 400 rangefinder. Universal Transverse Mercator (UTM) coordinates were also taken at each fish location with a GARMIN 45 global positioning system, the horizontal accuracy of these units is generally within 15 m (Holdcroft 1996).

Home Range Estimation

Lake location points for individual coaster brook trout were entered into a GIS (geographic information system) in database file format. Telemetry locations within tributaries were not utilized in the calculation of home ranges. A fixed kernel home range, which allows for a constant smoothing parameter over the entire surface was calculated from these location points for each coaster brook trout using Animal Movement Analysis Arcview Extension (Hooge and Eichenlaub 1997). Each home range consisted of a 50% and a 95% probability contour, which allowed for discrimination between area of overall use and core areas. If any portion of the calculated probability contours overlapped onto terrestrial areas they were clipped to include only those areas overlapping with the lake polygon. All clipped home range attributes were updated using X tools Arcview Extension.

Lake Habitat Descriptive Survey

Six areas were selected for habitat surveys by plotting lake location points for all coaster brook trout and calculating a fixed kernel utilization distribution for these points. Three of each lake habitat type (summer/winter) with the highest amount of utilization based upon number of point locations and number of different tagged individuals utilizing the area were selected for habitat surveys. For each selected area three parallel 200 m long transects spaced 50 m apart were set up perpendicular to selected shoreline areas. The littoral slope of these areas was measured by recording the depth of these transects at 20 m intervals using a depth sounder, range finder, and compass. Transects were swum with scuba gear to evaluate the dominant substrate, subdominant substrate, presence or absence of cover and cover type. Dominant and subdominant substrate were determined according to their total abundance along the transect line. Substrate types were classified using the Wentworth Sediment Classification Index (Wentworth 1922)

Lake Habitat and Movement Statistical Procedures

Depth and distance to shore readings taken during individual coaster brook trout lake locations were used to investigate brook trout habitat use for various time periods. To test whether coaster brook trout use different depths, slopes, and distances to shore depending on the month, a one-way Analysis of Variance (ANOVA) using month as the grouping variable, along with a Tukey's HSD test was used. A one-way ANOVA with a Tukey's HSD test was also used to assess whether brook trout occupy different depths at different times of the day. To eliminate bias toward any individual which may have a greater number of location points, the mean was calculated for each parameter for individual fish to be used within analyses.

The movement of coaster brook trout within the lake was examined for different time periods including season, month, day, and hour. The maximum distance travelled for tagged brook trout was calculated by measuring the straight line distance between the two furthest points an individual brook trout was located. The distance travelled in 24 hours was obtained by measuring the distance between locations recorded for an individual brook trout on consecutive days. These distances were grouped by month and a one-way ANOVA with a Tukey's HSD test was performed to investigate whether coaster brook trout are more active during certain months as opposed to others. To test whether brook trout are more active during certain time periods of the day, the distance travelled in each of the 4 hour intervals from the 24 hour tracking were grouped and analyzed using a one-way ANOVA with a Tukey's HSD test.

Stream Site Selection

Streams selected for habitat surveys were those utilized by coaster brook trout during the fall spawning run of 1999. Individual reaches were selected based upon coaster brook trout locations during the latter portion of their stream residency before exiting into Lake Superior. A single reach extended to include the most utilized stream areas within a given stream. Sampled stream reaches were typically 80-120 m in length and encompassed numerous riffle/pool complexes.

Stream Habitat Survey Methods

Streams were surveyed on August 15-16 2000 when stream discharge was at baseflow in accordance with the Ontario Stream Assessment Protocol (Stanfield *et al.* 1998). Stream temperature and discharge were measured at every stream reach. Temperature was taken in a shaded riffle area for all streams. Discharge was measured at a point of uniform cross sectional flow in the stream. Water depth and velocity at 60% depth were measured using a Marsh McBinney flow meter at 20 points across a transect. Discharge of the stream (Q) was calculated using the formula:

$$Q = \sum (\text{interpoint distance} \times \text{depth} \times \text{velocity}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Instream habitat was measured at a number of points along a series of transects, the number of which depended upon the minimum width of the stream reach. Streams with a minimum width less than 1 m, 1 - 1.49 m, 1.50 - 3.00 m, and greater than 3.00 m were surveyed at 2 points with 20 transects, 3 points with 15 transects, 5 points with 12 transects, and 6 points with 10 transects respectively. For each point along a transect, depth, velocity, 3 point particle sizes, and maximum particle size within a 30 cm diameter cover ring were recorded. At each point, presence of cover, and cover type including rock shape (round/flat), macrophytes, undercut banks, and woody debris were recorded. Quality of cover was also documented as either none, embedded, or unembedded. Woody debris and aquatic vegetation identified as filamentous algae, non-filamentous algae, grass, moss, macrophytes, or terrestrial plants were also recorded at each point.

The gradient of the stream reach was determined by measuring the % slope in 10 m increments along a straight line distance from bottom to the top of the reach using a clinometer. Bank slope was also measured using a clinometer on both sides of the stream at the top, middle, and bottom of the reach. Canopy cover % was measured with a densiometer facing upstream, downstream, left, and right at the beginning, middle, and end of the reach.

The riparian zone for the upper, middle, and lower reach on both the left and right bank were classified into a wetland type using the Wetland Ecosystem Classification Guide for Northwestern Ontario (Harris *et al.* 1996). The ecosite type for the upland areas of the left and right bank were classified using the Forest Ecosystem Classification Guide for Northwestern Ontario (Sims *et al.* 1997). Soil core samples were collected using a standard soil auger to assist in FEC and WEC classification.

Stream reaches were one-pass electrofished using a Smith-Root backpack electrofisher unit equipped with a gas generator. All species were identified and sampled for weight. Brook trout were sampled for length and weight. Following sampling, all fish were released into their original reach.

Stream Movement

Coaster brook trout stream residence time, entrance dates and exit dates were recorded. The dates, location, and number of preliminary runs (a brief stream residency before exiting into Lake Superior to enter at a later date) were also recorded. Distance moved by coaster brook trout in a 24 hour period was calculated for individuals located on consecutive days.

Results

Lake Habitat

Twenty coaster brook trout were implanted with radio transmitters and tracked from June 16, 1999 until October 19, 2000. Tagged brook trout had a mean length of 44.8 cm and a mean weight of 1219.8 g. Individual brook trout were located over time periods ranging from 33 to 479 days, with the mean tracking period for coaster brook trout being 291 days. A total of 638 locations were obtained for the tagged coaster brook trout with 483 locations being within Lake Superior and the remaining 155 locations within tributary streams. The mean number of locations per tagged brook trout was 32; the minimum and maximum number of locations for coaster brook trout was 6 and 73 respectively. Table 1 summarizes the attributes of the brook trout implanted with transmitters in the study.

Coaster brook trout were located almost exclusively in the shallow water areas of Lake Superior's Nipigon Bay throughout their lake residency. Out of a total of 483 locations, 444 (92%) were in areas less than seven meters deep (Figure 2). The mean and median depth of pooled coaster brook trout locations were 3.4 m and 2.5 m respectively. Coaster brook trout were located in areas as shallow as 0.6 m and as deep as 26.4 m within Nipigon Bay. Individual coaster brook trout had similar depth ranges (Figure 3).

Coaster brook trout were most frequently located close to the shoreline within Nipigon Bay. Of 483 distance to shore readings taken from coaster brook trout locations, 454 (94%) were less than 400 m from shore (Figure 4). The

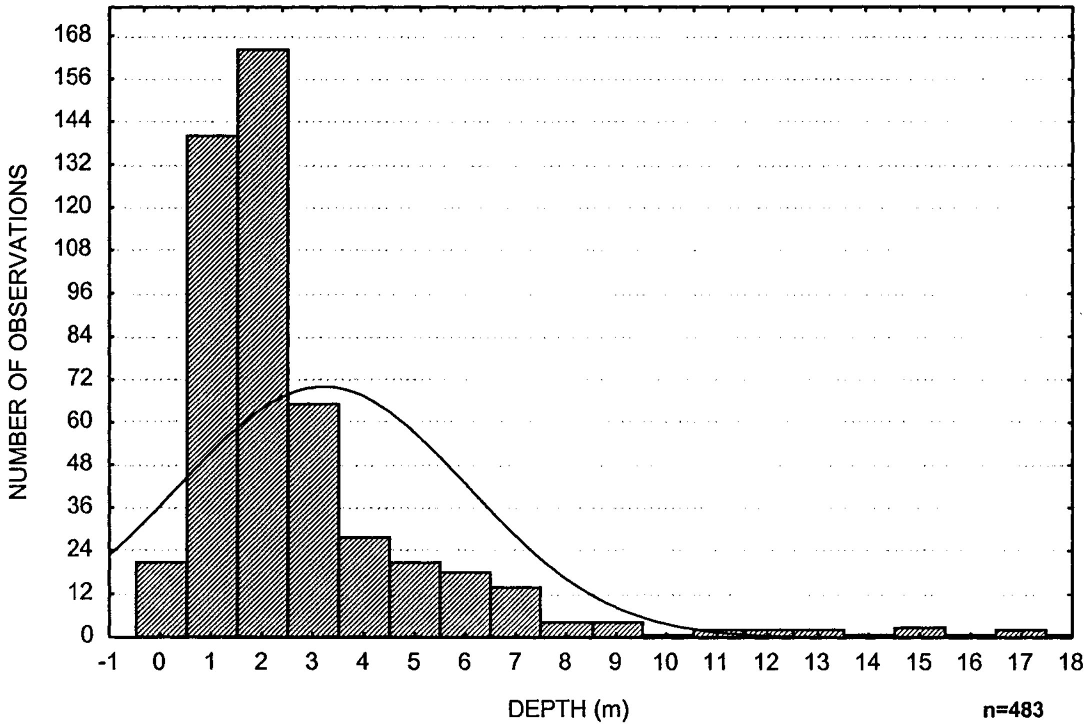

Figure 2: Frequency distribution of coaster brook trout lake location depths

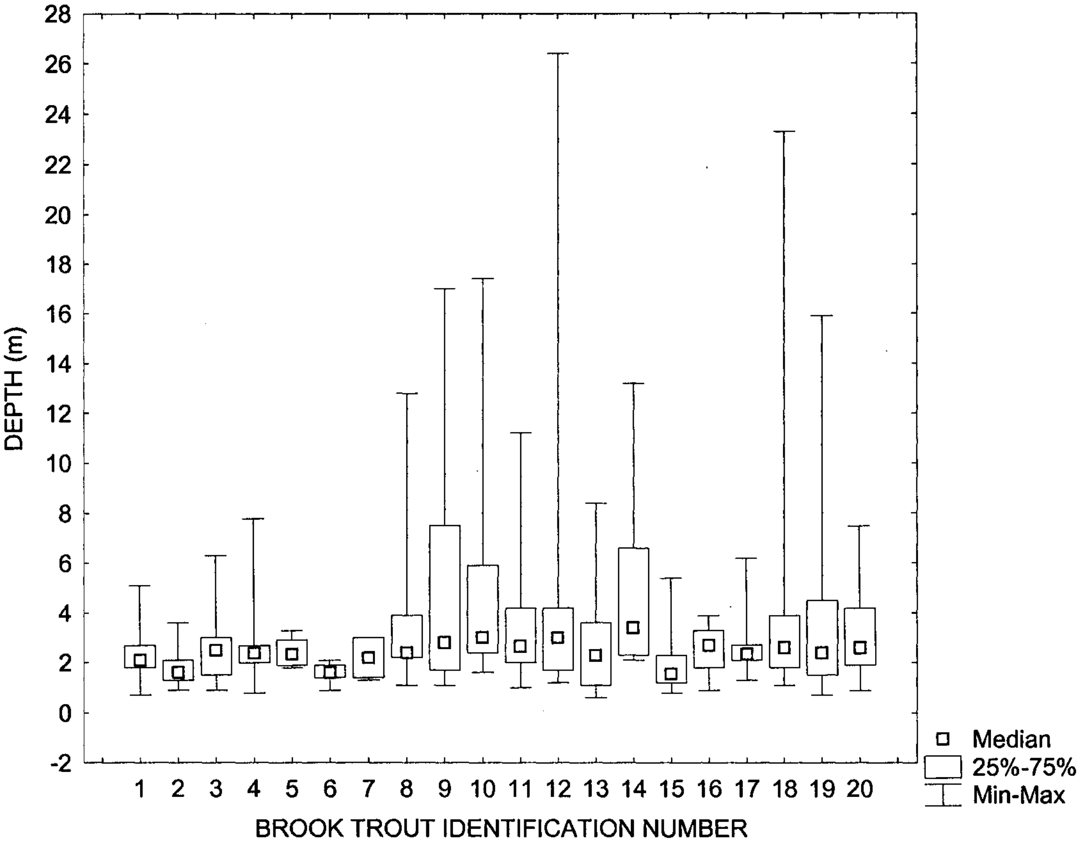

Figure 3: Depth distribution of individual coaster brook trout lake locations. Bars indicate median, 25%-75% quartiles, and min-max values. Sample sizes for individual brook trout shown in Table 2.

