DEVELOPMENT AND APPLICATION OF PASSIVE INTEGRATED TRANSPONDER TECHNOLOGY TO INVESTIGATE THE MOVEMENT AND REPRODUCTIVE ECOLOGY OF ADULT SLIMY SCULPIN (Cottus cognatus) IN SMALL NEW BRUNSWICK STREAMS

by

Rachel Ann Keeler

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Supervisor: Richard Cunjak, Ph.D., Canadian Rivers Institute, UNB Fredericton

Examining Board:
  Graham Forbes, Ph.D., Department of Biology, UNB
  Tom Al, Ph.D., Department of Geology, UNB

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ABSTRACT

Passive integrated transponder (PIT) tags are the only electronic tags small enough (11.5 mm) to individually identify and monitor small-bodied fishes (e.g. most cottids and many cyprinids). This research used adult slimy sculpin (*Cottus cognatus*) as a model to further develop and test a portable PIT antenna capable of detecting PIT tags without removing fish from the water. The PIT tags had limited effects on the survival and growth of slimy sculpin in a laboratory setting for an extended period (up to 8 months). A PIT tag antenna was developed and was used to search for sculpin (n=337) implanted with PIT tags at six sites in five tributaries of the Kennebecasis River, NB. Sites were searched for sculpin, approximately biweekly, from June 2003 to July 2004. More than 85% of implanted sculpin were detected during the study and this spatial information was used to consider two main areas of sculpin ecology: annual movement and reproductive ecology. Annual movement of PIT tagged sculpin was extremely low, with a median home range of 9 m. Reproductive habitat was investigated, and male sculpin preferred cobble habitat in shallow areas of the stream, and there was a strong relationship between the size of the male and the number of eggs in the nest, but not with nest size. Female sculpin appear to select nests based on the male quality rather than nest quality. This research demonstrates that PIT technology is useful for studying the ecology of wild, small-bodied fishes.
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1 GENERAL INTRODUCTION

1.1 Passive Integrated Transponder (PIT) Technology

Fisheries researchers are limited in their options when identifying and monitoring wild, small-bodied fish (e.g. most cottids and many cyprinids). For larger fish species, radiotelemetry is often used to remotely follow the movements of individuals in freshwater; this is not possible for small-bodied fish because even the smallest radio tags available on the market are too large for the adults or juveniles of many fish species. Even if the radio tag size can be reduced in the future, such development would likely come with great expense, and limited battery life would result in short study durations. Therefore, it is important that alternative technologies are developed for fisheries researchers studying individual small-bodied fish.

Passive integrated transponder (PIT) technology has been developed as a technique for individually tagging fish and has been used to tag a variety of small-bodied fish (Prentice et al. 1990a, Peterson et al. 1994, Ombredane et al. 1998, Skalski et al. 1998, Baras et al. 1999, 2000, Das Mahapatra et al. 2001). Its use in ichthyological research has rapidly increased over the last two decades, largely in response to technological improvements (reviewed in Lucas & Baras, 2000). Until recently, PIT tag systems were limited in their effectiveness in the field because fish had to be physically disturbed and recaptured (e.g., by electrofishing) in order to be scanned for tags. In response to this limitation, researchers and manufacturers started to consider designs for portable and stationary antennas capable of detecting PIT tags remotely.
Prentice et al. 1990b, Roussel et al. 2000). Roussel et al. (2000) were the first to field test the efficiency of a portable PIT tag system; when used with 23.1 x 3.9 mm PIT tags, the equipment had a detection range of 70-100 cm. This was an important contribution to PIT technology but smaller PIT tags (11.5 mm) suitable for small-bodied fish were not compatible with this antenna system. In addition, since more advanced technologies were not available for movement studies on small-bodied species in the past, marking techniques used in such studies on cottids have been potentially disruptive (e.g. electrofishing) and recapture success has been limited to <50% of marked individuals (McCleave 1964, Brown and Downhower 1982, Greenberg and Holtzman 1987, Hill and Grossman 1987, Morgan and Ringler 1992, Gray 2003, Schmetterling and Adams 2004).

1.2 Slimy Sculpin Ecology

The ecology of the slimy sculpin (Cottus cognatus) is poorly understood even though they are common and abundant throughout most of Canada and the northern United States of America (Scott and Crossman 1998). They are normally found in cool streams or deep lakes. Sculpin are a cryptic, benthic species and are usually found in habitats where the substrate is large enough to provide cover. Previous studies have shown that home ranges of slimy sculpin and the closely related mottled sculpin (Cottus bairdi) are limited to <100 m (McCleave 1964, Brown and Downhower 1982, Greenberg and Holtzman 1987, Hill and Grossman 1987, Morgan and Ringler 1992, Gray 2003), although
Schmetterling and Adams (2004) found more extensive movements in some individuals (>250 m).

Like many other fresh water cottid species, slimy sculpin are a nest guarding, polygynous fish. Spawning occurs annually in the spring (May), but individuals can spawn several times during their lifespan. Males establish territories containing an appropriate nest site, which is normally a rock or some sort of submerged debris. Females are attracted to the nest and deposit their adhesive eggs to the under surface of the rock. Females deposit their entire clutch into one male's nest; males can receive the clutches of many females. Males guard the nest rock during the incubation of the eggs and for a short period after the young hatch (Van Vliet 1964, Scott & Crossman 1998).

1.3 Objectives and Outline of Thesis

The main objective of this research was to develop a portable passive integrated transponder (PIT) system to investigate the movement and reproductive ecology of slimy sculpin in small New Brunswick streams. The thesis is organized into five sections: a general introduction, three main body chapters, and a final discussion.

The first step in this thesis (Chapter 2) was to develop and test a PIT tag system that could be used in conjunction with the 12 mm PIT tags suitable for small-bodied fish species, using adult slimy sculpin as a model. This research had two main components: a laboratory test of PIT tagged sculpin survival, growth and tag retention and a field test of the efficiency of a portable PIT tag
antenna. It was expected that PIT technology would have higher recapture success and therefore, provide better estimates of movement than techniques used in the past. Once the feasibility, effectiveness and limitations of this system could be determined, the antenna system was able to be used to address ecological questions about slimy sculpin in small streams.

The objective of the movement study discussed in Chapter 3 was to consider movement and how it was influenced by site, season, time of day, sex and fish length. It was hypothesized that movement of individuals at different sites would vary as a result of environmental differences among the sites. It was predicted that movement would vary with the reproductive changes occurring in sculpin throughout the year. For example, it was expected that males would show strong site fidelity when they were nest-guarding. Winter movement in cold climates has never been reported in the literature so it was especially important to determine sculpin location in this season. It has been an assumption of movement studies in the past that movement is consistent throughout the year even though, it is often only monitored in the summer months.

The research described in Chapter 4 was conducted to examine the basic reproductive ecology of slimy sculpin in the Kennebecasis River, New Brunswick. The specific details of reproduction investigated include: timing of spawning, spawning movements, biological and physical characteristics of the nest sites. The other main objective of this chapter's research was to consider how male reproductive success, measured as the number of eggs in his nest, related to nest size and male size (length). It was predicted, based on research
of other cottid species, that reproductive success would be positively related to the length of the male regardless of nest size.

1.4 Literature Cited


2 EVALUATING A PIT TAG SYSTEM TO MONITOR INDIVIDUAL SMALL-BODIED FISH

2.1 Abstract

Fisheries researchers are limited in their options when identifying and monitoring the movements of small-bodied fish in the field. The size of passive integrated transponder (PIT) tags (11.5 mm × 2.1 mm) make them suitable for many small-bodied and juvenile fish. However, PIT tag readers have had low effectiveness in the field to date because fish needed to be recaptured to be scanned for tags. Adult slimy sculpin, a small-bodied fish, were used as a model to further develop and test a portable PIT tag antenna capable of detecting tags without removing fish from their location. The 12 mm PIT tags had a minimal impact on survival (81-100%) compared to control (95%) and tag retention was very high (94-100%) for slimy sculpin (size range: 63-91 mm TL) monitored in the laboratory from October 2002 to May 2003. There was no significant difference in individual growth between sculpin implanted with PIT tags and those marked with VIE (visible implant elastomer). The portable antenna had a detection distance of 17-30 cm and was dependent on the orientation of the PIT tag. The efficiency of this antenna was very high (90%) when searches were conducted for PIT tagged sculpin in closed stream sites. This study demonstrates that PIT tag technology has limited effects on the survival and growth of slimy sculpin and is very effective at detecting individual fish in the field. This system has the potential to increase the number of tagged
individuals located, minimize disturbance and provide the researcher with the ability to ask ecological and applied questions about small-bodied fish that were logistically difficult to consider in the past.

2.2 Introduction

Fisheries researchers are limited in their options when examining the mobility of small-bodied fish (e.g. most cottids and cyprinids) in the field. For larger fish species, radiotelemetry is often used to remotely follow the movements of individuals. This is not possible for small-bodied fish since even the smallest radio tags available on the market are too large for the adults or juveniles of many fish species. Even if the radio tag size can be reduced in the future, the expense and limited battery life would severely limit the duration of studies. Therefore, it is important that alternative technologies are developed for fisheries researchers studying individual small-bodied fish.

In the current study, a passive integrated transponder (PIT) system was developed and tested on adult slimy sculpin (*Cottus cognatus*). Passive integrated transponder (PIT) technology has been developed as a technique for individually tagging fish and has been used to tag a variety of small-bodied fish (Prentice et al. 1990a, Peterson et al. 1994, Ombredane et al. 1998, Skalski et al. 1998, Baras et al. 1999, 2000, Das Mahapatra et al. 2001). Its use in ichthyological research has rapidly increased over the last two decades, largely in response to technological improvements (review in Lucas & Baras, 2000). Until recently, PIT tag systems were limited in their effectiveness in the field because fish had to be physically disturbed (e.g., by electrofishing) and
recaptured in order to be scanned for tags. In response to this limitation, researchers and manufacturers started to consider designs for portable and stationary antennas capable of detecting PIT tags remotely (Prentice et al. 1990b, Roussel et al. 2000). Roussel et al. (2000) were the first to field test the efficiency of a portable PIT tag system; when used with 23.1 x 3.9 mm PIT tags, the equipment had a detection range of 70-100 cm. This was an important contribution to PIT technology but smaller PIT tags (11.5 mm) suitable for small-bodied fish were not compatible with this antenna system.

The purpose of this study was to develop and test a PIT tag system that could be used in conjunction with the 11.5 mm PIT tags suitable for small-bodied fish species, using slimy sculpin as the test species. This research had two main components; a laboratory experiment of PIT tagged sculpin survival, growth; and, tag retention and a field test of the efficiency of a portable PIT tag antenna.

2.3 Methods

2.3.1 Laboratory Test

Two different groups of slimy sculpin were used for the laboratory experiment. In the first group, 16 slimy sculpin (63-91 mm TL) were captured by electrofishing in McBean Brook in central New Brunswick (N 46° 10.05', W 66° 36.36') on October 12, 2002. They were brought into the laboratory facilities at the University of New Brunswick and acclimated in tanks for more than two weeks. They were maintained at 12:12 light-dark cycle and fed fresh or frozen...
brook trout (*Salvelinus fontinalis*) eggs daily. Water temperature ranged from 10°C to 16°C during the experiment. On October 20, 2005, these sculpin were anaesthetized, measured and implanted with an 11.5 mm PIT tag. To implant the PIT tag, a small incision (3-4 mm) was made on the ventral surface, anterior to the urogenital papilla and the PIT tag was manually inserted into the peritoneal cavity (procedure modified from Gray (2003)). Survival and tag retention of these individuals was monitored daily until May 2003.

The second group of 38 sculpin were collected by electrofishing from the same site on McBean Brook and from the Kennebecasis River (N 45º 50.35', W 65º 15.06) on December 3, 2002. They were held under the same conditions as sculpin in the first group. On January 10, 2003, 18 sculpin were implanted with PIT tags following the same procedures described above and 20 were individually marked with visible implant elastomer (VIE; Northwest Marine Technology, Inc.). VIE is a coloured liquid plastic that can be inserted into the top layer of the skin with a syringe at various locations on a fish. The VIE mark solidifies and provides a lasting individual identification when different colour and location combinations are used. Red, yellow and green colours were used in seven locations: right or left marks around the caudal, pectoral, or dorsal fins or between the eyes. The VIE fish were used as a ‘pseudo’-control group, since it was important to have a group of sculpin to compare with the PIT tagged fish that could be identified to determine individual growth. Bruyndoncx et al. (2002) found that VIE marks had no effect on the survival of 57 bullhead (*Cottus gobio*) held in a laboratory for 4 wk.
Sculpin weight and lengths were checked approximately biweekly for individuals of both groups until May 2003. Survival and tag retention was also monitored. A repeated measures ANOVA was used to compare the growth of individuals from the VIE and PIT tag groups.

2.3.2 PIT Antenna Design and Field Test

The PIT tag antenna was developed from components made by Destron Fearing Corp. (MN, USA) using 11.5 mm PIT tags that are commercially available from Biomark, Inc (ID, USA) in North America¹ (as described in Cucherousset et al. 2005). The antenna consisted of a coil of wires attached to capacitors and was enclosed in “spa flex”, a durable, flexible thick plastic tubing (38 mm dimension), bent into an oval shape (diameter 33 x 27 cm) with the ends sealed with silicon to make the antenna coil water proof. The pole of the antenna was made from a 1.65 m length of PVC pipe. The antenna was connected to a tuning box (2001-TU30, Destron Fearing Corp.) and then attached to the PIT tag reader (FS2001/ISO, Destron Fearing Corp.). The reader had a LCD display, data logging memory and was protected in a water-resistant case (24 x 11 x 8 cm). The reader displayed the tag code sent from the antenna and could be programmed to produce a beeping sound upon detection of a tag. The reader was carried in a customised apron worn by the researcher so that the LCD screen could be continuously monitored. The entire

¹ Destron Fearing Corp. recently developed a portable antenna for sale, however, the unit was unavailable at the time of testing.
unit was powered by rechargeable lead acid batteries (12V, 2A) carried in a backpack. The 134.5 Hz PIT tags (TX1400ST, Destron Fearing Corp.) used in this study were 11.5 mm in length, 2.1 mm in diameter and weighed 0.06 g in the air.

The PIT antenna was field-tested (as described in Cucherousset et al. 2005) in three small tributaries of the Kennebecasis River, southern New Brunswick, Canada: Windgap Stream (Site 1), Dee Stream (Site 2), and Shannon Stream (Site 3). The channel width was similar at all stream sites (3.4-3.6 m average) and the lengths of the sites ranged from 37-85 m. The substrate in these sites consisted of mostly pebble, cobble and boulders. Each site was electrofished to collect adult slimy sculpin; these individuals were anaesthetised in clove oil (0.04 mL/L water) and their total length measured. For all sculpin larger than 60 mm, PIT tags were implanted as described for the laboratory sculpin.

Following a 24 hr recovery period in live boxes set in the stream, sculpin were released into the sites. The sites were closed prior to release with barrier nets at both ends. At each site, the sculpin were tracked once 5 to 30 min after release. While tracking, the operator walked upstream moving the antenna in the water close to the stream bottom, ensuring that all areas of the stream were covered within the detection range.
2.4 Results

2.4.1 Laboratory Test

Survival for PIT tagged sculpin from group 1 and 2 was very high (81-100%) (Figure 2.1). For group 1, two PIT tagged sculpin died in November and an additional one died in January, all of the other sculpin (n = 16, 81%) survived until May. For group 2, all PIT tagged sculpin (n = 18) survived from January 10, when they were tagged, until the end of the experiment. One VIE marked sculpin died in February and all other VIE sculpin (n = 19/20, 95%) in group 2 survived until May.

Tag retention was high for both PIT tag groups (88% and 100% for groups 1 and 2, respectively). One sculpin from group 1 lost its PIT tag in January 2003 and the loss appeared to result from the incision wound not healing properly. All VIE marks were maintained from January until May and were visible with the naked eye on close inspection, or easily seen when illuminated with an infrared light. Red was the darkest VIE colour and not as visible as the other two colours through the sculpins' mottled pigmentation, however green and yellow were sometimes difficult to distinguish under infrared light.

PIT tagged sculpin were of similar size to the VIE sculpin at the beginning of the experiment (average TL ± SD = 70 ± 4.8 mm, 72 ± 9.2 mm, respectively). Individual growth in length were not significantly different between the PIT tag and VIE marked sculpin (Figure 2.2; F = 0.45, p = 0.51, n= 18, 19 for PIT, VIE). The average (± SD) length at the end of the experiment was 80 ± 5.2 mm and
82 ± 8.0 mm for PIT and VIE fish. The PIT tagged sculpin also weighed less than the VIE sculpin at the time of tagging (average (± SD) 3.8 ± 0.9 g, 4.3 ± 2.1 g for PIT, VIE); however individual weight gain was not significantly different between the two mark groups (Figure 2.2; F = 0.58, p = 0.45, n= 18, 19 for PIT, VIE). At the end of the experiment, the average mass (± SD) was 6.6 ± 1.5 g and 6.8 ± 2.7 g for PIT and VIE sculpin. The only decrease in growth was seen immediately following the procedure to individually identify sculpin and occurred in both the PIT tagged and the VIE marked sculpin.

### 2.4.2 PIT Antenna Field Test

The maximum detection distance of the antenna for detecting tags ranged from 17-30 cm depending on the orientation of the tag. In total 22, 54 and 58 sculpin were tagged per site. PIT tagged slimy sculpin ranged in size from 60-102 mm in length and averaged (± SD) 74 ± 9 mm. Only, two sculpin died as a direct result of the capture and tagging procedure and tag retention was 100% for the first 24 hr. The number of tagged sculpin detected by the antenna was used to determine the detection efficiency of this system; 76%, 96% and 97% of the sculpin were detected at stream sites 1, 2, and 3, respectively.

### 2.5 Discussion

The purpose of this research was to test a PIT tag system capable of monitoring individual fish tagged with 11.5 mm PIT tags. It was important to start this process by ensuring that the PIT tags used in this study did not have a negative impact on the survival and growth of tagged individuals. Our results
suggest that PIT tags had a negligible effect on sculpin survival over a long time period. In group 1, only three of the 16 individuals tagged died in the eight months they were monitored. Two of these individuals died in the first month possibly resulting from the PIT tag surgery; however the third sculpin died three months later so it is unlikely that it was directly related to the surgery. The group 1 tagging session was the first time that the surgeon performed the PIT tag implantation and these initial deaths may have been a result of inexperience. There were no mortalities of group 2 fish and mortality for sculpin in the field was <1% within the first 24 hr, supporting the suggestion that group 1 had lowered survival due to technical inexperience. One of 20 died in the control for group 2.

Tag retention was also high for all groups (94-100%); only one sculpin lost its tag and was also in group 1. The high survival and tag retention are consistent with past research on the effects of PIT tags. Gray (2004) found 100% survival and tag retention for eight PIT tagged slimy sculpin over one month. Tag retention for juvenile salmonid species has also been high in laboratory and field studies (>95%; Prentice et al. 1990a, Peterson et al. 1994, Ombredane et al. 1998).

Individual growth was monitored for sculpin from group 2 by marking half the sculpin with PIT tags and half with VIE. There was no difference between the growth of the sculpin from the two marking techniques (Figure 2.2). The growth of the sculpin was slightly depressed in the first week following surgery and then there was a consistent increase in the growth of sculpin for the remainder of the study. Prentice et al. (1990a) and Baras et al. (2000) also saw initial depression of growth for PIT tagged juvenile Chinook salmon,
Onchorhynchus tshawytscha, and Eurasian perch, Perca fluviatilis, respectively, but no lasting effects for the remainder of their studies. A growth depression was seen in both the PIT tagged and the VIE marked sculpin suggesting that it may result from handling stress rather than effects of the PIT tag surgery.

The impact of PIT tags on the survival and growth of slimy sculpin in the laboratory was minimal in this study, suggesting that PIT tags would be effective tags for marking individual fish in the field. Other researchers have found PIT tags an effective technique to monitor individual small bodied fish (slimy sculpin, Gray 2004), and juveniles of salmonids and other fish species (for example, Chinook salmon, Onchorhynchus tshawytscha, Prentice et al. 1990a, brown trout Salmo trutta, Ombredane et al. 1998; Nile tilapia, Baras et al. 1999).

The second main objective was to construct and test a portable PIT tag antenna compatible with the 11.5 mm tags used to tag small-bodied fish like sculpin. The antenna was capable of detecting tags within a range of 17-30 cm and was around 90% efficient at detecting PIT tagged individuals in closed sites. In the past, the PIT tag reader’s ability to determine the code from the PIT tag has had limited range and so the fish have had to be removed from the water before the code could be read. Consequently, tagged fish had to be recaptured repeatedly by electrofishing, a technique that is less effective, and potentially disturbs fish and alters their behaviour (Keeler and Cunjak, unpubl.).

Application of this antenna may be restricted to species and sites that are consistent with the limitations of this technique. For example, Cucherousset et al. (2005) demonstrated that only 80% of age-0 brown trout (Salmo trutta) were detected with a similar portable PIT tag antenna. The difference is probably
attributable to the behaviour of the study species. Cottid fishes like the slimy
sculpin are ideal to study with the PIT tag antenna since they are cryptic, benthic
fish with limited mobility (Gray 2004, see Chapter 3); they normally hide under
stones and move only short distances when startled. Results from the salmonid
research highlight a major limitation of portable PIT antennas when used on
mobile stream fish that display pronounced escape behaviour (Roussel et al.,

The second major limitation for the antenna is related to water depth and
instream habitat complexity. The presence of large rocks (boulders) and woody
debris preclude effective coverage of all potential fish refugia with the antenna.
Therefore, the field application of this equipment is currently restricted to shallow
streams where the linear distance beneath complex habitat cover does not
exceed the detection limits of the antenna.

Despite the limitations, the new portable PIT antennas represent an
alternative tracking method when standard radiotelemetry is impossible because
of small fish size (e.g. age-0 salmonids, most cyprinids or benthic species of
Cottidae, Percidae, Cobitidae, Petromyzontidae). The data can be collected in
conjunction with microhabitat measurements to provide information on habitat
use by fish in shallow waters without having to physically disturb and remove
individuals. In small streams (<5 m wide), the new portable PIT antennas can
be efficiently operated at a pace that enables the coverage of long distances in a
short period of time. The PIT tag is a relatively inexpensive option ($5 US each)
and is expected to last the duration of the tagged individual’s lifetime (>10
years).
In conclusion, 11.5 mm PIT tags had a minimal impact on the survival and growth of PIT tagged sculpin and tag retention was very high. In this study, a portable PIT tag antenna was developed with the ability to read PIT tags in fish at a greater range than past PIT tag readers. The efficiency of this antenna was very high (90%) when searches were conducted for tagged sculpin in closed sites. This PIT tag system has the potential to improve fisheries research by increasing the number of tagged individuals located, minimizing disturbance and providing researchers with the ability to ask ecological and applied questions about small-bodied fish.

2.6 Acknowledgements

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2.7 Literature Cited


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Figure 2.1 - The percent survival for adult slimy sculpin individually marked with either PIT tags or VIE marks. Survival was monitored from October 30, 2002 or January 10, 2003 until May 12, 2003 for groups #1 and # 2, respectively. Group #1 sculpin were implanted with PIT tags, while group #2 sculpin were either implanted with PIT tags or marked with VIE.
Figure 2.2 – Comparative change in total length (a) and wet weight (b) of adult slimy sculpin individually marked with either PIT tags (solid line) or VIE (dashed line). Sculpin were initially tagged on January 10, 2003 and monitored weekly in the laboratory until May 12, 2003. The error bars represent standard deviation from the mean.
3 MOVEMENT OF ADULT SLIMY SCULPIN IN SMALL TRIBUTARIES OF THE KENNEBECASIS RIVER, NEW BRUNSWICK

3.1 Abstract

Slimy sculpin are a small benthic fish that inhabit cold lakes and rivers in North America. Despite the fact that this fish is often abundant and ubiquitous throughout their geographic distribution, very little is known about their basic ecology. The objective of this study was to estimate the movement of slimy sculpin and to consider the impact of site, season, time of day, sex and fish length. A total of 337 adult sculpin were implanted with 12 mm PIT (passive integrated transponder) tags at six sites in five tributaries of the Kennebecasis River, NB in either June 2003 or December 2003. Sites were searched, approximately biweekly from June 2003 to July 2004, with a remote PIT tag antenna capable of reading the PIT tags without removing the sculpin from the stream. This method has not been used to track sculpin in the past and resulted in a high proportion of the fish detected at least once in the study (84.5%). In addition, there was no bias in the size or the sex of the sculpin that were located. Movement was limited; the annual linear home range was <25 m for 75% of the sculpin detected more than twice (68% of all tagged sculpin) in this study. Sculpin showed no preference for movement in the upstream or downstream direction during the study ($W_{sum}=11241$, $p=0.5$). There was no significant difference between the annual movement of sculpin at different sites;
however, movement at each site varied by season and was highest in spring. Movement was not related to fish length but slight differences were seen between males and females for their respective reproductive seasons; females showed similar movements throughout the year while males had increased activity during gonadal maturation and spawning, specifically during the nest acquisition. This study provides movement information which supports the recent application of this species as an environmental bioindicator species.