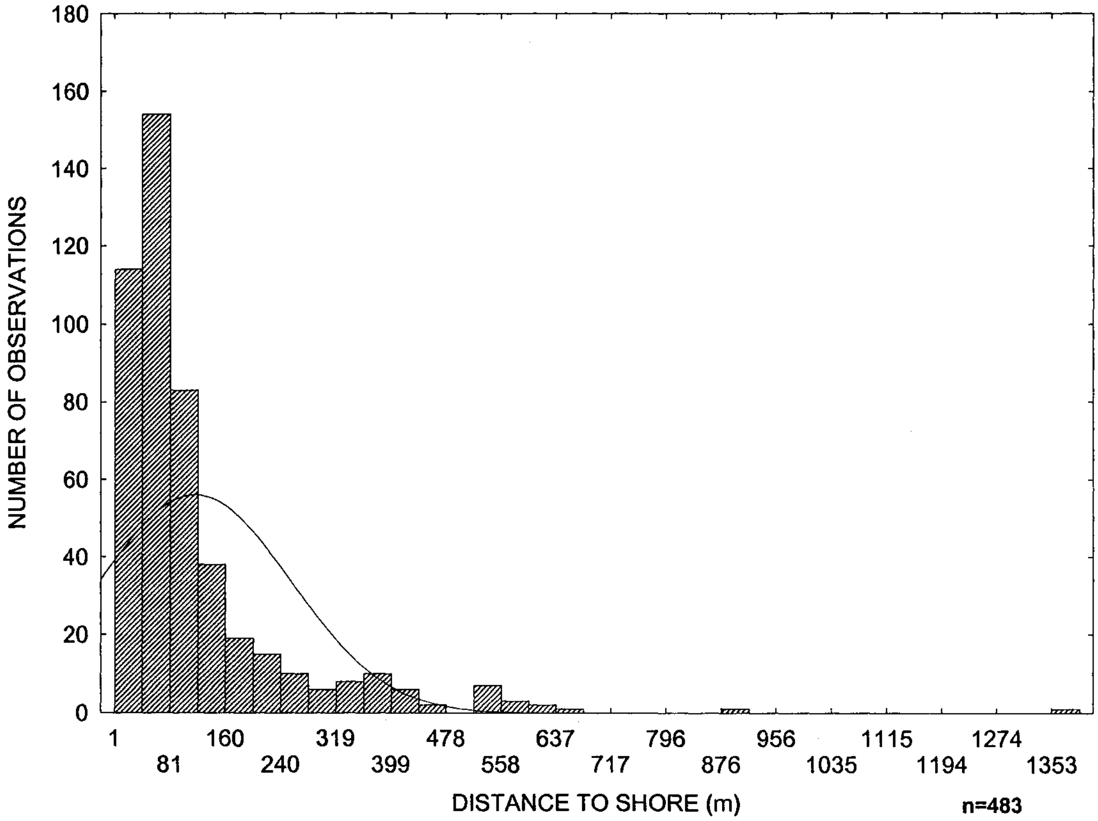

Figure 4: Frequency distribution of distance to shore values for all coaster brook trout lake locations.

mean and median distance to shore for pooled coaster brook trout locations was 116.1 and 75 m respectively. Coaster brook trout were located in areas between 5 and 670 m from shore. Individual coaster brook trout were quite variable with regards to their observed distance from shore (Figure 5).

During the open water months for Lake Superior (May-December) the mean depth at which coaster brook trout were located differed by month (ANOVA, F=16.146, p=0.001; Figure 6). Coaster brook trout were located in significantly deeper areas during July and August compared with the other months (Tukey's HSD, $\alpha<0.05$). The mean depth at which coaster brook trout were located in during July and August was 4.16 m and 3.61 m respectively. The depth at which coaster brook trout were located exhibited the greatest range in the month of July. The mean depth in which coaster brook trout were located in for all other months was less than 3 m.

The mean distance to shore for individual coaster brook trout differed in different months (ANOVA, F=3.533, p=0.002; Figure 7). Coaster brook trout were located significantly further from shore in the month of July (mean 176.3 m) in comparison to the month of November (mean 70.2 m)(Tukey's HSD, $\alpha<0.05$).

Coaster brook trout located at four hour increments throughout a 24 hour cycle were located in deeper areas during daylight hours and shallow areas during the night (ANOVA, F=3.187, p=0.02; Figure 8). The mean depth at which brook trout were located was significantly shallower at 04:00 (1.2 m) when compared to fish located at 12:00 (2.6 m)(Tukey's HSD, $\alpha<0.05$). Depths

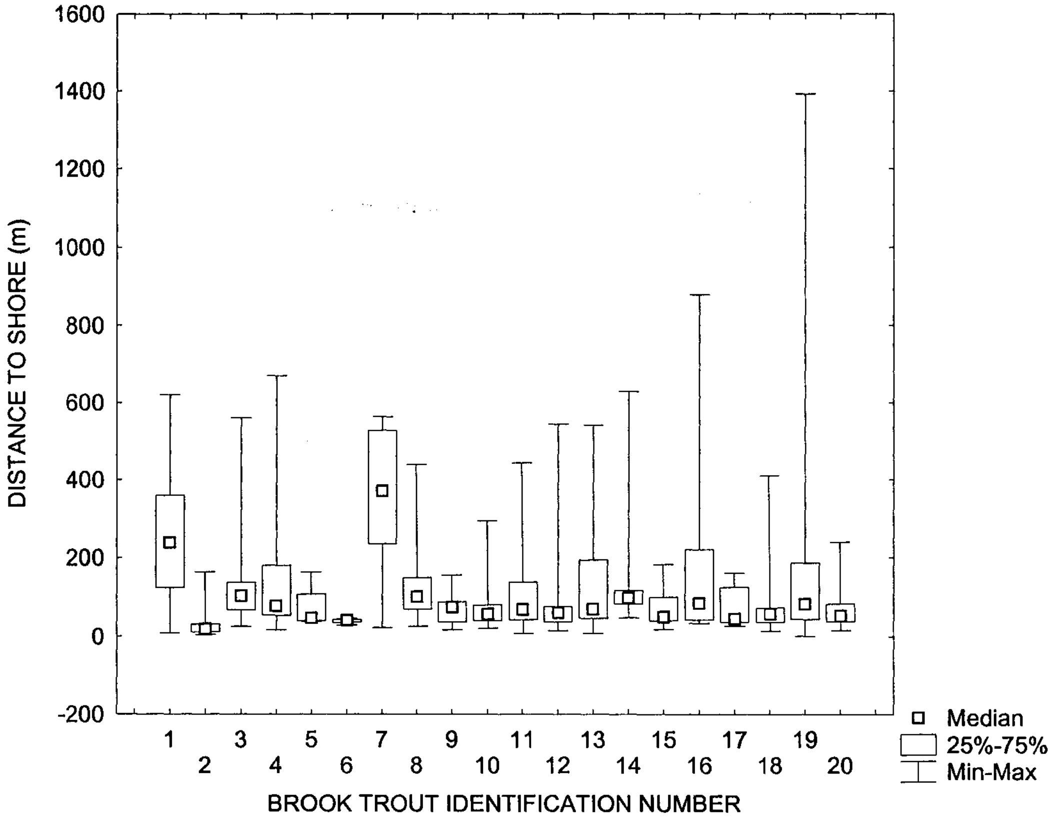

Figure 5: Distance to shore distribution of individual coaster brook trout lake locations. Bars indicate median, 25%-75% quartiles, and min-max values. Sample sizes for individual brook trout shown in Table 2.

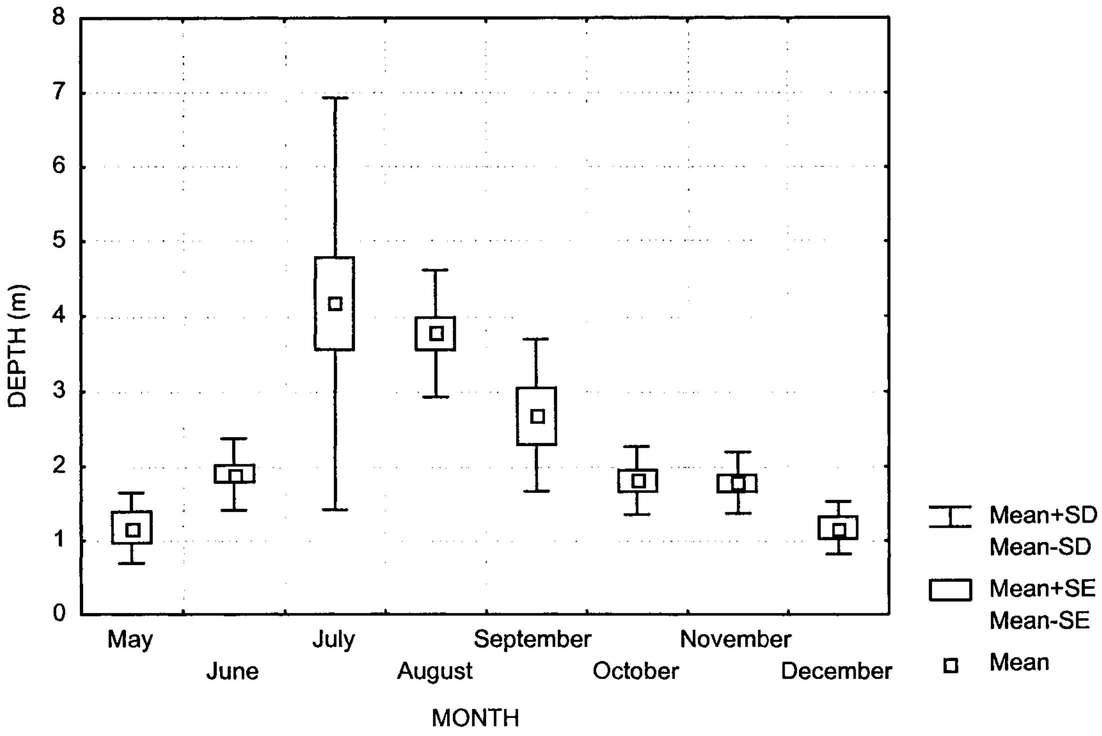

Figure 6: Distribution of means for coaster brook trout lake location depths grouped by month. Bars indicate mean, mean ± standard error, and mean ± standard deviation. Sample sizes for individual months shown in Table 2.