3.2 Introduction

The ecology of the slimy sculpin (*Cottus cognatus*) is poorly understood even though they are abundant and ubiquitous throughout most of Canada and the northern United States of America (Scott and Crossman 1998). They are normally found in cool streams or deep lakes. Sculpin are a cryptic, benthic species and are normally found in areas of the stream where the substrate is large enough to provide cover. In this species, spawning occurs annually in the spring (mid-May). Males establish territories containing an appropriate nest site, normally a rock or on submerged debris. Females are attracted to the nest and deposit their adhesive eggs to the under surface of the rock. Males guard the nest rock during the incubation of the eggs and for a short period after the young hatch (Van Vliet 1964, Scott & Crossman 1998).

It has been suggested that sculpin would be an effective species to monitor environmental effects for reasons that include their limited mobility (Gray et al. 2002, Gray 2003). In light of this, it is important to quantify movement for slimy sculpin and also, to determine the factors that may influence their
movement. Using a variety of marking techniques (i.e. external and internal tags), previous studies have shown that home ranges of slimy sculpin and the closely related mottled sculpin (*Cottus bairdi*) are limited to <100 m (McCleave 1964, Brown and Downhower 1982, Greenberg and Holtzman 1987, Hill and Grossman 1987, Morgan and Ringler 1992, Gray 2003), although Schmetterling and Adams (2004) found more extensive movements in some individuals (>250 m). Past cottid movement studies have often used marking techniques that have the potential to disturb normal fish movements (e.g. electrofishing) and recapture success limited to <50% of marked individuals reencountered during the study (McCleave 1964, Brown and Downhower 1982, Greenberg and Holtzman 1987, Hill and Grossman 1987, Morgan and Ringler 1992, Gray 2003, Schmetterling and Adams 2004).

In the current study, slimy sculpin movement was individually monitored with PIT (passive integrated transponder) tags. A PIT tag is a radio frequency device that transmits a unique alphanumeric code for each tag. PIT tags are surgically implanted into the body cavity of the sculpin, and a PIT tag reader receives the unique code from each individual fish. A new PIT tag antenna was developed for this study with the ability to remotely detect tags in wild sculpin in the stream, provided the antenna was within 17-30 cm of the fish (Cucherousset et al. 2005). It was expected that PIT tag technology would have higher recapture success and therefore, better estimates of movement than techniques used in the past that may disturb or displace fishes during sampling (e.g. electrofishing).
The objective of this project was to quantify movement and how it was influenced by site, season, time of day, sex and fish length. It was hypothesized that movement of individuals at different sites would vary as a result of environmental (i.e. habitat) differences among the sites. Specifically, it was predicted that movement would be greatest at sites where water temperatures were high (>20 °C). Seasonal differences have rarely been considered for sculpin; Natsumeda (1999, 2001) saw shifts in movement of male Japanese fluvial sculpin (*Cottus pollux*) during the spawning period. Thus, it was predicted that activity (i.e. movement) would increase prior to the spawning period for male sculpin and then males would show strong site fidelity when they were nest guarding. Estimates of winter movement of sculpin in cold climates have never been reported in the literature, so it was especially important to determine sculpin activity and habitat use during this season.

### 3.3 Materials and Methods

Six sites were selected in five tributaries of the Kennebecasis River in southern New Brunswick (Figure 3.1). These sites were selected because they had high slimy sculpin abundance in relation to other tributaries of the Kennebecasis River. The study streams had many similar environmental characteristics (Table 3.1). All the streams were either 2nd or 3rd order tributaries with drainage areas ranging from 6-22 km²; the length of each site ranged from 35-150 m and widths ranged from 3-5 m, slopes ranged from 0.53-1.41% and the bankful tractive force was calculated for each site (2.33 - 6.84 kg m⁻²; Table 3.1). Environmental characteristics were measured during the same week in
spring 2004. The velocities at each site ranged from 0.20-0.35 m sec$^{-1}$ on average, at all sites except Lower Windgap where velocity was higher (0.57 m sec$^{-1}$; Table 3.1). Average water depths for the sites ranged from 0.17-0.25 m (Table 3.1). A modified Wolman pebble count (as described in Rosgen 1996) was conducted to determine median substrate size ($D_{50}$). The median rock size, or $D_{50}$, values varied between sites and ranged from 12 mm at Harrison Brook to 100 mm at McLeod Brooks, and 48 mm at the remaining sites (Table 3.1). Temperature was monitored every hour with a temperature logger (VEMCO, NS, CAN). Hourly water temperature values were averaged to provide mean daily and maximum water temperatures throughout the study.

Slimy sculpin were collected by electrofishing from the six study sites in June 2003 and from five sites in December 2003 (Upper Windgap site not sampled due to ice cover). The catch per unit effort (CPUE) or the total elapsed electrofishing time (s) was determined for each site for all sculpin and sculpin >60 mm at the time of initial tagging in June 2003. Sculpin were anaesthetized in clove oil (0.04 mL/L water) and measured (total length). For sculpin >60 mm total length (TL), a small incision (3-4 mm) was made on the ventral surface, anterior to the urogenital papilla and a PIT tag was manually inserted into the peritoneal cavity (modified from Gray 2003). Based on a laboratory experiment on PIT tagging (Chapter 2), and observations in the field regarding the abdominal cavity size of sculpin, sculpin >60 mm were considered large enough to tag. Sex was determined for sculpin during the December tagging by examining the shape of the urogenital papilla (this technique was not known in
June 2003). The 134.5 Hz PIT tags (TX1400ST, Destron Fearing Corp.) used in this study were 11.5 mm in length, 2.1 mm in diameter and had a mass of 0.06 g. The number of sculpin tagged at each site varied in June and December as a function of the abundance of sculpin at the sites (Table 3.2). Following a 24-hr recovery period in live boxes set in the stream, sculpin were released into the sites within 20 m from their capture location.

'Recaptures' of sculpin were made by remotely detecting the presence of the implanted PIT tag with a portable PIT antenna. The antenna was constructed for this project using components made by Destron Fearing Corp. (MN, USA) available from Biomark, Inc. (ID, USA) (see Cucherousset et al. 2005 for further details). The maximum detection distance of the antenna for detecting tags ranged from 17-30 cm depending on the orientation of the tag (Cucherousset et al. 2005). While tracking, the operator walked upstream or downstream moving the antenna across the stream bottom, ensuring that all areas of the stream site were surveyed. There were no shifts in movement observed between upstream and downstream sampling events suggesting that sampling did not disturb sculpin.

Areas upstream and downstream of the study sites (i.e. buffer zones) were also regularly tracked in search of tagged sculpin; this made the sites consistent in length (122-152 m). The exception was Dee Brook, where only 87 m was normally tracked because a metal culvert immediately downstream of the study site precluded tag detection (Table 3.1).

Estimates of the 'recapture success' were determined in several ways. First, the total number of tagged sculpin detected at least once throughout the
entire study was determined. Second, the percent of tagged sculpin detected
during each tracking event was determined; this value could also provide an
average percent of sculpin detected each tracking event, by site or by season.
Third, the number of times an individual sculpin was detected divided by the
total number of tracking events, provided an estimate of the probability of
detecting an individual sculpin.

Changes in the location of individual sculpin over time were used to
assess movement. There are a variety of ways to measure movement;
however, three were considered in this study. The first was site fidelity, the
displacement of the individual from the initial location detected, over a given time
period (i.e. all year, spawning period, etc.) The second measure was activity, or
the average amount of movement. Activity was calculated as the total distance
moved divided by the number of times an individual sculpin was detected.
Lastly, home range was defined as the linear distance between the most
downstream and the most upstream positions detected for an individual over the
sampling period. For each site, separate values for site fidelity, home range
and activity were calculated for all sculpin for the duration of the study. Only two
measurements are necessary to calculate movement but to be conservative and
since there was a lot of uncertainty about the location of individuals observed
twice, only individuals detected at least four times were included in the annual
movement measures. Movement was also assessed for the effect of season.
In this case, individuals detected two or more times were included; two
detections seemed appropriate since there were not very many sampling
occasions per season.
Seasons were defined based on trends in water temperature throughout the year. Summer lasted from June until the end of September and was a time when temperatures were consistently warm (> 5°C). In autumn, from October to December, there was a persistent decline in water temperature approaching 0°C, which was the onset of winter and ice formation (for most sites) normally lasting until spring (end of March). Spring lasted until end of May and was characterized by variable and increasing temperatures.

For sculpin of known sex, movement was assessed separately for males and females during their reproductive seasons, as defined by Brasfield et al. (unpubl.). For females, these seasons included recrudescence, pre-spawning, spawning and post-spawning; males also have four reproductive seasons but maturation occurs instead of pre-spawning. In addition, the reproductive seasons were broken down further for male sculpin to illustrate the movement that occurred during nest acquisition (Apr to mid-May), spawning and nest guarding (mid-May to mid-June) and (mid-June to July).

Diel movement patterns were determined once per site in June 2004 at each site. Sites were tracked twice in the same day, 4-6 hr apart, either morning and afternoon (daylight) or late afternoon and night (daylight and dark, respectively). The displacement that occurred within these two tracking events was then calculated for each individual to compare night and day movements.

A PIT tag can persist in the environment and can be detected with the PIT antenna, even after the tagged individual has died. To prevent this from resulting in bias of low movement in the data set, the sites were searched for
‘dead’ tags three times during the study: autumn 2003, spring 2004 and autumn 2004. For such tags discovered during these searches, all records for the dead sculpin were eliminated to the last evidence of life (i.e. movement upstream >0.5m). In total, data was eliminated for 18 sculpin following retrieval of their tag during a search.

The effect of season, site and the interaction of the two on the proportion of sculpin detected per tracking event was considered with ANOVA. Multiple comparisons of the two main factors were determined with a Tukey-Kramer test. For the remainder of the analyses, non-parametric tests were used because the data, even after transformation, violated the assumptions of normality and homogeneity of variance. The likelihood of detecting an individual sculpin was determined with a Mann-Whitney U-test in relation to sex and a Spearman's rank correlation coefficient in relation to length. Differences in the movement of individuals between sites were compared with a Kruskal-Wallis test and then multicomparsions were conducted with a Kruskal-Wallis z-test using Bonferroni values. Spearman's rank correlation coefficients were used to consider the relationship between length and the three measures of movement. The patterns of seasonal movement varied by site so the effect of season on movement was tested separately by site with Kruskal-Wallis test and then multicomparsions were conducted with a Kruskal-Wallis z-test using Bonferroni values. A Wilcoxon signed-rank test was used to test the difference between upstream and downstream displacement of sculpin. Differences in the movement of males and females were not tested statistically, only observed graphically, because the seasons and the timing of the seasons varied and therefore were
not comparable. A student t-test compared the daytime and night-time displacement of individual sculpin. Results were considered significant at an alpha of 0.05. Statistical analysis for this project was conducted with Number Cruncher Statistical Software (© 2004, Jerry Hintz, UT, USA).

3.4 Results

In total, 1046 sculpin were captured in June 2003 and 245 were tagged (individuals > 60 mm TL). The effort was reduced in December since fewer individuals were needed for tagging purposes; 426 sculpin were collected and 92 were tagged (Table 3.2). The total number of sculpin tagged per site ranged from 22-58 in June and 6-25 in December (Upper Windgap not included due to ice cover; Table 3.2). Mean length for all the tagged sculpin was 75 mm in both June and December (Table 3.2). During initial tagging in June 2003, the abundance of sculpin was high and similar among sites (1-4 sculpin/min), except at Shannon Brook, where there was a much higher catch per unit effort (CPUE) for all sculpin (9 sculpin/min) and for sculpin >60 mm (2 sculpin/min; Table 3.2). Mortality within the first 24 hours was <1% (these 2 sculpin were excluded from further analysis) and no tags were lost.

Each site was tracked between 17 and 38 times from June 2003 to July 2004 (Table 3.2). McLeod and Shannon Brooks were tracked the most because these sites were ice-free during the winter months. In total, 283 PIT tagged sculpin (84.5%) were detected at least once during the course of this study. The percent of sculpin detected at least once, ranged from 84-90% for Harrison, Lower Windgap, Shannon and McLeod Brooks. Dee and Upper Windgap Brooks
had a much lower detection percentage (56%, 72% for Dee and Upper Windgap; Table 3.2). Similarly, the average percent of sculpin detected per tracking event during the study was also lower in Dee and Upper Windgap Brooks (33% and 38%, respectively) than in the other streams (43-48%; Table 3.2). The percent of fish detected varied significantly among sites (F=29.41, p<0.0001), and among seasons (F=114.54, p<0.0001), as well, seasonal trends in detection varied significantly by site (F=2.83, p=0.0007). The proportion of tagged sculpin detected declined over time at all sites except Shannon where detections increased between fall and winter (Figure 3.2). The likelihood of detections per individual was not related to the length (rs=0.09 p=0.12, n=320) or the sex of the individual (U=2003, p=0.05, n= 68, 55 (female, male)).

Annual home range showed that sculpin moved very short distances, in general. The median home range was 8.8 m for tagged individuals detected more than 3 times (n=218, 65% of all tagged sculpin). More than 50% of the sculpin used <10 m of stream for their annual home range (Figure 3.3) and the annual home range did not vary significantly among sites (Figure 3.4; H=2.3, p=0.8, n=230). There was no relationship between the length of the sculpin and the annual home range (rs=0.09, p=0.2, n=226). In addition, there was also no relationship between the number of times that an individual was detected and their annual home range (Figure 3.5, R² =0.06, p=0.003, n=224).

Annual site fidelity (the displacement from the initial location a sculpin was detected) was also determined for 218 sculpin. The annual site fidelity was high; >50% of the sculpin were within 10 m of their original location at the end of the study (Figure 3.3). The maximum displacement was 90 m upstream and
64.5 m downstream. Sculpin showed no significant preference for displacement in the upstream or downstream direction ($W_{sum}=11241$, $p=0.5$) so the absolute values were considered. Median movement away from their original location was 4.5 m during the study. The annual site fidelity did not vary significantly by site ($H=9.9$, $p=0.08$, $n=218$). There was no relationship between the length of the sculpin and the annual site fidelity ($r_s=-0.01$, $p=0.88$, $n=213$).

Activity (or the mean movement) was low for the duration of the study; >75% moved <5 m per movement (Figure 3.3). The activity did not vary significantly by site ($H=5.7$, $p=0.3$, $n=216$). There was no relationship between the length of the sculpin and the activity ($r_s=0.08$, $p=0.2$, $n=212$).

Although no differences were observed between annual movement among sites, there were significant differences in seasonal trends, so the effect of season on movement was considered separately by site. Seasonal home range varied significantly at all sites except Upper Windgap (pooled in Figure 3.6a; $H$, $p = 17.5$, 0.002; 31.7, <0.001; 9.7, 0.008; 1.8, 0.4; 13.6, 0.004; 23.3, <0.001 for Harrison, Lower Windgap, Dee, Upper Windgap, Shannon and McLeod Brook sites, respectively). Spring home range was significantly larger than all other seasons at Lower Windgap, Dee and McLeod Brooks (median spring home range was 6 m, 5 m, and 8 m, respectively). At Shannon Brook, spring home range (median = 6 m) was larger than summer and winter. The fall home range was significantly lower than in the spring (median = 4.5 m) at Harrison Brook.
Seasonal site fidelity varied by site (pooled in Figure 3.6b). There were no significant differences in the seasonal site fidelity for Harrison, L. Windgap, Dee and U. Windgap Brooks (H, p = 3.1, 0.2; 2.3, 0.3; 5.1, 0.08; 1.7, 0.4, respectively). At Shannon Brook, the site fidelity was significantly different in direction between the summer (more upstream movement) and the winter (more downstream movement) (H = 9.6, p = 0.02). Significantly more upstream movements were seen in the summer than the spring at McLeod Brook (H = 8.3, p = 0.04).

Seasonal activity also varied by site (pooled in Figure 3.6c). There were no significant differences in the seasonal activity for Dee and U. Windgap Brooks (H, p = 1.4, 0.5; 4.1, 0.1, respectively). At Harrison Brook, the activity was significantly lower in the fall than the spring (H = 6.4, p = 0.04). The summer activity was significantly lower than in the spring at Lower Windgap Brook (H = 14.5, p < 0.001). At Shannon and McLeod Brooks, spring activity was significantly higher than in the summer but not the winter (H, p = 18.9, <0.001; 12.5, 0.006, respectively). At all the sites, activity was highest in the spring; therefore, sculpin were moving farther on average per movement at this time of year.

Differences in the displacement of male and female sculpin, during their reproductive seasons, were minimal for most of the year (Figure 3.7). However, female movement was generally consistent throughout the year whereas some male sculpin showed slightly higher movement in the spawning and maturation seasons compared with other times of the year. It appears that this increase in
movement occurs as males locate nests late in the maturation season and early in the spawning season (Figure 3.8).

Diel movement patterns were considered by comparing the daily displacement with the nocturnal displacement of 85 individual sculpin in all six streams (Figure 3.9). There was no significant difference between the daytime and nighttime displacement of individuals (t = 0.17, p = 0.87, n=85).

Mean water temperature for each site from the end of June to the beginning of November ranged from 10.4-14.3°C (Table 3.1). Maximum daily water temperatures were ≥ 20 °C often during the study at the Upper and Lower Windgap Brook sites but these temperatures never occurred at Shannon and McLeod Brooks (Figure 3.10a). Maximum water temperatures ranged from 19.9-23.7°C for all sites except McLeod Brook, which was much cooler (16.5°C) and Upper Windgap, which was much warmer (25.6°C; Table 3.1). The sites at Shannon and McLeod Brooks had sufficient ground water to remain ice-free for most of the winter (Figure 3.10b); these were the only two sites tracked from January to March.

### 3.5 Discussion

The main goal of this research was to investigate the movement of sculpin in small streams. Annual movement, as judged by all three variables, was low. More than 50% of all the tagged sculpin (detected >3 times) had <10 m for their annual home range and annual site fidelity. The activity or the mean movement of 50% of the sculpin was <5 m. These results are consistent with past research that suggested sculpin were quite sedentary, having home ranges
For all annual measures of movement (i.e. site fidelity, activity and home range), values were similar among study stream sites. It was expected that movement patterns would vary in response to different environmental and biological conditions at each site (e.g. water temperature). Water temperature is generally an important environmental criteria explaining the distribution of sculpin (Edwards 2001) with temperatures above 23º C considered lethal (Symons et al. 1976, Otto and Rice 1977). In addition, Gray (2003) found a complete lack of young-of-the-year sculpin at sites where temperatures reached 25 ºC. It was predicted that sites with high water temperatures (>20ºC) would show the greatest movement, as sculpin had to find ways to deal with this potentially stressful environmental parameter, (i.e. movement towards cold water seeps during high temperature events). Temperatures above 20ºC rarely occurred at most sites but were fairly frequent at the Upper and Lower Windgap Brook sites. Summer was not a time of high movement in tributaries of the Kennebecasis River and movement was not higher at the sites in Windgap Brook, where temperatures were often above 20ºC. It is unclear why increased movement was not seen and is an area that would be interesting for further research. Possibly, sculpin were already situated in areas where extreme water temperatures were not occurring; since, temperature was not measured at the site of individual sculpin and compared to other locations, these microhabitat data may have been missed in this study. Alternatively, the range of water
temperatures seen in the sites of the Kennebecasis River may have not been as stressful as predicted by the literature. It would be interesting to consider temperature effects in rivers where slimy sculpin are closer to their southern geographic range and more vulnerable to high temperature stress events. The consistently low movement seen at all sites suggests that movement patterns were consistent and may be representative of slimy sculpin populations inhabiting similar streams elsewhere.

Movement of individual sculpin did not vary based on size; there was no relationship between fish length and the amount of movement. It is possible that this lack of relationship resulted from the limited range in total length of sculpin tagged. A major limitation of this study was that only sculpin >60 mm could be PIT tagged. If another tagging technique was employed on young of the year and juvenile sculpin, it is likely that a relationship between size and movement would be evident since intraspecific competition and cannibalism have been shown to be important factors in the distribution of sculpin (Downhower 1979).

Movement did appear to vary by season and by sex. When seasonal home ranges are considered for all tagged sculpin, spring stands out as a season of increased home range size at most sites (likely not significant at Upper Windgap Brook because of small sample sizes). Sculpin appeared to move more during the spring spawning period; however, based on the examination of the displacement of males and females at this time, males appear to be responsible for this increase since females show minimal shifts in movement throughout the year. This increase in movement occurs in early
spring when male sculpin are looking for appropriate nest sites. Following their
time at the nest site during their spawning and nest guarding period, males often
returned to their initial location. It is interesting that some Kennebecasis River
males moved up to 120 m just prior to spawning. With an annual home range of
<10 m, it is surprising that some males would move so far for a nest.
Natsumeda (2001) found that the nests used by male Japanese fluvial sculpin
were always within their pre-spawning home ranges. In the Kennebecasis
River, it appears that males are moving into areas with specific nest site
characteristics or increased access to females.

It is also important to discuss movement observed in winter since this has
never before been studied in cold climates for slimy sculpin. The sites on
Shannon and McLeod Brooks were adequately ice-free during the winter for
sculpin to be located throughout the winter; however water temperatures were
only slightly above freezing and surface ice formed at other sections of the
streams where water moved more slowly. Movement during the winter was not
different than during other seasons; sculpin were actually as active at this time
of the year as they were in the spring. This is an interesting finding and
supports reproductive research on slimy sculpin in the Kennebecasis River
which found that females were actively feeding and increasing their gonadal
somatic index by >10% during winter (Brasfield et al., unpubl). It is difficult to
ascertain if the sculpin at the other sites were behaving in the same way under
ice cover. It is unlikely that their movements varied greatly in the winter since
most sculpin were found at the same locations in the beginning of spring as they
were last detected just prior to the onset of winter.
A limitation of this study involved the time of site sampling; sculpin movement was normally monitored between the hours of 10 am and 5 pm. Slimy sculpin are considered a nocturnal species (Van Vliet 1964), so this sampling methodology could have biased results, if sculpin were making larger movements during the night. However, daytime and night-time movement did not vary in June, when diel movements were considered. In addition, if larger movements were being made at night, sculpin usually returned to their initial location by morning since annual displacement was so low. Seasonal variability in diel movement was not determined in this study or considered in the past by other researchers monitoring sculpin movement; it is an assumption of this research that there was not a major seasonal difference since diel movements were only considered once during the study. More night-time sampling may be needed in the future to elucidate this potential bias.

In studies considering movement, one of the first steps is to determine the efficiency of the method used to monitor individuals over time. Individual movement in this study was determined by using PIT (passive integrated transponder) tags. Passive integrated transponder tags have constituted a highly effective method for distinguishing and tracking individual small-bodied fish in other studies (Baras et al. 2000, Roussel et al. 2000, Das Mahapatra et al. 2001). The size of the PIT tag is very important since adult slimy sculpin do not normally exceed 100-120 mm in length (Scott and Crossman 1998). In the past, the PIT tag reader's ability to determine the code from the PIT tag has had limited range and so the fish have had to be removed from the water before the code could be read. Consequently, tagged fish had to be recaptured repeatedly.
by electrofishing, a technique that potentially disturbs fish or alters their
behaviour (Keeler and Cunjak 2005 unpublished). In the present study, the new
PIT tag antenna had the ability to read PIT tags at a greater range than past PIT
readers; this resulted in improved 'recapture success'. Of the 337 sculpin PIT
tagged, 283 (84.5%) were detected at least once during the course of this study.
On average, each time the sites were tracked, approximately 45% of the sculpin
were located.