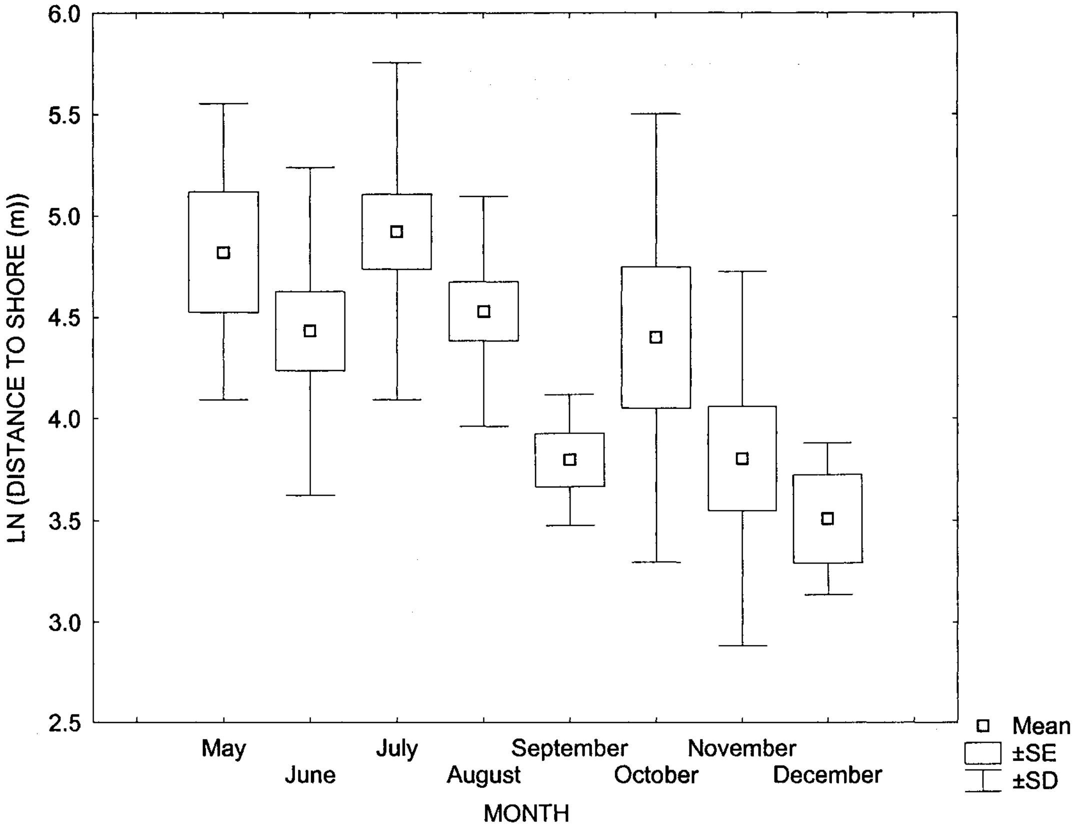

Figure 7: Distribution of means for coaster brook trout distance to shore values grouped by month. Bars indicate mean, mean ± standard error, and mean ± standard deviation. Sample sizes for individual months shown in Table 2.

Table 2: Division of individual coaster brook trout lake locations by month.

Brook Trout Identification Number	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Total**
1	0	3	14	9	0	2	0	0	28
2	0	14	6	0	0	0	2	0	22
3	0	3	5	11	2	0	2	0	23
4	2	5	19	11	1	3	1	1	43
5	0	3	1	0	0	0	0	0	4
6	0	4	1	0	0	0	0	0	5
7	0	1	1	2	0	1	1	0	6
8	0	3	5	12	1	0	0	0	21
9	0	3	5	14	2	3	2	1	30
10	0	2	7	14	0	0	1	0	24
11	2	6	22	20	0	2	2	1	55
12	0	4	3	8	2	2	2	0	22
13	1	7	8	15	0	2	1	0	34
14	0	0	4	14	3	0	0	0	21
15	0	12	2	0	0	0	2	0	16
16	0	0	7	1	0	0	1	0	9
17	0	3	6	0	0	0	0	0	9
18	2	4	6	9	0	2	2	0	25
19	1	5	14	18	3	1	1	0	43
20	1	3	20	15	0	1	2	1	43
Total Locations	9	85	156	173	14	19	22	4	
Total # Brook Trout	6	17	20	15	7	10	14	4	

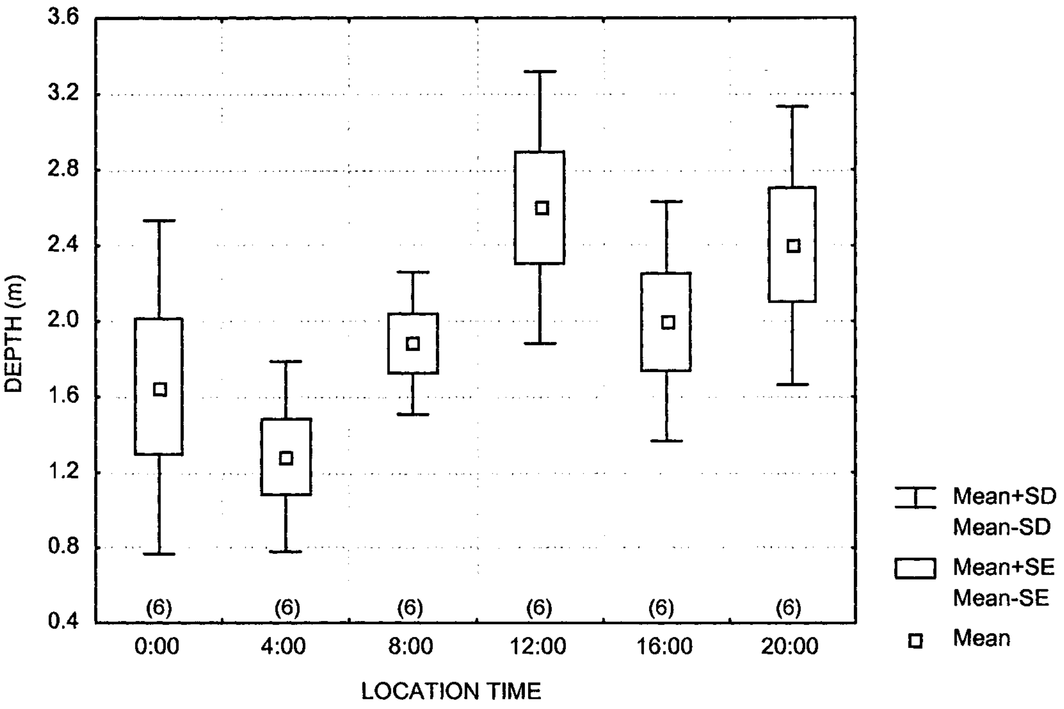

Figure 8: Depth distribution of coaster brook trout located at 4-hour intervals in a 24-hour cycle. Bars indicate mean, mean ± standard error, and mean ± standard deviation. Sample sizes for individual time periods shown above grouping variable.

occupied by coaster brook trout were most variable at 00:00, ranging from 0.3 m to 3.0 m.

Home Range Estimation

Home range estimates, calculated using a fixed kernel, produced both 50% and 95% probability contours for individual coaster brook trout. Home range sizes for coaster brook trout were highly variable (Table 3). Kernel probability contours of 50%, referred to as core areas, ranged from 0.088 to 41.131 sq. km, while 95% probability contours ranged from 0.347 to 185.818 sq. km. The mean and median home range size (95% probability contour) for coaster brook trout were 41.262 and 23.031 sq. km respectively.

Coaster brook trout home range size (95% probability contour) were not influenced by the number of telemetry locations made for an individual brook trout (r^2 = 0.046, p = 0.363; Figure 9). Home range size was also not related to the fork length of coaster brook trout (r^2 = 0.009, p = 0.691; Figure 10).

Dichotomy of Lake Habitat Use

Coaster brook trout were located in deeper areas throughout July and August within Lake Superior. When lake locations for July and August were pooled and plotted they were distributed almost exclusively along separate shoreline segments from lake locations pooled and plotted from the remaining months. Areas inhabited by coaster brook trout were then divided into shallow water habitat or deep water habitat based upon the time of year they were

Table 3: Summary of individual brook trout tracking periods, number of lake locations per fish, and 50% and 95% fixed kernel countour home ranges.

Brook Trout Identification Number	Transmitter Frequency/ Code	Period Tracked	No. of Lake Locations	50% Kernel Contour (sq. km)	95% Kernel Contour (sq. km)
1	151.510	16-Jun-99 - 28-Oct-99	28	0.983	5.222
2	151.540	18-Jun-99 - 26-Jul-00	22	0.117	0.347
3	151.550	18-Jun-99 - 8-Nov-99	23	34.681	144.402
4	151.570	17-Jun-99 - 31-Jul-00	43	1.212	5.763
5	151.610	16-Jun-99 - 6-Jul-00	4	41.131	185.818
6	151.640	10-Jun-99 - 21-Jul-99	5	20.166	71.154
7	151.650	12-Aug-99 - 4-Jul-00	6	0.113	0.288
8	149.400_51	19-Jul-99 - 1-Oct-00	21	8.292	55.594
9	149.400_55	1-Jul-99 - 7-Dec-99	30	0.266	1.849
10	149.420_51	17-Jun-99 - 8-Nov-99	24	3.069	15.168
11	149.420_53	17-Jun-99 - 14-Sep-00	55	10.414	33.904
12	149.420_54	28-Jun-99 - 7-Jul-00	22	6.602	57.172
13	149.420_55	17-Jun-99 - 9-Oct-00	34	19.908	96.231
14	149.420_56	15-Jul-99 - 9-Sep-99	21	2.588	7.137
15	149.420_58	18-Jun-99 - 27-Jun-00	16	0.432	2.375
16	149.700_70	16-Jun-99 - 9-Aug-99	9	5.301	30.894
17	149.700_71	18-Jun-99 - 21-Jul-99	9	0.099	0.646
18	149.700_73	28-Jun-99 - 19-Oct-00	25	6.953	60.669
19	149.700_74	8-Jul-99 - 14-Sep-00	43	7.654	38.871
20	149.700_75	1-Jul-99 - 28-Aug-00	43	2.217	11.734

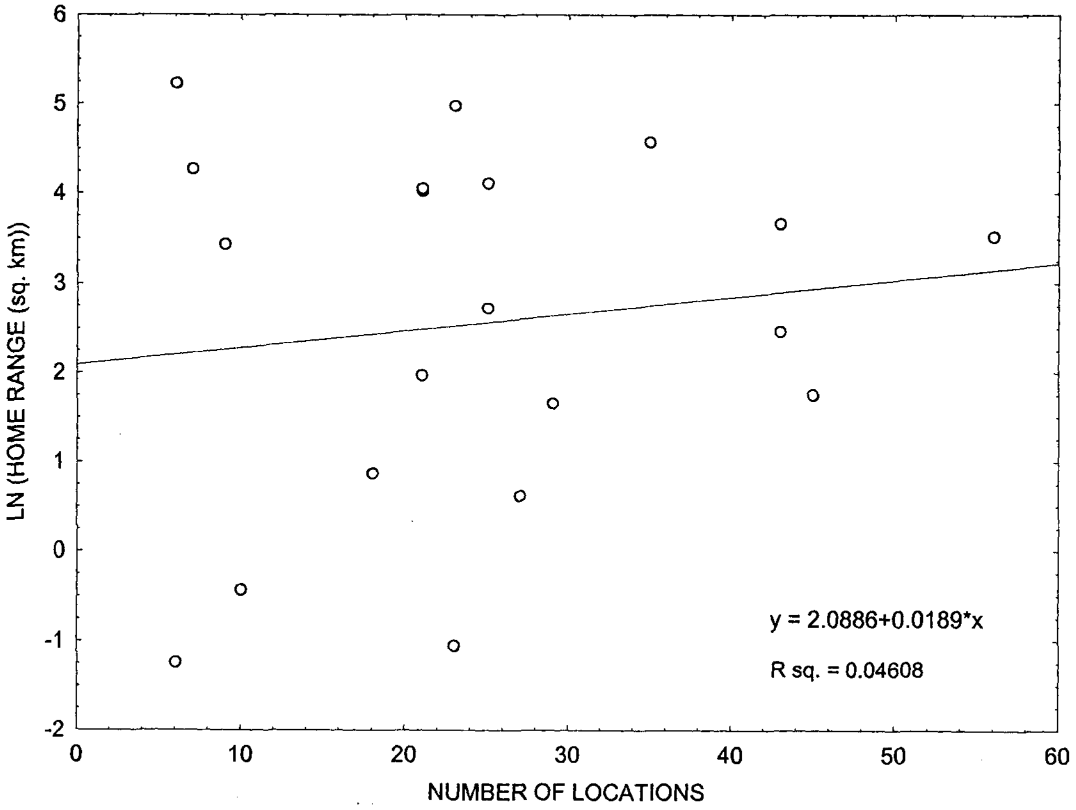

Figure 9: Home range size regressed against number of lake locations for individual coaster brook trout.

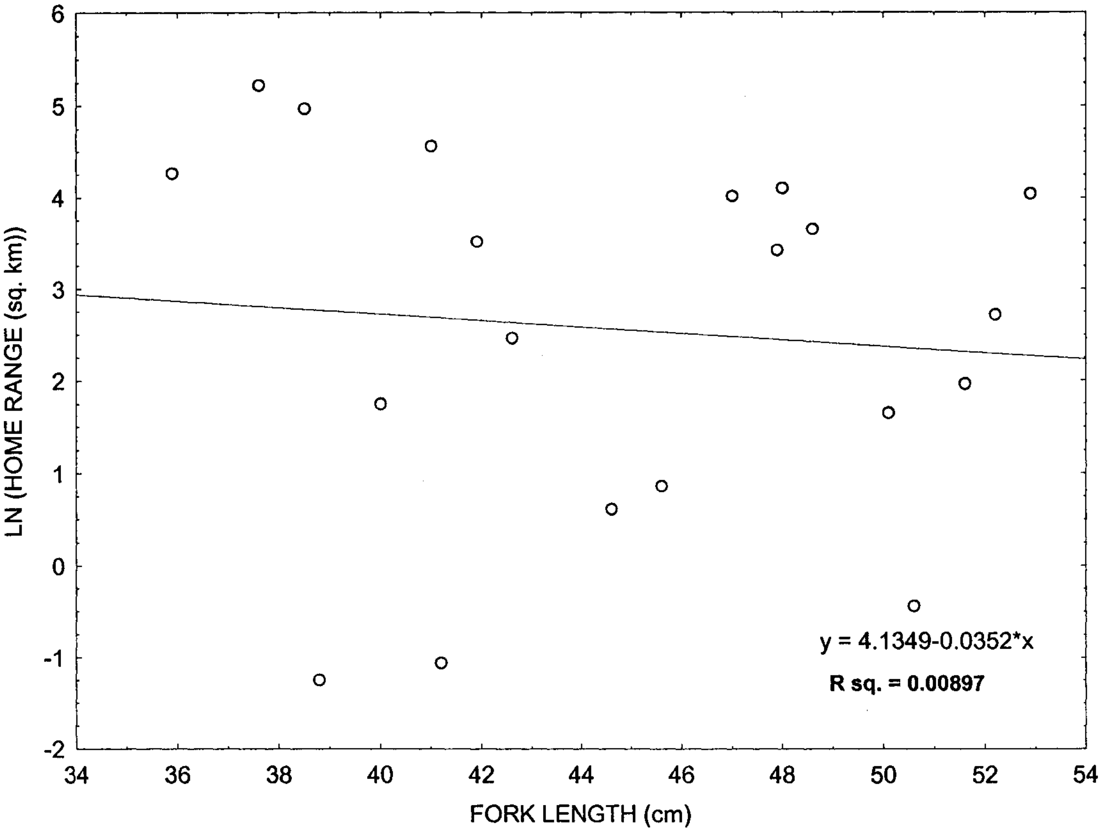

Figure 10: Home range size (sq. km) regressed against fork length (cm) for individual coaster brook trout.

utilized. Both shallow and deep water habitat shoreline areas were surveyed using a standard protocol.

Deep-water habitat had a steeper mean littoral slope (5.86%) when compared to coaster brook trout shallow-water habitat (1.46%) (ANOVA, F=40.00, p=0.003; Figure 11). Individual brook trout location depths and distance to shore values were used to calculate the slope from the shoreline to the location point. Pooling these slope values by month revealed that brook trout occupy steeper shoreline areas in July, August and September in comparison to other months (ANOVA, F=2.562, p=0.013; Figure 12).

Bottom substrates of deep-water habitat areas were generally finer textured than shallow-water habitat areas. Dominant substrates of deep-water habitat areas included sand and gravel with subdominant substrates of either gravel or cobble. Dominant substrates of shallow-water habitat areas included sand, gravel, and cobble with subdominant substrates of cobble and small boulders. Bottom substrates within these nearshore areas are a function of the surficial geology and wave action of the shoreline areas. Surficial geology of shallow water habitat areas were dominated by bedrock knobs and plateaus while deep-water habitat areas were typically glaciolacustrine and outwash origin (Northern Ontario Engineering Geology Terrain Study 59). Cover habitat was present within all the shallow-water habitat areas surveyed and none of the deep-water habitat areas surveyed.

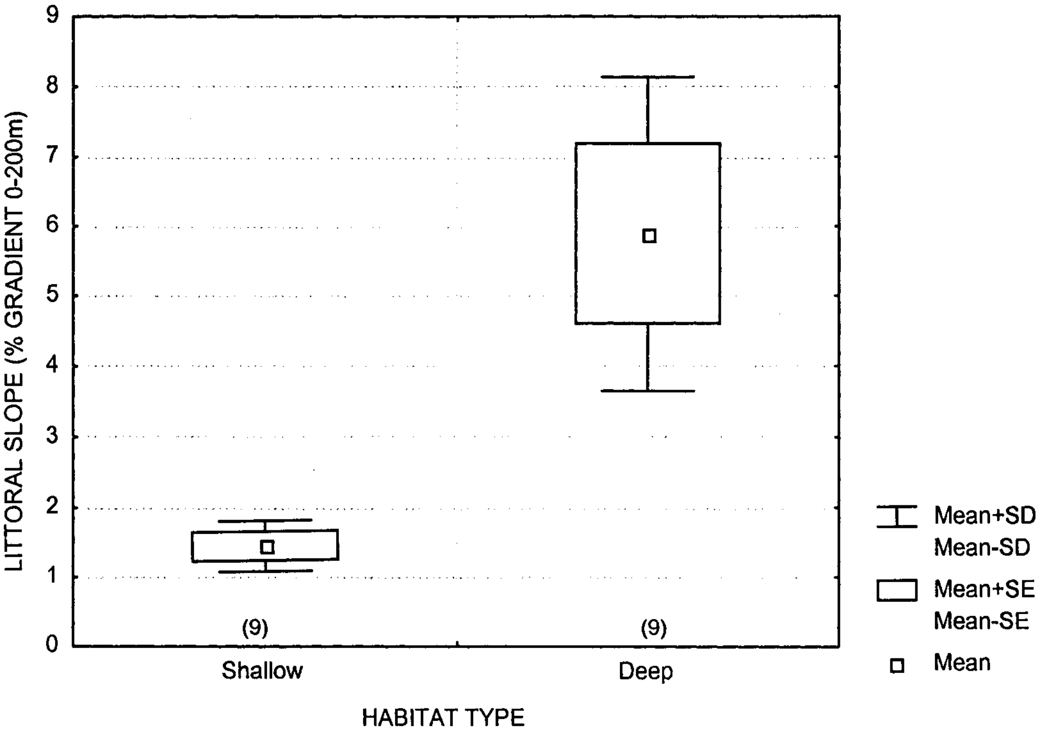

Figure 11: Littoral slopes (% gradient 0-200m) of shallow and deep shoreline habitat. Bars represent mean, mean ± standard error, and mean ± standard deviation. Samples sizes shown above grouping variable.

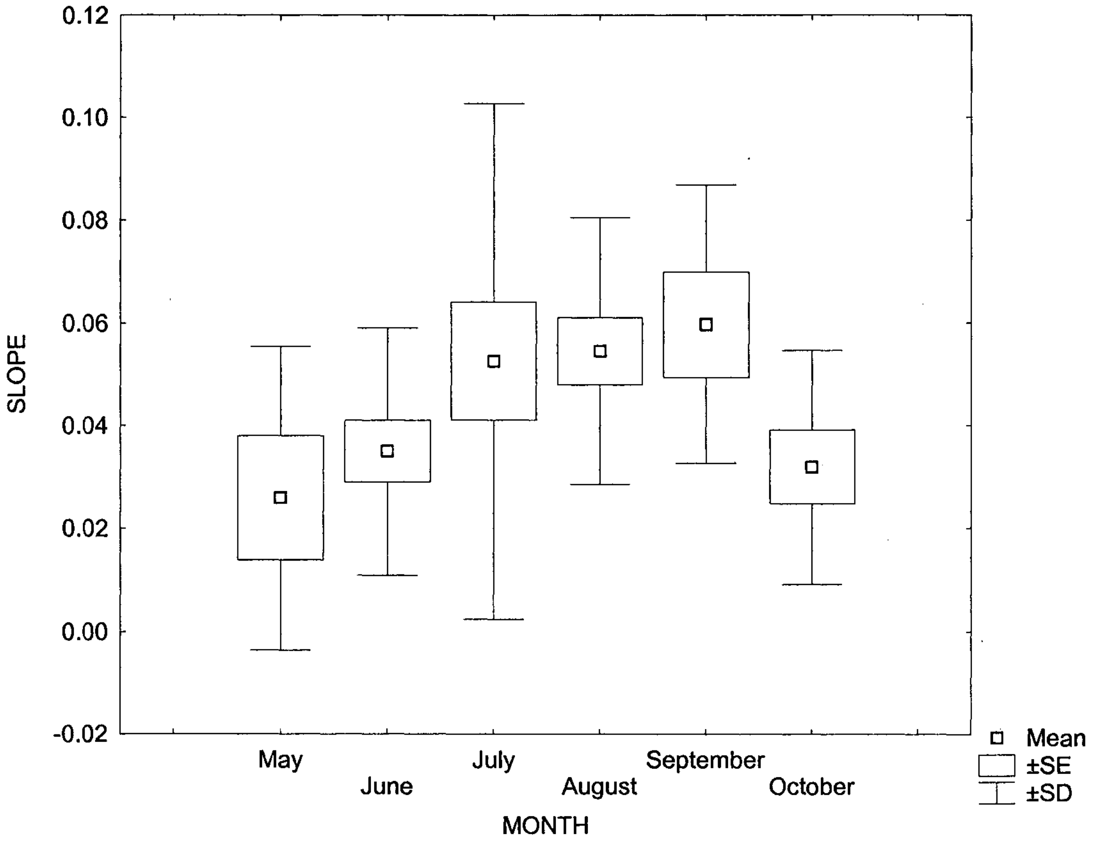

Figure 12: Distribution of means of coaster brook trout shoreline slopes calculated from depth and distance to shore values from individual locations. Bars indicate mean, mean ± standard error, and mean ± standard deviation. Sample sizes for individual time periods shown in Table 2.