Dee and Upper Windgap Brook had very low detection rates when
compared to the consistently high rates seen at the other sites. It is unclear why
this occurred; these sites had the lowest number of sculpin tagged so it could be
an issue of sample size. It is also possible that these habitats were of lower
quality than the other sites (e.g. CPUE was lowest at these two sites) and that
more sculpin were shifting to other locations during the study where they could
maintain limited movement. Movement at these two sites may be
underestimated, but since these sites contribute very few fish to the entire study,
the overall study conclusions are not greatly affected (i.e. annual movement
values include 65% of all PIT tagged individuals). Even with the Dee and Upper
Windgap Brook sites included, the percent of sculpin detected in this study is
impressive when compared to past research, which normally recaptured <50%
of the marked sculpin once (McCleave 1964, Brown and Downhower 1982, Hill
and Grossman 1987, Gray 2003). Also, there was no relationship between the
number of detections and the annual home range of individuals which suggests
that movement of sculpin is not being under or overestimated for individuals that
were not detected on every occasion.
In addition to high ‘recapture’ success, there was no observable bias in the PIT tag technique as measured by the proportions of detections for individuals based on sex or body length and this supports observations in the field that this technique was not disruptive to normal sculpin movement. Past researchers have used a variety of techniques to estimate sculpin home range but there have been limitations to each study. One of the main problems common in past research is the difficulty for researchers to document that their techniques did not disturb the natural movements of sculpin. For example, in one study that used external tags to monitor sculpin, the researchers were required to move all the rocks in the streambed to find hidden sculpin (Greenberg and Holtzman 1987). The PIT antenna has the potential to be a useful alternative to these more disruptive techniques for movement studies in streams which allow its use (i.e. small streams).

It has been suggested that sculpin would be an effective species to use for monitoring environmental effects due to their limited mobility (Gray 2003). The present study supports Gray's (2003) conclusion that the movement of sculpin is low enough for them to reflect local conditions and therefore, qualify as bioindicators. Slimy sculpin movement in the six sites of the Kennebecasis River was low throughout the year and even during spring, their most active time, only minor increases in movement were observed and most sculpin returned to their initial location following spawning activity. Further, there did not appear to be large movements to over-wintering habitat even in these ice-covered streams. Finally, with the increased precision of the PIT tag method,
movement was still found to be low and results were consistent among sites, suggesting these results would be applicable elsewhere.

In conclusion, annual movement of PIT tagged adult sculpin was extremely low for all three measures of movement. There were no differences in the movement observed among the sites studied suggesting that these results may be consistent in other streams of similar size. The PIT tag antenna was able to detect (84.5%) of the sculpin at least once during the study and detected around 45% of the sculpin each time the sites were searched. In addition no bias was observed in the size or sex of the sculpin detected. The PIT tag technology used in this study provided the most precise estimate of home range and movement described in the literature, as well as, the possibility to investigate other questions about sculpin ecology in the future.

3.6 Acknowledgements

Field work and assistance for the research was provided by the students and employees of the University of New Brunswick and Canadian Rivers Institute. P. Batt, S. Brasfield, A. Fraser, M. Gray, S. McWilliam, and A. Reddy contributed many hours to this research. Special thanks to Tyler Evans and Todd Debreuil of the S.O. Conte Anadromous Fish Research Center (USA) who provided instruction on the construction of the prototype Destron Fearing portable antenna. Financial support was provided by the Canada Research Chairs program to RAC.
3.7 Literature Cited


Brasfield, S. M., G. R. Tetreault, M. E. McMaster, and K. R. Munkittrick, K. R. unpubl. Seasonal patterns of energy storage, energy expenditure, and *in vitro* gonadal steroidogenic capacity in slimy sculpin (*Cottus cognatus*).


Table 3.1 – Environmental characteristics of six study sites in tributaries of the Kennebecasis River, New Brunswick. Site characteristics for each site were determined in spring 2004, unless otherwise specified.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Harrison</th>
<th>L. Windgap</th>
<th>Dee</th>
<th>U. Windgap</th>
<th>Shannon</th>
<th>McLeod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream order</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Drainage area (km²)</td>
<td>13</td>
<td>22</td>
<td>14</td>
<td>10</td>
<td>7.25</td>
<td>6.5</td>
</tr>
<tr>
<td>Site length (m)</td>
<td>148</td>
<td>125</td>
<td>87</td>
<td>125</td>
<td>152</td>
<td>122</td>
</tr>
<tr>
<td>Mean width (m) (SD)</td>
<td>3.9 (1.0)</td>
<td>5.0 (1.0)</td>
<td>4.0 (0.7)</td>
<td>3.8 (0.9)</td>
<td>3.3 (0.7)</td>
<td>3.0 (0.5)</td>
</tr>
<tr>
<td>Mean velocity (m/s) (SD)</td>
<td>0.35 (0.21)</td>
<td>0.57 (0.22)</td>
<td>0.26 (0.21)</td>
<td>0.20 (0.10)</td>
<td>0.33 (0.19)</td>
<td>0.25 (0.17)</td>
</tr>
<tr>
<td>Mean depth (m) (SD)</td>
<td>0.25 (0.14)</td>
<td>0.25 (0.09)</td>
<td>0.20 (0.08)</td>
<td>0.19 (0.10)</td>
<td>0.17 (0.09)</td>
<td>0.19 (0.09)</td>
</tr>
<tr>
<td>Mean summer water temperature (°C)</td>
<td>12.4</td>
<td>13.5</td>
<td>11.7</td>
<td>14.3</td>
<td>12.0</td>
<td>10.4</td>
</tr>
<tr>
<td>Maximum water temperature (°C)</td>
<td>20.3</td>
<td>23.7</td>
<td>20.8</td>
<td>25.6</td>
<td>19.9</td>
<td>16.5</td>
</tr>
<tr>
<td>D&lt;sub&gt;50&lt;/sub&gt; (mm)</td>
<td>12</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>100</td>
</tr>
<tr>
<td>Slope (%)</td>
<td>0.72</td>
<td>0.53</td>
<td>0.57</td>
<td>1.41</td>
<td>0.92</td>
<td>1.39</td>
</tr>
<tr>
<td>Tractive Force (kg/m²)</td>
<td>5.05</td>
<td>3.08</td>
<td>2.33</td>
<td>6.84</td>
<td>4.31</td>
<td>5.37</td>
</tr>
</tbody>
</table>
Table 3.2 - Characteristics of slimy sculpin sampled and subsequently monitored for movement at six sites in five tributaries of the Kennebecasis River, New Brunswick between June 2003 to July 2004. CPUE refers to catch (number of sculpin)-per-unit-effort measured in time the electrofisher was in operation and was determined for the June 2003 sampling event.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Harrison</th>
<th>L. Windgap</th>
<th>Dee</th>
<th>U. Windgap</th>
<th>Shannon</th>
<th>McLeod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sculpin captured (Jun)</td>
<td>300</td>
<td>128</td>
<td>135</td>
<td>80</td>
<td>277</td>
<td>126</td>
</tr>
<tr>
<td>Sculpin tagged (Jun)</td>
<td>41</td>
<td>54</td>
<td>22</td>
<td>32</td>
<td>59</td>
<td>37</td>
</tr>
<tr>
<td>Sculpin captured (Dec)</td>
<td>97</td>
<td>53</td>
<td>47</td>
<td>0</td>
<td>139</td>
<td>90</td>
</tr>
<tr>
<td>Sculpin tagged (Dec)</td>
<td>11</td>
<td>25</td>
<td>6</td>
<td>0</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Mean tagged sculpin length (SD) (mm)</td>
<td>73.8 (8.9)</td>
<td>75.0 (7.9)</td>
<td>72.4 (7.5)</td>
<td>75.3 (9.1)</td>
<td>75.3 (9.2)</td>
<td>73.8 (10.6)</td>
</tr>
<tr>
<td>CPUE for all sculpin (sculpin/min)</td>
<td>3.7</td>
<td>3.0</td>
<td>2.0</td>
<td>1.3</td>
<td>9.1</td>
<td>2.7</td>
</tr>
<tr>
<td>CPUE sculpin &gt;60mm (sculpin/min)</td>
<td>0.6</td>
<td>1.4</td>
<td>0.4</td>
<td>0.5</td>
<td>1.8</td>
<td>0.8</td>
</tr>
<tr>
<td># of tracking events</td>
<td>23</td>
<td>30</td>
<td>25</td>
<td>17</td>
<td>36</td>
<td>38</td>
</tr>
<tr>
<td>% Detected once</td>
<td>84</td>
<td>90</td>
<td>56</td>
<td>72</td>
<td>89</td>
<td>87</td>
</tr>
<tr>
<td>Mean % detected/tracking event</td>
<td>45</td>
<td>48</td>
<td>33</td>
<td>38</td>
<td>43</td>
<td>45</td>
</tr>
</tbody>
</table>
Figure 3.1 – The six study sites were on five tributaries of the Kennebecasis River in New Brunswick. Refer to Table 2.1 and 2.2 for specific environmental and biological information on each site.
Figure 3.2 – The mean percentage of all PIT tagged sculpin detected during tracking at six sites on five tributaries of the Kennebecasis River from June 2003 to July 2004. Winter tracking events were only conducted at Shannon and McLeod, since the other sites were ice-covered. Each shape pattern represents a different site and the error bars represent the standard error of tracking events in the same season.
Figure 3.3 – The annual linear home range (a), absolute site fidelity (b) and activity (c) was determined for PIT tagged slimy sculpin from five tributaries of the Kennebecasis River (June 2003 -July 2004). Linear home range was considered the distance between the most downstream and the most upstream position for each individual sculpin. Site fidelity was the net displacement of an individual from the location it was first detected. There was no difference between upstream and downstream movement so the absolute annual site fidelity was used. Activity was the cumulative movement divided by the number of movements detected. Only individual with >3 detections during the study were included. Dashed lines illustrate the 50th percentile.
Figure 3.4 – The linear home range (a), annual site fidelity (b) and activity (c) was determined for PIT tagged slimy sculpin in 6 sites on tributaries of the Kennebecasis River from June 2003 to July 2004. Linear home range was considered the distance between the most downstream and the most upstream position (n = 32, 61, 11, 19, 61, 46, for Harrison to McLeod Brooks). Site fidelity was the net displacement of an individual from the location that it was first detected. Sample sizes per site from Harrison to McLeod Brooks are 33, 59, 9, 13, 59, and 45, respectively. Activity was the cumulative movement divided by the number of movements detected. Only individuals with >3 detections per year were included; the number of sculpin per site was 32, 58, 11, 17, 55 and 44 for Harrison to McLeod streams. Circles represent outliers the dashed lines represent the mean values for each site.
Figure 3.5 – The number of detections in relation to home range for PIT tagged sculpin for six sites in tributaries of the Kennebecasis River from June 2003 to June 2004. Linear home range was considered the distance between the most downstream and the most upstream position and only sculpin detected > 3 times were included. The number of potential detections varied by the study site (see Table 3.2) and whether a fish was tagged in June or December 2003.
Figure 3.6 – The linear home range (a), site fidelity (b) and activity (c) was determined, by season, for PIT tagged slimy sculpin in 6 sites on tributaries of the Kennebecasis River from June 2003 to June 2004. Linear home range was considered the distance between the most downstream and the most upstream position (n = 150, 114, 75 and 146 for summer to spring, respectively). Site fidelity was the net displacement of an individual from the location it was first detected (n = 145, 123, 81 and 149, summer to spring, respectively). Activity is the cumulative movement divided by the number of movements detected. Activity was calculated for individuals with >2 detections per season (n = 148, 72, 77, 118 for summer, fall, winter and spring). Only the values for sculpin from Shannon and McLeod Brooks were included in the winter, since the rest of the sites were ice-covered. Circles represent the 5th and 95th percentile and the dashed lines represent the mean value for each season.
Figure 3.7 – The comparative displacement for female and male PIT tagged sculpin throughout their reproductive seasons (as described by Brasfield et al. unpub.) Circles represent outliers and the dashed lines represent the mean value for each season.
Figure 3.8 – Movement of nesting male sculpin was considered throughout the year. Circles represent outliers and the dashed lines represent the mean value for each season.
Figure 3.9 – Diel movement was compared for PIT tagged slimy sculpin (n=85) at six sites in tributaries of the Kennebecasis River in June 2004. For this box plot, the circles represent outliers.
Figure 3.10 – The number of days when maximum water temperature was above the slimy sculpin’s preferred water temperature (≥20 °C; a) and at freezing (0 °C; b) for six sites in tributaries of the Kennebecasis River, NB. Water temperature was monitored for 389 days for each site with a temperature logger (VEMCO, NS, CAN).
4 REPRODUCTIVE ECOLOGY OF THE SLIMY SCULPIN IN SMALL NEW BRUNSWICK STREAMS

4.1 Abstract

The slimy sculpin, *Cottus cognatus*, is a small, benthic fish common to many areas of North America. In this species, males guard a nest rock and provide parental care; females, sometimes multiple females, deposit all their eggs into one nest. The purpose of this research was to examine the basic reproductive ecology of slimy sculpin and to consider how male reproductive success, measured as the number of eggs in his nest, related to nest size and male length. Nesting males were monitored at five sites on six small New Brunswick streams to learn more about the reproductive ecology of the species. Passive integrated transponder (PIT) tags were used to determine exact nest locations and individual movement throughout the spawning season. Microhabitat characteristics, such as depth and velocity, were considered at nest locations. The size of the male and his nest rock were measured in relation to his reproductive success, specifically, the number of eggs deposited in his nest. In total, 38 PIT-tagged, male sculpin with nests were monitored during the 2004 spawning period (April-June). Nests of 42 untagged males were also located during this time. Photographs were taken at all nests and at the nests of the untagged males, egg masses were collected and the number of eggs was counted. The number of eggs deposited by a single female varied from 50 to 200 eggs (mean (SD) = 106 (51)). The total number of eggs in a nest averaged
239, suggesting that most males guarded 2 or 3 females' egg masses. Movement of PIT-tagged male sculpin suggest that most males (60%) were not guarding a nest until early May, only about a week before eggs were deposited and they left the nest by the end of June. Males tended to use large cobble and boulders in shallow sections of the streams as nest sites. Larger males tended to acquire larger nest rocks ($r_s = 0.35$, $p = 0.015$) and had more eggs in their nest ($r_s = 0.50$, $p = 0.0007$), but there was no direct relationship between rock size and number of eggs ($r_s = 0.21$, $p = 0.08$). These findings suggest that female slimy sculpin are selecting nest sites based on the quality of the guarding male rather than nest size.

4.2 Introduction


In the current study, slimy sculpin, *Cottus cognatus*, were implanted with PIT (passive integrated transponder) tags and monitored with a portable PIT tag
antenna throughout the spawning season of 2004. Like many other cottid species, slimy sculpin are a nest guarding, polygynous, benthic, freshwater fish. Spawning occurs annually in the spring, but individuals can spawn several times during their lifespan. Males establish territories containing an appropriate nest site, normally a rock or some sort of submerged debris. Females are attracted to the nest and deposit their adhesive eggs to the under surface of the rock. Females deposit their entire clutch into one male's nest; males can receive the clutches of many females. Males guard the nest rock during the incubation of the eggs and for a short period after the young hatch (Van Vliet 1964, Scott & Crossman 1998).

Very little research has been conducted on the reproductive ecology and behaviour of the slimy sculpin. There were two main objectives for this research project:

1) To examine the basic reproductive ecology of slimy sculpin in tributaries of the Kennebecasis River, New Brunswick. The specific details of reproduction investigated include: timing of spawning, biological and physical characteristics of the nest sites.

2) To consider how male reproductive success, measured as the number of eggs in his nest, related to nest size and male size (length). It was predicted, based on research of other cottid species, that reproductive success would be positively related to the length of the male regardless of nest size.
4.3 Materials and Methods

Six sites were selected in five tributaries of the Kennebecasis River, southern New Brunswick, Canada (Figure 3.1). These sites were selected because sculpin were abundant, streams were similar in many environmental characteristics (e.g. stream size, gradient, etc.) and were easily accessible. All the streams were either 2nd or 3rd order tributaries with drainage areas ranging from 6.25-22 km² (Figure 3.1). Length of each study site ranged from 35-152 m and widths ranged from 3-5 m. Slope ranged from 0.53-1.41% and the tractive force was similar for each site (range 2.33-6.84 kg m⁻¹; Table 4.1).

Slimy sculpin were collected by electrofishing from the six study sites in June 2003 and from five sites in December 2003 (Upper Windgap site not sampled due to ice cover). Sculpin were anaesthetized in clove oil (0.04 mL/L water) and measured (total length). For all sculpin > 60 mm, a small incision (3-4 mm) was made on the ventral surface, anterior to the urogenital papilla and a PIT tag was manually inserted into the peritoneal cavity (procedures modified from Gray (2003)). The 134.5 Hz PIT tags (TX1400ST, Destron Fearing Corp.) used in this study were 11.5 mm in length, 2.1 mm in diameter and weighed 0.06 g in the air. The number of sculpin tagged at each site varied depending on local abundance of sculpin in the sites (Table 4.2). Sex was determined for sculpin tagged in December by examining the urogenital papilla. Following a 24-hr recovery period in live boxes set in the stream, sculpin were released into the sites within 20 m of their capture location.
'Recaptures' of sculpin were made by remotely detecting the presence of the implanted PIT tag with a portable PIT tag antenna. The antenna was constructed using components made by Destron Fearing Corp. (MN, USA) available from Biomark, Inc. (ID, USA) as described by Cucherousset et al. (2005). The maximum detection distance of the antenna for detecting PIT tags ranged from 17-30 cm depending on the orientation of the tag (Cucherousset et al. 2005). While tracking, the operator walked upstream or downstream moving the antenna across the stream bottom, ensuring that all areas of the stream were covered within the detection range.

Stream sites were surveyed for tagged sculpin from June 2003 until after the spawning period (July 2004) as part of a larger project looking at sculpin movement (Chapter 3). Sculpin still inhabiting the sites during the spring were included in this study (Table 4.2). Sculpin locations were determined throughout the year but for the specific objectives of this paper only movement during the spawning period (April-June) will be discussed.

Changes in the location of sculpin over time were used to measure movement, specifically site fidelity because it was suspected that nesting males would show higher site fidelity to the nest site than females during the reproductive season (spring). Site fidelity is defined as the displacement (measured in m) of an individual male during spawning period (April-June 2004) relative to his nest. Movements of sculpin were monitored before, during and after the spawning period at all sites, however the date and the number of times each site was surveyed varied (Table 4.2). Incidental checks of rocks indicated that eggs were present at all sites in mid-May, so the location of PIT-tagged
sculpin were checked for eggs between 19-22 May 2005 by carefully turning over rocks. At that time, all nesting males included in this study were guarding a nest with egg masses. Movement was monitored to determine when most males started guarding and when they abandoned nests.

Two groups of nests were identified. The first group of nests belonged to the PIT-tagged males and these sites were located with the PIT tag antenna during the spawning season. The second group of nests belonged to untagged males that were identified following searches for nest sites in the stream sites. The treatment of these two groups of nests was different. All nests were photographed, measured and characterized for microhabitat differences (substrate dimensions, water depth and velocity). At the untagged males' nests, egg masses were collected and the number of eggs was determined. For PIT-tagged males' nests, rocks were immediately replaced, so that natural spawning movements and hatching times could be determined. To determine the number of eggs in tagged males' nests, photographs were examined and a planimeter was used to measure the surface area of the egg masses in relation to a stainless steel washer (of known size) placed in each picture. The surface area of the egg mass was then divided by the surface area of the washer to provide a relative surface area that would be consistent among all nests.

On the same day as the nests were located, systematic habitat measures (water depth and velocity) were taken 3 times at every 5 m interval, to consider available habitat. A modified Wolman pebble count was conducted during the spawning period to determine the median rock size ($D_{50}$) and all substrate particles large enough to be nests (i.e. > 64 mm) was measured along all 3 axes.
and checked for eggs. Temperature was monitored with a logger (VEMCO, NS, CAN) at each study site to provide mean daily water temperatures throughout the reproductive period.

Non-parametric tests were used to analyze most of the data because of violations of the assumptions of normality and homogeneity of variance. Characteristics of tagged and untagged sculpin nest sites as well as movements of nesting males and females were compared with a Mann-Whitney U-test. Differences in the nest site habitat between sites were considered with a Kruskal-Wallis one-way ANOVA. Substrate use versus availability was considered with a Chi-square test. Differences between available and utilized water depths and velocities at each site were tested with a Mann-Whitney U-test. Relative surface area of egg masses of PIT-tagged males was regressed to the total number of eggs counted for the untagged male sculpin. The equation for this line was then used to determine the approximate number of eggs in the nests of tagged individuals (i.e. where egg masses were not directly counted). The number of eggs in a nest was compared with male size and with the nest rock size using a Spearman rank correlation test. Male length was measured at different times throughout the study: June 2003, December 2003 and in May 2004. Where possible, size measured in spring 2004 was used; a correction of 4.2 mm was added if the only size measurement available was from June 2003; this correction was the average growth for eight tagged individuals that were captured in June 2003 and subsequently recaptured in the spring of 2004.
Results were considered significant at an alpha value of 0.05. Statistical analysis for this project was conducted with Number Cruncher Statistical Software (© 2004, Jerry Hintz, UT, USA).

4.4 Results

In total, 38 PIT-tagged, male sculpin with nests were monitored during the 2004 spawning period (Table 4.2). The nests of 42 untagged sculpin were also photographed and measured at each site (mean length (SD) = 82 (8) mm). Seven of the untagged males were captured and measured (mean length (SD) = 73 (9) mm).

The number of egg clutches per male varied from 0 to 8, but most males guarded only a few clutches (mean (SD) = 2.5 (1.5); Figure 4.1a). The average number of eggs for a single female's clutch (i.e. fecundity) ranged from 50-200 eggs; the mean (±SD) number of eggs was 106 ± 51 (Figure 4.1b). The number of eggs per nest observed ranged from 50 to >800 eggs (Figure 4.1c, Figure 4.2). The average estimated number of eggs per nest was significantly different between tagged individuals (353 ± 247 eggs, n = 36) and untagged male nests (251 ± 176 eggs, n = 40) (U = 935, p = 0.03). However, the number of females was not significantly different between the two groups; 2.8 ± 1.7 females for tagged fish and 2.2 ± 1.3 females for untagged sculpin (U = 757, p = 0.1). Egg diameter ranged from 2.3 mm to 2.8 mm in the collected egg masses.

Most males (60%) moved into nest guarding locations, or within 0.5 m of their nest rock, after May 9; one male used the same area before April (Table 4.3). The majority of males (56%) remained at the nest site until mid-June; most
nests were abandoned by late June, although some males (9%) remained in the same area into July. The temporal patterns differed amongst sites; males stayed at the nest longer at Shannon, McLeod and Dee Brooks and left first at the Lower and Upper Windgap Brook sites.

There were differences in water temperature between the sites (Figure 4.3) during the spawning period. Temperatures increased above 10°C at all sites on 14 May 2004 following a rainfall and a warm front moving into the area. Based on observational data, temperature appears to be positively related to differences in dates of egg deposition and hatching. Some egg masses were deposited later, as judged by egg colour and size, and hatched later in Shannon and McLeod Brooks, where temperatures were the coldest (Figure 4.3).

There were a total of 590 substrate observations taken systematically at the sites and 73 nest rocks were characterized. The median rock size, or D$_{50}$, values varied between sites and ranged from 12 mm at Harrison to 100 mm at McLeod Brooks and the remainder of the sites were 48 mm (Table 4.1). Slimy sculpin used significantly more cobble and boulder substrate than was expected ($\chi^2 = 137, p<0.0001$) (Figure 4.4). The percent of substrate that was in the sculpin's preferred range varied between sites and was lowest at Harrison Brook (33%; Table 4.1). There were no significant differences in the median axis size of the rocks used by tagged (mean (SD) = 145 mm (58), n = 37) and untagged males (mean (SD) = 126 mm (35), n = 40) ($U = 855, p = 0.24$).

The velocities at each site ranged from 0.20-0.35 m sec$^{-1}$ on average at all sites except Lower Windgap where velocity was higher (0.57 m sec$^{-1}$; Table 4.1). Velocities were significantly different at each site ($H = 77, p<0.00001$), so
velocity preferences were tested separately by site. Nest sites did not show consistent trends, only 2 site were significant. At Upper Windgap the velocities at the nest sites were significantly higher than that which was available (U = 107, p = 0.006); it was the opposite at Dee Brook (U = 319, p = 0.01) (Figure 4.5). There were no significant differences in the nest site velocities of tagged (mean (SD) = 0.40 (0.2) m sec\(^{-1}\), n = 38) and untagged male sculpin (mean (SD) = 0.29 (0.2) m sec\(^{-1}\), n = 42) (U = 1005, p = 0.05).

Average water depths for the sites ranged from 0.17-0.25 m and were significantly different (H = 25, p = 0.0002), so depth preferences were tested separately by site. The mean (± SD) water depth where nest sites were observed was 0.16 ± 0.1 m (n = 67) for all sites combined. The mean depth of nest sites was similar at all sites and ranged from 0.13-0.20 m. Nest sites tended to be in shallower than mean site depth and were significantly different at all sites except Upper Windgap and McLeod (U = 713, p = 0.03; U = 628, p = 0.006; U = 309, p = 0.02; U = 409, p = 0.03 for Harrison, Lower Windgap, Dee and Shannon; Figure 4.5). There were no significant differences in the water depths observed at tagged (mean (SD) = 0.18 m (0.13), n = 38) and untagged males' nests (mean (SD) = 0.14 m (0.004), n = 42) (U = 952, p = 0.14).