Lake Movement

The maximum distance traveled for coaster brook trout, calculated as the straight-line distance between the two furthest location points for an individual brook trout, ranged from 2.94 to 46.02 km (Figure 13). The mean and median maximum distance traveled for coaster brook trout were 17.91 and 16.36 km respectively. Twelve of the twenty tagged coaster brook trout had a calculated range of greater than 10 km.

The movements of coaster brook trout over a 24 hour period were calculated for 20 individuals in June, July, and August (Table 4). The straight-line distance between locations of individual brook trout over a 24-hour period was relatively small with 66% of movement distances being less than 500 m (Figure 14). The majority of coaster brook trout 24-hour movements were less than 200 m in length. The mean and median 24-hour movement distance was 757 and 359 m respectively. Coaster brook trout periodically moved larger distances in a 24-hour period, with the maximum distance traveled being 16.45 km.

Coaster brook trout were more active in certain months when compared to others (ANOVA, F=4.705, p=0.015; Figure 15) moving significantly further in July (1391.1 m) than in June (304.9 m)(Tukey's HSD, $\alpha<0.05$). July was also the most variable month with respect to distance traveled in a 24-hour period ranging from 37 m to 5098 m.

The distance traveled by coaster brook trout during 4-hour intervals throughout a 24-hour period did not differ for any portion of the day or night (ANOVA, F=1.087, p=0.388; Figure 16). The time period with the highest mean

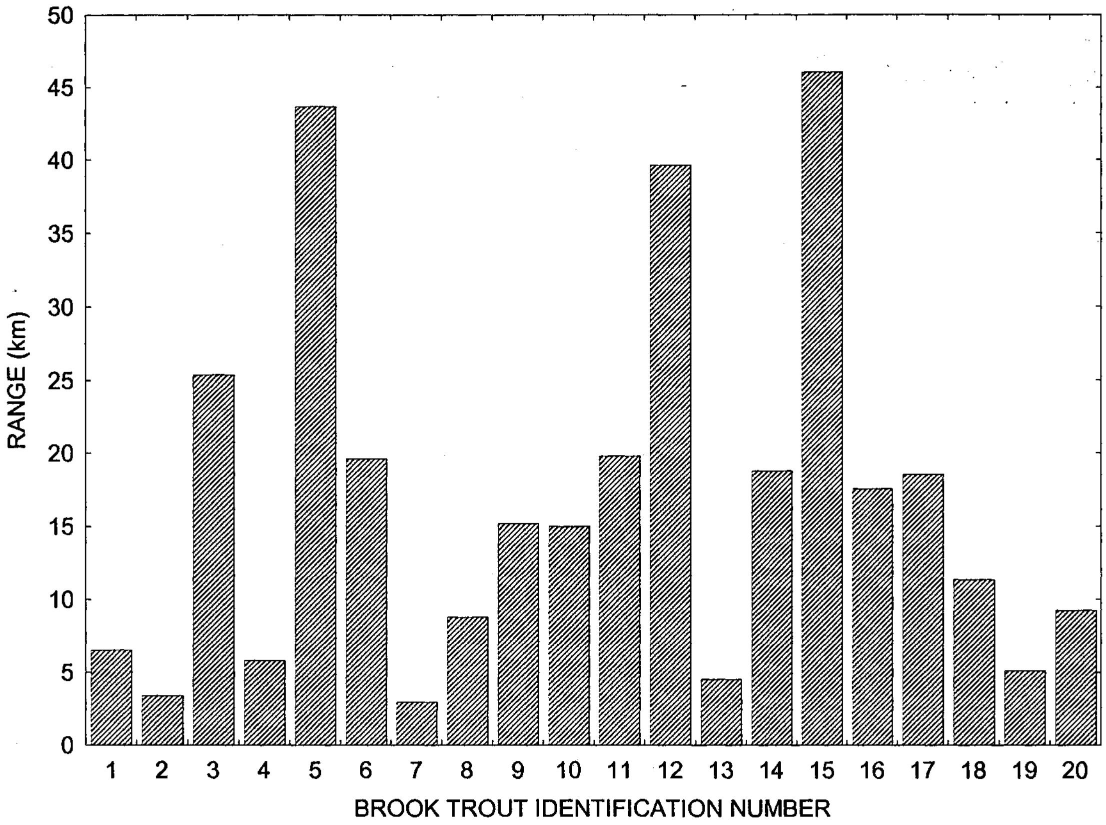

Figure 13: Range (calculated as the distance between the two furthest location points) of individual coaster brook trout.

Table 4: The number of 24-hour movement distances calculated for the months June, July, and August for each of the 20 coaster brook trout.

Brook Trout Identification Number	**June**	**July**	**Aug.**	**Total**
1	5	14	10	29
2	4	4	0	8
3	4	5	11	20
4	2	12	11	25
5	4	0	0	4
6	6	1	0	7
7	0	0	2	2
8	0	5	12	17
9	0	5	14	19
10	3	7	14	24
11	4	15	15	34
12	2	3	8	13
13	3	0	13	16
14	1	4	13	18
15	4	2	0	6
16	3	6	1	10
17	3	6	0	9
18	1	3	6	10
19	0	6	15	21
20	0	13	11	24
Total	49	111	156	
Total # Brook Trout	15	17	15	

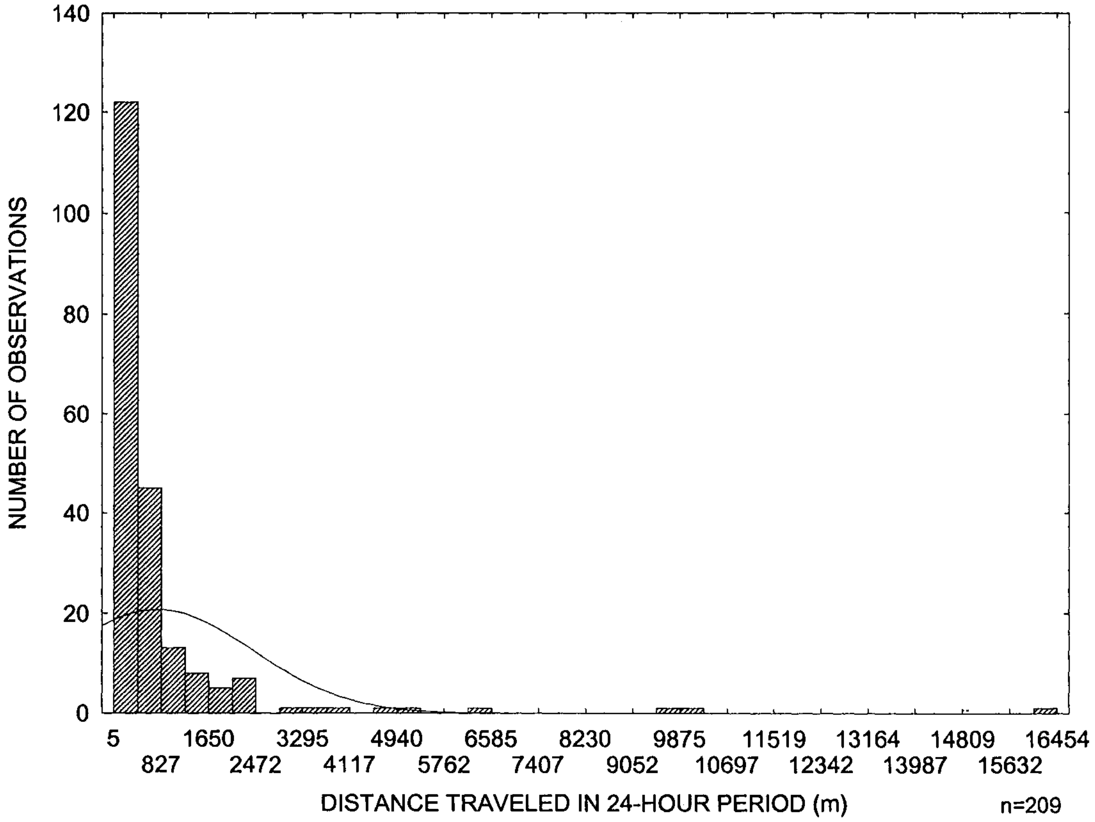

Figure 14: Frequency distribution of 24-hour movement distances for all coaster brook trout lake locations.

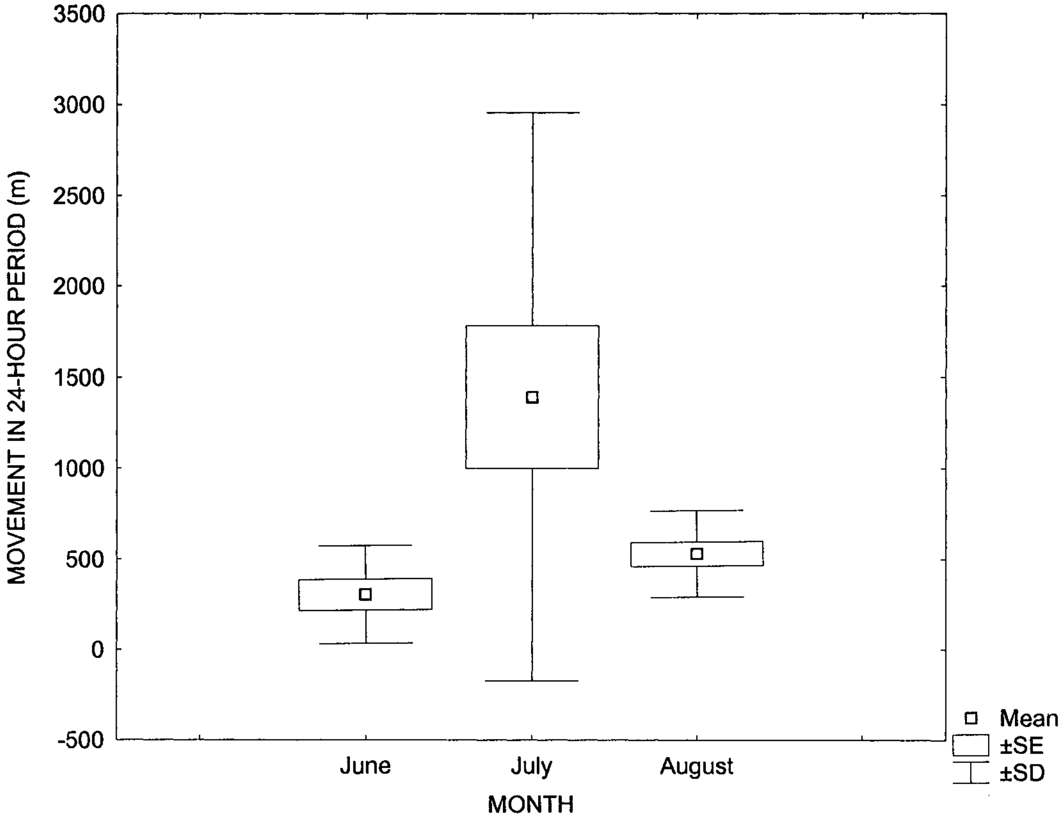

Figure 15: Distribution of means of coaster brook trout movements within a 24-hour period for the months June, July, and August. Bars indicate mean, mean ± standard error, and mean ± standard deviation. Sample sizes for each time period are shown in Table 4.

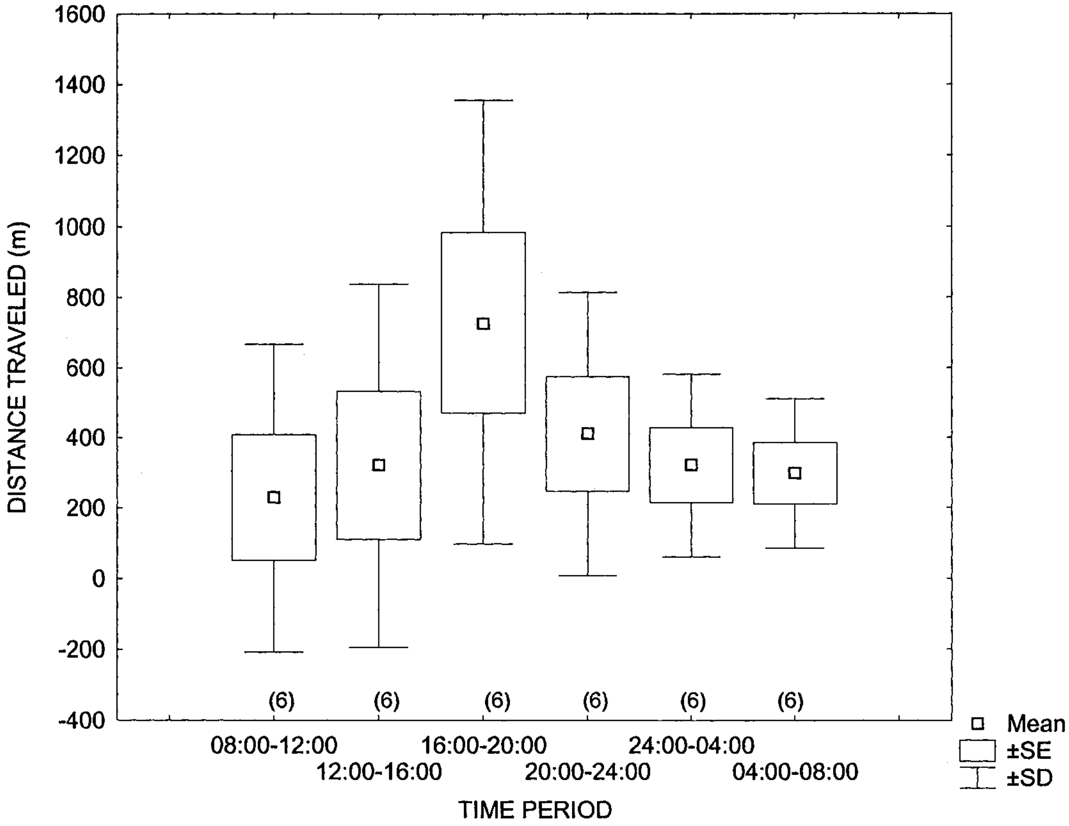

Figure 16: Coaster brook trout movements within 4-hour intervals of a 24-hour period. Bars indicate mean, mean ± standard error, and mean ± standard deviation. Sample sizes for each time period are shown above grouping variable.

movement was between 16:00 and 20:00 at 726 m. The lowest mean movement was observed between 08:00 and 12:00 at 229 m.

Stream Use

Tagged coaster brook trout used four different streams in the fall of 1999. A total of 12 tagged coaster brook trout entered streams, during the critical spawning period. Eight used the Cypress River, 2 used the Jackpine River, and 1 each for Dublin Creek and the Little Cypress River. These four streams are located along the north shore of Nipigon Bay in relatively close proximity to one another (Figure 1).

Watershed Scale Attributes

Streams utilized by coaster brook trout in the fall were of medium to small size in comparison to other Lake Superior tributaries (Table 5). Drainage area reflects the volume of water that can be generated from a rainfall event (Hornberger *et al.*, 1998). The mean drainage area for streams used by coaster brook trout in this study was 121.37 sq. km. Drainage area of utilized Nipigon Bay tributaries ranged from 8.38 to 288.04 sq. km. Channel length differs from drainage area by providing a measure of the travel time of water through a watershed (Hornberger *et al.*, 1998). The mean channel length of streams used by radio tagged coaster brook trout was 26.09 km. Channel length of utilized streams ranged from 49.45 to 4.4 km (Table 5).

Table 5: Summary of watershed-scale attributes of the Cypress River, Little Cypress River, Jackpine River, and Dublin Creek.

Parameter	**Cypress**	**L. Cypress**	**Dublin**	**Jackpine**
Mean Annual Runoff (mm)	348.387	350.581	340.232	344.824
Shape Factor	8.765	2.315	6.769	8.491
Mean Elevation (m)	450.449	296.571	412.864	442.642
Perimeter (km)	108.80	17.80	36.80	174.60
Slope of Main Channel (m/km)	6.872	21.729	25.430	5.838
Mean Annual Lake Evaporation (mm)	508.911	511.327	511.863	508.110
Mean Annual Precipitation (mm)	685.883	680.728	679.698	685.031
% Water and Wetland Cover (%)	6.884	250.189	1.962	34.654
Drainage Area (sq. km)	166.21	8.38	22.52	288.04
Length of Main Channel (km	38.168	4.404	12.347	49.456
Mean Annual Snowfall (cm)	246.145	244.873	245.686	247.285
Base Flow Index	0.728	0.722	0.720	0.733

Main channel slope reflects the momentum of the runoff and the rate of change of elevation with respect to distance along the principal flow path (Gray 1970). Main channel slope generally varied inversely with watershed size for utilized tributaries (Table 5). The mean main channel slope of utilized Nipigon Bay tributaries was 14.97 m/km, with a minimum and maximum of 5.83 m/km and 25.43 m/km.

Watershed shape is a unitless metric which reflects how runoff will concentrate at an outlet and is negatively correlated with peak discharge (Hornberger *et al.*, 1998). Watershed shape increases with watershed size for streams utilized by coaster brook trout (Table 5). The mean watershed shape of the four Nipigon Bay tributaries was 6.58 with a minimum and maximum of 2.315 and 8.765.

Percentage of water and wetland cover increased with drainage area for coaster brook trout streams. The mean percentage of water and wetland cover of the four Nipigon Bay tributaries was 11.5% with a minimum and maximum of 1.962% and 34.654%. Other watershed scale characteristics for the Cypress River, Jackpine River, Dublin Creek, and Little Cypress River are summarized in Table 5.

Reach Scale Attributes

Reach scale attributes were collected on the Cypress River, Little Cypress River, and Dublin Creek. Although coaster brook trout utilized the Jackpine River, no locations were made during the critical spawning period due to the inaccessible nature of the upstream reaches of this river and consequently no survey was done. Surveyed reach boundaries encompassed areas of highest use by radio tagged coaster brook trout during the latter portion of their stream residency. Reaches typically included areas of visually confirmed redd excavation by coaster brook trout and/or the presence of brook trout eggs. Selected reaches ranged from 81.8 to 117.3 m in length and encompassed numerous riffle-pool sequences (Table 6).

Stream reaches used by spawning coaster brook trout were generally narrow in width with medium velocities during base-flow conditions in comparison to other stream reaches available. The mean active stream width of selected reaches was 4.62 m and ranged from 3.16 m to 5.92 m. The mean velocity of surveyed stream reaches was 0.136 m/s with a minimum and maximum of 0.103 m/s and 0.178 m/s. The mean gradient of selected reaches was 1.82% and ranged from 1.52 to 2.0% (Table 6).

Surveyed stream reaches were generally shallow, with cover only being available in the form of woody debris, large boulders, or canopy cover. The mean depth of selected reaches was 0.158 m and ranged from 0.141 to 0.181 m. Maximum depths of individual stream reaches ranged from 0.42 to 0.87 m. Densiometer readings of canopy cover ranged from 36.1 to 47.3%. The dominant particle size in each reach was gravel with each stream's dominant cover type being large unembedded rocks. Woody debris was present in each stream reach, averaging one woody debris structure for every 16.7 m of stream.

Fish species assemblages were similar within all surveyed streams, with brook trout, rainbow trout, and coho salmon being present in each. Total fish biomass/m^3 ranged from 11.43 g/m^3 to 16.74 g/m^3, with brook trout biomass ranging from 4.27g/ m^3 to 10.71 g/m^3. Reach scale attributes are summarized in Table 6.

Stream Movement

Coaster brook trout began to enter tributaries of Nipigon Bay in mid-summer, continuing throughout the fall. The first coaster brook trout to enter a stream in 1999 was on July 27, the last tagged coaster brook trout to enter a stream was on October 11. The majority of tagged coaster brook trout entered streams in 1999 between August 15 and September 9.

Brook trout entering streams in the late summer and fall were observed to enter for brief durations before exiting back to Lake Superior to re-enter at a later date. Seven of the twelve tagged coaster brook trout exhibited this behaviour. With the exception of two brook trout that entered and exited multiple times, all other brook trout exhibiting this behaviour did so only once.

Individual coaster brook trout were also located in more than one tributary stream in the fall of 1999. Of the seven tagged coaster brook trout that exited streams shortly after entering them, four exhibited a wandering behaviour, entering a different stream soon after.

Coaster brook trout remained in the estuary and lower stream reaches before ascending to upstream reaches. The majority of tagged coaster brook

Table 6: Summary of reach-scale stream attributes of the Little Cypress River, Cypress River, and Dublin Creek.