There was a significant positive relationship between the size of the male sculpin (length) and the size of his nest rock (\(r_s = 0.36, p = 0.015, n = 45\); Figure 4.6). The relationship between male length and area of nest rock was similar (\(r_s = 0.40, p = 0.007, n = 45\)). The number of female clutches was compared with the male length and the slope was not significantly different than zero (\(r_s = 0.19, p = 0.26, n = 38\)). A positive linear relationship was determined between the
relative surface area of the egg masses and the number of eggs ($r^2 = 0.583$, $p<0.0001$, $n = 35$). The equation from this relationship, $y = 52.665x + 22.102$, was used on the nests where the egg masses were not collected to approximate the number of eggs. The relationship between the nest rock size and the number of eggs was not significantly different than zero ($r_s = 0.21$, $p = 0.08$, $n = 72$; Figure 4.7). The relationship between number of eggs and area of nest rock was also not significant ($r_s = 0.17$, $p = 0.16$, $n = 72$). There was a positive relationship between the length of the male and the number of eggs in his nest ($r_s = 0.50$, $p = 0.0007$, $n = 42$; Figure 4.8).

4.5 Discussion

The purpose of this research was to investigate the reproductive ecology of the slimy sculpin in small New Brunswick streams. The fecundity of individual female slimy sculpin in the small tributaries of the Kennebecasis River ranged from 50-200 eggs (mean of 106). Van Vliet (1964) showed that fecundity of females varied by age, size and their location. In some of the rivers he studied in Saskatchewan, the fecundity was very high (Montreal River: 347-685 eggs), while in the La Rouge River fecundity was similar to the values found in the Kennebecasis River (116-165 eggs). Mousseau et al. (1987) found similar differences in fecundity for lake dwelling slimy sculpin populations in three central Ontario lakes; average female reproductive success ranged from 136-334 eggs. Females in Lake Michigan had higher fecundity than Kennebecasis River populations, with an average of 270 eggs in the ovaries; again, there was a direct relationship between female length and fecundity (Fotz 1976).
The direct triggers for male slimy sculpin to initiate nest guarding are unknown. Most nest guarding did not occur in Kennebecasis River tributaries until after 9 May 2004, with spawning starting the following week. In Japanese fluvial sculpin (Cottus pollux), onset of nest building varied by male size but occurred only 2 days before spawning and only about a week before males shifted to a parenting phase (Natsumeda 2001).

Water temperatures around 10°C appear to trigger spawning behaviour in female sculpin. Van Vliet (1964) observed the importance of similar temperature regimes (around 8°C) in stimulating spawning of lake dwelling populations of slimy sculpin in northern Canada, suggesting that temperature requirements might be similar throughout the species’ geographic range. Van Vliet (1964) indicated that incubation time was around 28 days for his Saskatchewan populations of slimy sculpin. If this is correct for the Kennebecasis River sculpin, we would expect to see fewer males at the nest by mid-June (one month following spawning in mid-May). Indeed, by early July <10% of the males remained within 0.5 m of the nest site. The amount of time that the males spent at the nest varied but probably related to slight differences in spawning and incubation times between the sites in the Kennebecasis River. Males remained longest at the nest in Shannon and McLeod Brooks where temperatures were the coldest (Figure 4.3). In other species, the amount of time that the males remain with the nest is crucial for egg development and survival (Marconato & Bisazza 1988, Goto 1989, Natsumeda 2001).

Male sculpin in tributaries of the Kennebecasis River showed a strong preference for cobbles when selecting nest sites from the available habitat.
Substrate of this size is larger than required for mere cover or for space to accumulate egg masses. It is likely that the nesting sculpin showed a preference for substrate that is highly stable in the streambed and unlikely to be moved in high water events. In fact, bankful tractive force needs to be greater than mean substrate dimensions to move that rock in a flood event (Newbury and Gaboury 1994). The tractive force ranged from 2.3 – 6.8 kg m\(^{-2}\) (Table 4.1) suggesting that nest sites would need to have a mean dimension >68 mm to remain stable in the streambed at all sites and male sculpin did show a strong preference for substrate >64 mm. (Figure 4.4). The size of nests appeared to change with the amount of appropriate substrate available. For example, at Harrison Brook where boulders were rare and substrate dimension was lowest among sites, male sculpin had the smallest nest rocks. It was also observed, only at Harrison Brook, that two male sculpin were sharing the same rock for their nests. Past research has also shown the importance of substrate availability in other sculpin populations (Mousseau & Collins 1987, Natsumeda 2001). For example, Mousseau et al. (1987) argued that substrate availability influenced the degree of polygamy in lake dwelling populations of slimy sculpin. However, differences in the extent of polygamy among the six sites in the Kennebecasis River were not detected. The percent of male sculpin unable to secure mates may have varied among sites due to substrate availability but that was not measured in this study.

The water velocities observed at each nest were different and nesting males did not show any consistent trends in water velocity preferences between sites (Figure 4.5). Velocities were initially selected since it was hypothesized
that the sculpin might show a preference for riffles and run over pools, which should normally show a higher velocity than expected. Natsumeda (1999) found that male Japanese fluvial sculpin moved into raceway habitat during the spawning period. Pygmy sculpin (*Cottus paulus*) also preferred areas of higher flow for nest sites (Johnson 2001). Kennebecasis River slimy sculpin may not show preference for areas of higher water velocities for a number of reasons. First, the range of average water velocities between sites was highly variable (Table 4.1); in sites dominated by riffles, sculpin may prefer areas with lower than average velocities, while in sites with slower water, sculpin may select areas with higher velocities. In addition, mean water velocity measured at 0.6 of the depth, may not be related to snout velocities and therefore mean velocities may have little impact on slimy sculpin nests. Finally, it is possible that these streams were of high quality and that nest sites were not limited to zones of specific velocities, resulting in a lack of any obvious trends.

Slimy sculpin at all sites showed a preference for shallow water depths for their nest sites, although trends were only significant at four sites (Figure 4.5). Trends were not always significant because sample sizes were small and power low; however, trends were consistent at all six sites. Many nests were in very shallow areas; in fact, many nests were in areas that dried up shortly after spring freshet. Pygmy sculpin in Alabama, US also preferred shallow areas for their nests (Johnson 2001). It may be that shallow areas provide protection for the nesting males from conspecifics and larger fish species (e.g. brook trout, *Salvelinus fontinalis*) during the guarding period. Alternatively, there may be unknown, environmental factors that are important at these shallow depths.
Reproductive success as measured in this study focused on the number of eggs secured by a male rather than the number of females with whom he spawned. In our opinion, this is a better indicator of male fitness and the potential number of progeny. There was a strong relationship between male size and the estimated number of eggs in nests, although it does not explain all of the variability in the data (Figure 4.8). The approximation of the number of eggs was limited by two dimensions; measurements of the height of the nest would have improved the estimates since some egg masses were layered.

The reproductive success of male slimy sculpin as measured by the number of eggs in his nest, averaged 239 for tributaries of the Kennebecasis River. Another study in New Brunswick found that median number of eggs in slimy sculpin nests at agricultural and forested sites were 170 and 280, respectively (Gray 2003). In Saskatchewan populations, the average number of eggs in a nest ranged in different locations from less than those seen in the Kennebecasis River (151 eggs) to average values well above (630 eggs) (Van Vliet 1964). Similar findings were seen in three lake dwelling slimy sculpin populations in central Ontario; average male reproductive success ranged from 150-571 eggs (Mousseau et al. 1987). Larger males tended to obtain larger nest (Figure 4.6) and larger males generally obtained more eggs (Figure 4.8), although there was no direct relationship between number of eggs and size of the nest rock. This suggests that although males preferred larger nest, females selected males based on their size, not the nest size. Males of many species have shown a preference for larger nest sites and larger males are often more successful in securing these sites (Downhower & Brown 1980, Brown 1981,

Brown & Downhower (1982) experimentally manipulated a mottled sculpin (*Cottus bairdi*) population and showed that females chose nest sites based on male quality not nest quality. It is believed that females select larger males because they provide better parental care (Downhower & Brown 1980, Brown 1981, Brown & Downhower 1982, Marconato & Bisazza 1988). Parental care in cottid species is very important since eggs in abandoned nest were eaten immediately by conspecifics and other predators (Cole 1982, Marconato & Bisazza 1988, Bisazza et al. 1989). Larger males protected their nest better from predators and were less likely to abandon or cannibalize their own nest (Downhower & Brown 1980, Marconato & Bisazza 1988, Bisazza et al. 1989, Marconato et al. 1993). They also stayed at the nest longer, possibly due to larger energy reserves enabling them to withstand the starvation period during nest guarding (Marconato et al. 1993).

A few studies have questioned the importance of male size. In some research on goby species, females selected nest quality over male size but this may be unique to locations where nest site limitations have led to intense intrasexual competition and reduced female 'choosiness' (Lindström 1988, Bisazza et al. 1989, Forsgren 1997). It was observed in these studies that larger males always usurped smaller males from nests under natural conditions.
(Lindström 1988, Bisazza et al. 1989, Forsgren 1997). In the case of one freshwater goby, *Padogobius martensi*, intrasexual competition was initiated by the female's release of pheromones immediately before spawning (Bisazza et al. 1989). A lab study of sand gobies, *Pomatoschistus minutus*, showed that increased hatching success occurred in males selected by females; condition, length, colour and dominance were not important and the mechanism of selection was unknown (Forsgren 1997). Courting vigor has also been important for a marine goby, *Coryphopterus nicholsi*, (Cole 1982) but this species has an extended spawning season so males of higher quality may be unavailable due to preexisting parental responsibilities under natural conditions.

Female reproductive success is directly related to the male she selects, since the male provides all of the parental care for her clutch of eggs. This system would suggest that evolution would favour a female that was able to estimate some measure of quality over a female that did not discriminate. It does appear that, in slimy sculpin populations of small New Brunswick streams, females are following this pattern and choosing larger males, although further work with larger samples may help elucidate these relationships.

PIT tag technology provided a unique opportunity to study the behaviour of individual sculpin in the field during the spawning season. PIT-tagged males guarding nest were monitored frequently with minimal disturbance using a PIT tag antenna. The nests of PIT-tagged males were located, as well as nests of unknown males to ensure that PIT tags did not alter male reproductive behaviour or success. Nests of tagged and untagged males did not vary in their microhabitat characteristics. The number of females or egg masses also did not
vary, however, tagged males had significantly more eggs in their nests. More eggs may be due to the fact that only the largest males were implanted with PIT tags (>60 mm) and larger males may have been more successful at attracting higher quality females (i.e. those with more eggs). Limited differences between tagged and untagged sculpin nests suggest that PIT tags did not have a detrimental effect on male slimy sculpin's reproductive behaviour.

In conclusion, the objective of this study was to provide new information about the reproductive ecology of the slimy sculpin. Spawning time and movements were monitored with the assistance of PIT tag technology in five small New Brunswick streams. Measurements of the available habitat and nest sites suggest that slimy sculpin prefer cobble habitat in shallow areas of the stream. Photograph of the nests provided an indication of the number of eggs in each nest. With this information, a strong relationship was identified between egg number and the size of the male. It appears that female sculpin are selecting nests based on the male quality rather than nest quality; these results are consistent with research on other sculpin species.

4.6 Acknowledgements

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Fearing portable antenna. The Canada Research Chairs program provided financial support to RAC.