Attribute	Little Cypress	Cypress	Dublin
reach length (m)	86.7	117.3	81.6
minimum active stream width (m)	0.74	1.4	3.6
average active stream width (m)	3.16	4.79	5.92
fish species present	brook trout, rainbow trout, coho salmon,	brook trout, rainbow trout, coho salmon, slimy sculpin, longnose dace	brook trout, rainbow trout, coho salmon
fish biomass (g)/cubic meter	17.1	11.43	16.74
brook t. biomass (g)/cubic meter	9.6	4.27	10.71
average velocity m/s	0.103	0.127	0.178
summer baseflow discharge	0.00908	0.00963	0.125
average depth (m)	0.141	0.153	0.181
maximum depth (m)	0.42	0.64	0.87
no. woody debris	7	5	3
dominant aquatic vegetation	filamentous algae	non-filamentous algae	non-filamentous algae
dominant cover type	unembedded round rock	unembedded round rock	unembedded round rock
subdominant cover type	unembedded flat rock	embedded round rock	embedded round rock
clinometer gradient %	1.52	1.93	2.01
average densiometer reading %	47.3	41.5	36.1
dominant particle size	gravel	gravel	gravel
subdominant particle size	clay	rubble	small boulder
average bank slopes %	7.3	18	23.3
upland ecosite types (L-bank)	ES33 Hardwood-Fir-Spruce-Mixedwood: Moist, Silty-Clayey soil	ES36 Intermediate Swamp: Black Spruce: Organic soil	ES44 Thicket Swamp: Organic-Mineral soil
upland ecosite types (R-bank)	ES44 Thicket Swamp: Organic-Mineral soil	ES37 Rich Swamp: Cedar: Organic soil	ES37 Rich Swamp: Cedar: Organic soil
dominant wetland types (L-bank)	N/A	W31 Rich Conifer Swamp: Cedar-Tamarack	W35 Thicket swamp: speckled alder/ bluejoint grass
dominant wetland type (R-bank)	W35 Thicket swamp: speckled alder/ bluejoint grass	W35 Thicket swamp: speckled alder/ bluejoint grass	W35 Thicket swamp: speckled alder/ bluejoint grass

trout ascended to upstream reaches between September 7 – 14. By September 27, ten of twelve coaster brook trout using streams had migrated to upstream areas.

The use of pools suggests that there is a minimum depth that provides cover for coaster brook trout. The use of deep pools decreased in the latter part of the river residency period in 1999. Ninety-eight percent of stream locations made in the month of September were in pools with a maximum depth greater than 1.5 m. Within the month of October, the number of locations in pools with a maximum depth greater than 1.5 m had decreased to 57%.

Coaster brook trout generally exited streams back into Lake Superior in mid-October. By October 25, nine of twelve coaster brook trout utilizing streams had returned to Lake Superior. By November 9, all coaster brook trout had been located within Nipigon Bay.

Coaster brook trout resided in tributary streams of Lake Superior for extended periods within the fall. The mean stream residency time for coaster brook trout in 1999 was 46 days (Figure 17). The minimum and maximum stream residency of radio-tagged coaster brook trout was 2 and 72 days respectively.

Coaster brook trout exhibited strong fidelity to spawning streams in the fall of 2000. Although numbers of coaster brook trout with operable transmitters had decreased by the fall of 2000, 6 brook trout entered streams in that year. Each brook trout also showed strong fidelity to their individual spawning area, being located in the same discrete reaches as in the previous year. Tracking intensity was reduced during the fall of 2000 and stream residence times could not be

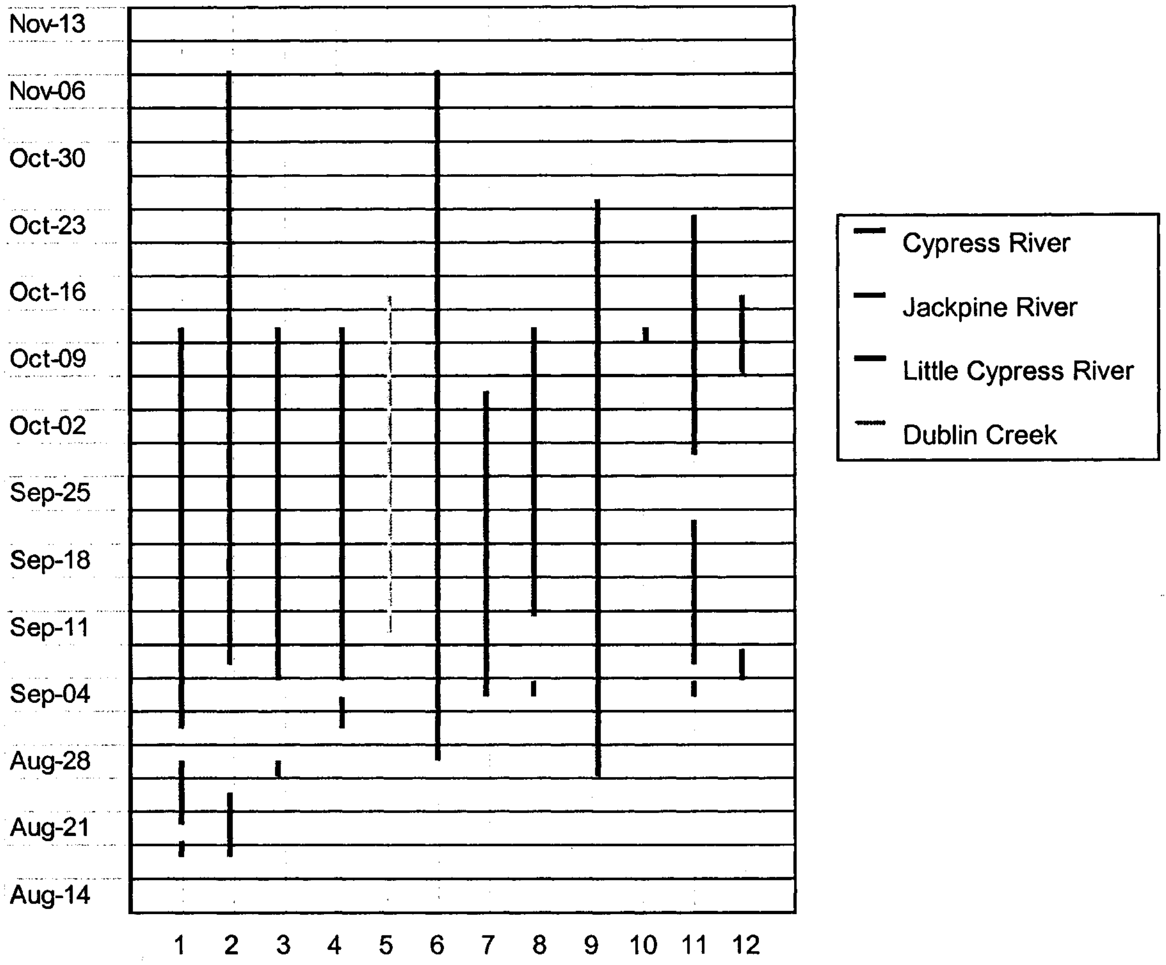

Figure 17: Individual coaster brook trout fall stream residency timeline for 1999 illustrating movement between Lake Superior and tributary streams as well as between tributary streams for the months August through November.

calculated for this year. From the limited number of days spent locating fish it can be surmised that the timing and habitat selection was very similar to 1999. Similar to the previous year, brook trout in 2000 were located in shallow spawning areas in early to mid-October and exited by the third week of October.

Discussion

My results illustrate that coaster brook trout within Nipigon Bay utilize areas with very specific habitat characteristics. Even though Nipigon Bay has a great diversity of habitat, brook trout primarily utilize the shallow nearshore areas, which comprise only a small percentage of the total habitat that is potentially available. A tendency for brook trout to use relatively shallow, nearshore areas in Lake Superior was also found by Newman et al. (1999) and Slade (1994). These findings are also consistent with anadromous brook trout, which were most often observed in the 2-4 m nearshore depth contour (White 1940).

The most highly utilized lake habitat of coaster brook trout in general terms can be described as a band of nearshore waters adjacent to the shorelines of both the mainland and the surrounding islands. The width of this habitat band is dictated by both depth and distance to shore. Brook trout typically selected areas of 7 m in depth or less and 600 m from shore or less. If nearshore waters have a shallow slope, then a greater offshore area was utilized. Conversely, a steep nearshore slope would yield only a narrow band of preferred habitat. These findings are consistent with studies of habitat use by lake-dwelling brook trout which indicate that this species may inhabit a range of depths but are generally located in nearshore areas within 1 m from bottom (Baldwin 1948, Flick and Webster 1962, Lackey 1970).

Approximately one third of Nipigon Bay can be categorized as shallow-offshore waters (< 7 m in depth, > 1 km from shore) based upon navigational depth maps. Although this area met the depth preference habitat criteria, tagged fish in this study used only a portion of the area available to them. Areas of Nipigon Bay designated as deep-offshore waters (> 7 m in depth, > 1 km from shore) were not often utilized. Isolated telemetry locations in deep offshore areas were likely due to individuals being located in transition between mainshore and offshore island habitats, but the possibility of these offshore areas being used for feeding cannot be overlooked.

Following ice-out, brook trout were located most frequently in areas that were extremely shallow and close to shore. An explanation for this pattern could be the tendency for these shallow nearshore areas to be the first to warm up following ice-out. Brook trout typically seek out the warmest possible water in the period following ice-out as these areas are generally closest to their temperature optimum for this time of year (Biro 1998). As summer progressed, brook trout were continually located further from shore in areas of greater depth. This is likely attributable to a tendency to remain in temperatures within their preference (Lackey 1970). During July and August coaster brook trout were located in deeper areas in comparison to other months. Deepwater habitat is often used as a temperature refuge by brook trout in lakes during July and August to avoid temperatures above their tolerance (Baldwin 1948, Lackey 1970, Olson *et al.* 1988). In addition to deepwater habitat as a temperature refuge, during the months of July and August coaster brook trout were located in localized shallow shoreline areas that appeared to be springs with groundwater discharge. Brook trout commonly use groundwater upwelling areas in lakes as a temperature refuge in mid-summer (Biro 1998).

In areas with very shallow littoral zone slopes, without sufficient deepwater habitat I observed brook trout moving to other shoreline areas with deepwater habitat. As water temperatures warmed, this habitat shift was observed for brook trout inhabiting the nearshore waters of Nipigon Bay's north shore within a period of a few days. Brook trout residing adjacent to offshore islands typically did not abandon their shallow nearshore areas until approximately a week later. This delay is most likely due to the cooler water temperatures (based upon surface water temperature readings) in these areas because of their proximity to Lake Superior's colder offshore waters. The abandonment of shallow nearshore areas for deeper habitat could also be indicative of individuals moving from feeding areas to staging areas. This explanation is less likely due to the synchronization of individuals within the same area and the delay in movement by nearshore insular brook trout.

Following the completion of spawning in late October, brook trout returned to Lake Superior from the tributary streams. At this time brook trout once again used the same shallow nearshore areas they inhabited following ice-out and before nearshore water temperatures exceeded their tolerable limit. Brook trout remained in these shallow nearshore areas throughout the fall and winter. Lackey (1970) also noted this trend of progressive increased average depth preference approaching summer followed by a rise in average depth in fall by brook trout.

Closer scrutiny of the nearshore habitat utilized by brook trout throughout the year revealed some physical differences between the habitat types.

Nearshore areas used by coaster brook trout in the summer had steeper littoral slopes than the nearshore areas utilized in spring/early summer and the fall after completing spawning. Rather than move to offshore areas to access deep waters of preferable temperature, brook trout selected adjacent nearshore areas with steeper slopes. Offshore areas may not be attractive to brook trout because their preferred forage may not inhabit these waters or these areas may be too far from inshore foraging areas. Shallow nearshore habitat also had a much higher occurrence of cover including large boulders, shoal edge, and aquatic vegetation. Due to the extremely shallow depths that coaster brook trout inhabit during certain months of the year it is expected that they will select areas which provide escape and concealment from predators such as cormorants, ospreys, and otters. Deep nearshore habitat was relatively devoid of the aforementioned cover types. Cover may not be critical to brook trout when occupying deep areas as increased depth may reduce predation pressure.

Habitat types also differed with respect to their shoreline surficial geology. Shallow nearshore areas were adjacent to bedrock knobs and plateaus while deep nearshore areas were adjacent to outwash plains and lacustrine deltas. The difference in surficial geology was reflected in the dominant substrate in the nearshore areas of these two habitat types. Shallow nearshore areas consisted of primarily glacially deposited materials such as boulders and cobbles while deep nearshore areas consisted of finer materials such as small gravels and sand. Nearshore habitat surveys were made along exposed shoreline areas to minimize the effect of lake deposited materials on assessing the dominant and subdominant substrate types.

When located at four-hour intervals throughout a 24-hour period, coaster brook trout were found in significantly deeper waters during the day compared to night. Throughout the day, brook trout in Nipigon Bay are usually associated with drop-off structure, large boulders, or aquatic vegetation. During crepuscular time periods, coaster brook trout were observed to leave cover or deeper waters moving to extremely shallow areas close to shore with limited cover. It is likely these individuals were leaving their daytime cover locations to feed during these low light conditions. Along Minnesota's Lake Superior shoreline, brook trout were observed leaving cover areas in the late evening to feed in shallow areas on insects (Newman *et al.* 1999). Although not known as low-light predators, brook trout are capable of feeding in complete darkness due to an acute olfactory sense (Hoar 1942).

Coaster brook trout appear to be quite variable with respect to the amount of total lake area they utilize. Home range estimations for individual coaster brook trout yielded a wide range of home range sizes from a few square kilometers to over a hundred square kilometers. This can be attributed to individuals exhibiting one of two movement behaviours throughout their lake residency. Plotted individual brook trout locations suggest brook trout either inhabit a small number of core areas, resulting in a small home range or move frequently utilizing numerous areas for only a brief duration yielding a much larger home range. The reason for this difference in strategies cannot be attributed to size differences among brook trout and is not an artefact of the number of telemetry locations. Tagged brook trout in this study were not sexed, and for this reason it cannot be determined if home range size differed between males and females.

Linear range or the straight-line distance between the two furthest location points offers another measure of the total area utilized and is applicable to a nearshore species which occupies only a narrow band of habitat along the periphery of a larger basin. Similar to the fixed kernel home range the linear range of coaster brook trout varied from less than a few kilometers to nearly fifty. These results are not consistent with anadromous saltwater brook trout, which rarely stray more than a few kilometers from their natal stream (Naiman *et al.* 1987). When residing in small streams, brook trout may be very sedentary occupying areas of less than 100 m^2 (Power 1980). When a brook trout's feeding, spawning, and over-wintering areas are separate, their range is usually much larger. Coaster brook trout have a decidedly smaller range than other salmonines in the Great Lakes such as rainbow trout which are far ranging following their association with their spawning stream, and travel between interconnecting Great Lakes is not uncommon (Hansen and Stauffer 1971). The brook trout is not physically adapted to long distance travelling in a lentic environment; its square tail and low aspect ratio are not conducive to high speed swimming and pelagic cruising (Naiman *et al.* 1987).

Coaster brook trout movements within a 24-hour period were generally small with most locations being within 200 m of the previous day's location.

Brook trout typically moved only short distances within their core areas for extended periods of time. Larger movements were often indicative of individuals moving from one core area to another, or shifting from shallow-water habitat to deep-water habitat.

Brook trout moved greater distances in 24-hour periods in July when compared with June or August. This is likely because July is the month when nearshore water temperatures exceed the preferred range for brook trout initiating movement to deep-water habitat. Shallow and deep-water core habitat areas for individual brook trout are often kilometers apart making a noticeable difference between these movements and the typical daily movements within a core area.

The results from this study suggest that coaster brook trout exhibit fairly fixed movement patterns and habitat selection during their residency in tributaries of Nipigon Bay. Brook trout began entering tributaries sporadically beginning in late July. The residency time during these early upstream movements was generally brief, lasting no more than a few days before individuals returned to Lake Superior. During periods of unfavorably high lake temperatures, brook trout often move into tributaries in search of temperature refugia (Power 1980). It is difficult to assess whether water temperature or instinct is responsible for this behaviour. Ephemeral upstream movements continued until mid-August when brook trout ceased to return to Lake Superior after a few days within their tributaries. The observed behaviour pattern differs from mature anadromous brook trout that return to their natal streams in a non-pulsed manner throughout the months of August and September (MacGregor 1973, Montgomery *et al.* 1990).

Upon first entering Nipigon Bay tributaries in late summer and early autumn, brook trout inhabited slow pools in the lower river or remained within the estuarine portion of the river. Brook trout in the lower estuary were observed to aggregate in schools and move as a group. Similar aggregations of anadromous brook trout were observed within still-water sections of Nova Scotia's Moser River in August and September (Wilder 1952). The lower river and estuary portions of most Nipigon Bay tributaries utilized by brook trout provide adequate cover as these waters are generally deep and unaffected by low-flow periods. Movement of brook trout from the lower estuarine waters to upstream holding pools was associated with a significant rain event in both 1999 and 2000 (personal observation). White (1940) observed a similar correlation between an increase in stream flow and an increase in upstream movement of anadromous brook trout within their spawning streams.

Movements from the estuary and lower river portions to upstream holding areas by coaster brook trout was generally accomplished in a single day. Due to the presence of natural barriers to migration, three of the four streams used by tagged coaster brook trout have less than 10 km of accessible river from Lake Superior. Upstream movements of this magnitude by coaster brook trout are similar to single day upstream movements by anadromous brook trout which ascend several kilometers daily to reach their spawning areas (Naiman *et al.* 1987).

Unlike other tributaries, the Little Cypress River did not have any tagged brook trout enter until late September. The individual tagged brook trout using this stream during the critical spawning period was located in the lower estuarine waters of an adjacent river for the previous three weeks. This difference in behaviour could be explained as a function of the diversity of tributaries utilized by coaster brook trout. Tributary characteristics such as drainage area and morphology affect the amount of cover through depth available to large migratory salmonids. Comparatively the Little Cypress River is much shallower in either the estuary or lower river and is likely not suited to holding large brook trout for extended periods.

Once ascending tributaries to upstream reaches following significant rain events, brook trout once again sought out deep pools. Brook trout remained within these holding pools until the last week of September. Throughout the last week of September and early October brook trout moved into shallow runs, pool tail-outs, and tributaries to the main rivers. Similarly, anadromous brook trout entering a large river system remained within areas of the main river system and entered smaller tributaries to spawn in October (Wilder 1952). Due to the shallow nature of the streams where brook trout were located at this time, it was possible to visually observe them during this period. During the first two weeks of October, coaster brook trout were observed in acts of courtship, redd digging, and egg deposition.

The link between groundwater input and brook trout spawning areas has been solidified in many studies (Witzel and MacCrimmon 1983; Curry and

Noakes 1995; Blanchfield and Ridgway 1997). Stream banks adjacent to areas with observed coaster brook trout spawning were observed to either be wet well above the level of flow or have concentrations of marsh marigold (*Caltha palustris*), which is an indicator of focused ground water discharge (Rosenberry *et al.*, 2000).

By the third week in October most brook trout had returned to Lake Superior. The descent from their spawning areas was brief and highly synchronized with most brook trout making the journey within the same three day period. The same deep pools which held some brook trout for over a month during the pre-spawn ascent were utilized for no more than one to two days during their descent.

The length of stream residency for brook trout averaged 46 days but varied considerably between individuals from 2 to 72 days. The mean stream residency time for coaster brook trout is similar to the 60 day mean duration that brook trout were located on or near their spawning grounds in a small Southern Ontario Lake (Blanchfield and Ridgway 1997). The vast differences in residency times between brook trout could be related to the sex of the individual. Female brook trout generally spend less time on spawning grounds than males (Blanchfield and Ridgway 1997). The sex of brook trout used in this study was not determined because individuals were tagged in the spring when sexual dimorphism is not apparent.

Tagged brook trout did not over-winter within spawning streams; the last brook trout exited by the first week of November and did not return. This behaviour differs from that of anadromous brook trout which over-winter exclusively within their freshwater spawning tributaries (Naiman *et al.* 1987; Montgomery *et al.* 1990). This difference is likely attributable to the intolerance of brook trout to low temperatures and high salinity characteristic of seawater during the winter months (Saunders *et al.* 1975).

Based upon observations of redd excavation by tagged brook trout within Nipigon Bay tributaries it appears that most spawning occurred during the second week of October at a time when water temperatures within these streams declined to 8°C. Blanchfield and Ridgway (1997) observed peak spawning periods for brook trout to be associated with drops in temperature from 11.3 to 10.3°C and 8.8-5.9°C. Temperature has little if any effect on ova development, with the regulation of the ovarian cycle controlled primarily by photoperiod (Henderson 1963).

Coaster brook trout appear to have strong homing abilities based upon the locations from the 1999 and 200 spawning runs, both to their home streams and more precisely to their own distinct spawning reaches. Very few studies have examined the ability of brook trout to return to a natal area for reproduction. White (1940, 1941) found evidence for homing in anadromous brook trout within the Moser River but with some error in choosing between tributaries of the same river system. Similarly, displaced fish from Matamek Lake, Quebec returned with great precision to their natal streams (O'Connor and Power 1973).

Problems associated with obtaining useful telemetry data on coaster brook trout include having to cover the vast amount of potential habitat both within

Nipigon Bay and surrounding areas. Although most tagged coaster brook trout remained within Nipigon Bay for the duration of the study, it is highly probable based upon their movement capabilities that some individuals strayed outside this area and did not return. Numerous individuals were lost for extended periods with some never being located again. Locating tagged individuals during the spawning period was especially challenging with the numerous tributaries accessible only by walking, and the short stream residency time observed in some tagged coaster brook trout. Five of the twenty tagged brook trout were reported as being caught and released by anglers with one of these being caught three times. This figure indicates both the high susceptibility of these fish to angling, and their relatively low abundance within Nipigon Bay. Mortality, whether natural, post-surgical, or angling also contributed to reducing the sample size of individuals tracked throughout this study.

Land-use activities such as forest harvesting, or shoreline development may have significant impacts upon critical coaster brook trout spawning habitat by altering the localized flow of groundwater into brook trout spawning areas. Tertiary roads built for the removal of harvested timber also serve as potential access points for anglers to upstream areas of coaster brook trout spawning streams. Presently, the north-shore of Nipigon Bay has a limited road network, thus restricting access to these areas to individuals willing to walk significant distances. Increased access to these areas will likely cause an increase in harvest during the brief period in August when adult coaster brook trout ascend streams and before the angling season has closed on Labour Day.

Although this study did not identify any lake spawning areas within Nipigon Bay, it is highly probable that there are lake-spawned individuals contributing to the coaster brook trout population of Nipigon Bay. Future research should be aimed toward identifying these areas and assessing their contribution to the overall population. Anecdotal information suggests that although coaster brook trout numbers are well below historic levels, they have increased over the last decade. Obtaining population estimates of adult coaster brook trout within individual streams and gathering temporal trend information on these systems will allow for the monitoring of the effectiveness of our management strategies. Life history information of this remnant coaster brook trout stock, including information on smolting, age at maturity, and repeat spawning would be immensely valuable as an aid to managing this resource.

Even with the many remaining gaps in our knowledge of coaster brook trout, many important steps have already been taken. Acknowledging that there is a need to protect and gain valuable information from those individuals that remain will certainly assist in achieving the long-term viability of this native species.

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