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Saskatchewan.
Table 4.1 – Physical characteristics of the six study sites in five tributaries of the Kennebecasis River, New Brunswick, that were used to study the reproductive ecology of slimy sculpin. Characteristics for each site were measured in spring of 2004.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Harrison</th>
<th>L. Windgap</th>
<th>Dee</th>
<th>U. Windgap</th>
<th>Shannon</th>
<th>McLeod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site number</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<tr>
<td>Stream order</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
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</tr>
<tr>
<td>Drainage area (km²)</td>
<td>13</td>
<td>22</td>
<td>14</td>
<td>10</td>
<td>7.25</td>
<td>6.5</td>
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<td>Site length (m)</td>
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<td>125</td>
<td>87</td>
<td>125</td>
<td>152</td>
<td>122</td>
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<tr>
<td>Mean width (m) (SD)</td>
<td>3.9 (1.0)</td>
<td>5.0 (1.0)</td>
<td>4.0 (0.7)</td>
<td>3.8 (0.9)</td>
<td>3.3 (0.7)</td>
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<td>Mean velocity (m sec&lt;sup&gt;-1&lt;/sup&gt;) (SD)</td>
<td>0.35 (0.21)</td>
<td>0.57 (0.22)</td>
<td>0.26 (0.21)</td>
<td>0.20 (0.10)</td>
<td>0.33 (0.19)</td>
<td>0.25 (0.17)</td>
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<tr>
<td>Mean depth (m) (SD)</td>
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<td>0.25 (0.09)</td>
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<td>0.17 (0.09)</td>
<td>0.19 (0.09)</td>
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<td>D&lt;sub&gt;50&lt;/sub&gt; (mm)</td>
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<td>48</td>
<td>48</td>
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<td>48</td>
<td>100</td>
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<tr>
<td>Substrate &gt;64mm</td>
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<td>63</td>
<td>54</td>
<td>54</td>
<td>55</td>
<td>73</td>
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<tr>
<td>Slope (%)</td>
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<td>0.53</td>
<td>0.57</td>
<td>1.41</td>
<td>0.92</td>
<td>1.39</td>
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<tr>
<td>Tractive Force (kg m&lt;sup&gt;-2&lt;/sup&gt;)</td>
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<td>3.08</td>
<td>2.33</td>
<td>6.84</td>
<td>4.31</td>
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Table 4.2 – Slimy sculpin were PIT-tagged and nest sites were located at six sites on five tributaries of the Kennebecasis River. The number of fish and nests varied between the sites. Biological characteristics for each site were determined in spring 2004 unless otherwise indicated.

<table>
<thead>
<tr>
<th>Number of:</th>
<th>Harrison</th>
<th>Lower Windgap</th>
<th>Dee</th>
<th>Upper Windgap</th>
<th>Shannon</th>
<th>McLeod</th>
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<tbody>
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<td>Sculpin tagged (Jun 03)</td>
<td>40</td>
<td>54</td>
<td>22</td>
<td>32</td>
<td>58</td>
<td>37</td>
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<td>Sculpin tagged (Dec 03)</td>
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<td>25</td>
<td>6</td>
<td>0</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Tagged sculpin in spring 2004</td>
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<td>52</td>
<td>10</td>
<td>9</td>
<td>34</td>
<td>28</td>
</tr>
<tr>
<td>Nests of tagged sculpin</td>
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<td>10</td>
<td>3</td>
<td>2</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Nests of untagged sculpin</td>
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<td>7</td>
<td>13</td>
<td>1</td>
<td>7</td>
<td>7</td>
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<tr>
<td>Tracking surveys</td>
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<td>9</td>
<td>9</td>
<td>5</td>
<td>10</td>
<td>10</td>
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</table>
Table 4.3 – Temporal patterns of nest associations by PIT-tagged male slimy sculpin in five tributaries of the Kennebecasis River from April to July, 2005. Males were considered to be at the nest if they were within 0.5m. A ‘-’ symbol represents time periods that were not sampled at a particular site. The numbers in brackets are shifts in the number of nests identified between 19-22 May, when some egg masses were disturbed to be photographed; for those males that subsequently abandoned nests post-disturbance, the data were not included in the percentages after that time period.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Number of nests</th>
<th>Jan - Apr</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harrison</td>
<td>4</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>L. Windgap</td>
<td>10 (8)</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Dee</td>
<td>3</td>
<td>-</td>
<td>0</td>
<td>33</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>U. Windgap</td>
<td>2 (1)</td>
<td>-</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Shannon</td>
<td>8</td>
<td>13</td>
<td>13</td>
<td>75</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>McLeod</td>
<td>11</td>
<td>0</td>
<td>9</td>
<td>18</td>
<td>100</td>
<td>91</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>2.2</strong></td>
<td><strong>3.7</strong></td>
<td><strong>7.3</strong></td>
<td><strong>18.2</strong></td>
<td><strong>39.5</strong></td>
<td><strong>100</strong></td>
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</table>

84
Figure 4.1 – The number of female clutches (a), eggs per clutch (b) and the total number of eggs in each nest (c) of slimy sculpin in six sites of the Kennebecasis River, NB. Data was based on results of photographs taken of the nests May 19-22, 2004.
Figure 4.2 – Photographs of slimy sculpin nests in five tributaries of the Kennebecasis River. The photographs illustrate the variability in the reproductive success (i.e. the number of eggs) of male slimy sculpin. Some males had only one female clutch (a) and others had many female clutches (b). The washers are the same size in real life.
Figure 4.3 – Mean water temperatures were calculated for each day during the spawning season at six sites on five tributaries of the Kennebecasis River. Dates of spawning, incubation and hatching for sculpin eggs in these sites are indicated on the graph and separated with vertical dashed lines.
Figure 4.4 – Available substrate (n = 590) was compared to slimy sculpin nest sites (n = 73) on five tributaries of the Kennebecasis River. Substrate was measured at the median axis with a modified Wolman pebble count and displayed according to the Wentworth scale size categories.
Figure 4.5 – Available depth and velocity values were compared to those seen at slimy sculpin nest sites at six sites in five tributaries of the Kennebecasis River during the spawning period (Spring 2004).
Figure 4.6 – The total length of male slimy sculpin was compared to the size (median axis) of his nest rock at five tributaries of the Kennebecasis River.
Figure 4.7 – The number of eggs in a male slimy sculpin nest was compared to the size (median axis) of his nest rock at five tributaries of the Kennebecasis River. For half of the males, the number of eggs were known; for the other half, the number of eggs was estimated from the relative surface area of the egg masses measured from photographs of the nests with the equation $y = 52.665 \times + 22.102$. 

$n = 72$

$r_s = 0.21$

$p = 0.08$
Figure 4.8 – The relationship between length of male slimy sculpin and his nest as measured in five tributaries of the Kennebecasis River. For half of the males, the number of eggs were counted directly; for the other half, the number of eggs was estimated from the relative surface area of the egg masses measured from photographs of the nests with the equation $y = 52.665x + 22.102$. 

$n = 42$

$r_s = 0.50$

$p = 0.0007$
5 SYNTHESIS

5.1 PIT Technology

The main objective of this research was to develop a passive integrated transponder (PIT) system to investigate the movement and reproductive ecology of adult slimy sculpin (*Cottus cognatus*) in small New Brunswick streams. The first step in this research was to test a PIT system capable of monitoring individual fish tagged with 11.5 mm PIT tags (Chapter 2). It was important to start this process by ensuring that the PIT tags used in this study did not have a negative impact on the survival and growth of tagged individuals. Results suggest that PIT tags had a negligible effect on sculpin survival over a long time period (up to eight months). Survival of sculpin in the laboratory was high (81-100%) and mortality for sculpin in the field was <1% within the first 24 hours. Tag retention was also high for all groups (94-100%). The high survival and tag retention are consistent with past research on the effects of PIT tags. Gray (2003) found 100% survival and tag retention for eight PIT tagged slimy sculpin over one month. Tag retention for juvenile salmonid species has also been high in laboratory and field studies (>95%; Prentice et al. 1990a, Peterson et al. 1994, Ombredane et al. 1998).

The impact of PIT tags on the survival and growth of slimy sculpin in the laboratory was minimal in this study, suggesting that PIT tags would be effective tags for marking individual fish in the field. Other researchers have found PIT tags an effective technique to monitor individual small-bodied fish (slimy sculpin, Gray 2004), juveniles of salmonids and other fish species (for example, Chinook

The next step in this research (Chapter 2) was to construct and test a portable PIT tag antenna compatible with the 11.5 mm tags used to tag small-bodied fish. The antenna was capable of detecting tags within a range of 17-30 cm and was around 90% efficient at detecting PIT tagged individuals in closed sites. In the past, the PIT tag reader's ability to determine the code from the PIT tag has had limited range and so the fish have had to be removed from the water before the code could be read. Consequently, tagged fish had to be recaptured repeatedly by electrofishing, a technique that is less effective, and potentially disturbs fish and alters their behaviour (Keeler and Cunjak unpub.).

In fact, the PIT tag system proved to be ideal to investigate the movement of sculpin in small streams. The new PIT tag antenna had the ability to read PIT tags at a greater range than past PIT tag readers; this resulted in improved 'recapture success'. Of the 337 adult sculpin PIT-tagged 283 (84.5%) were detected at least once during the course of this study (Chapter 3). On average, each time the sites were tracked around 45% of the sculpin were located. The percent of sculpin detected in this study is impressive when compared to past research, which normally recaptured <50% of the marked sculpin once (McCleave 1964, Brown and Downhower 1982, Hill and Grossman 1987, Gray 2003). In addition, there was no observable bias in the PIT tag technique as measured by the proportions of detections for individuals based on sex or body length.
PIT tag technology also provided a unique opportunity to study the behaviour of individual sculpin in the field during the spawning season (Chapter 4). PIT-tagged males guarding nest were monitored frequently with minimal disturbance using the portable PIT antenna. The nests of PIT-tagged males were located, as well as nests of unknown males to ensure that PIT tags did not alter male reproductive behaviour or success. Nests of tagged and untagged males did not vary in their microhabitat characteristics. Limited differences between tagged and untagged sculpin nests suggest that PIT tags did not have a detrimental effect on male slimy sculpin's reproductive behaviour.

5.2 Sculpin Ecology

Annual movement, as judged by all three variables (i.e. home range, site fidelity and activity), was low (Chapter 3). These results are consistent with past research, which has suggested that sculpin are quite sedentary, having home ranges <100 m (McCleave 1964, Brown and Downhower 1982, Greenberg and Holtzman 1987, Hill and Grossman 1987, Morgan and Ringler 1992, Gray 2003).

For all annual measures of movement values did not differ among sites. It was expected that we would see varying movement patterns resulting from a variety of differences in environmental and biological conditions at each site. This may suggest that movement values are consistent and could be representative of sculpin populations inhabiting similar streams elsewhere.

Winter movement is an important finding of this thesis since it has never been studied in cold climates for slimy sculpin. The sites on Shannon and
McLeod Brooks were adequately ice-free during the winter for sculpin to be located throughout the winter; however water temperatures were only slightly above freezing and ice formed at other sections of the streams where water moved more slowly. Movement during the winter was not lower than during other seasons; sculpin were actually as active at this time of the year as they were in the spring. It is difficult to ascertain if the sculpin at the other sites were behaving in the same way under ice cover. It is unlikely that their movements varied greatly in the winter since most sculpin were found at the same locations in the beginning of spring as they were last detected just prior to the onset of winter.

Sculpin appeared to move more during the spring pre-spawning period; however, based on the examination of the displacement of males and females at this time, males appear to be responsible for this increase since females show minimal shifts in movement throughout the year (Chapter 4). Based on results from Chapter 4, this increase in movement occurs in early spring when male sculpin are looking for appropriate nest sites. Following their time at the nest site during their spawning and nest guarding period, males often returned to their initial location. Most males did not occupy their nests in Kennebecasis River tributaries until after 9 May 2004, with spawning occurring during the following couple of weeks. In Japanese fluvial sculpin (*Cottus pollux*), onset of nest building varied by male size but occurred only 2 days before spawning and only about a week before males shifted to a parenting phase (Natsumeda 2001). It is interesting that some Kennebecasis River males moved up to 120 m just prior to spawning. This was rare, with most males moving <10 m but longer
distances (i.e. outside the study site) would also be more difficult to detect. With an annual home range of around 10 m (Chapter 2), it is surprising that some males would move so far for a nest. Natsumeda (2001) found that the nests used by male Japanese fluvial sculpin were always within their pre-spawning home ranges. In the Kennebecasis River, it appears that males are moving into areas with specific nest site characteristics or increased access to females.

Male sculpin in tributaries of the Kennebecasis River showed a strong preference for cobble when selecting nest sites from the available habitat. Substrate of this size is larger than required for mere cover or for space to accumulate egg masses. It is likely that the nesting sculpin showed a preference for substrate that is highly stable in the streambed and unlikely to be moved in high water events. Past research has also shown the importance of substrate availability in other sculpin populations (Mousseau & Collins 1987, Natsumeda 2001). For example, Mousseau et al. (1987) argued that substrate availability influenced the degree of polygamy in lake dwelling populations of slimy sculpin.

Slimy sculpin at all sites showed a preference for shallow water depths for their nest sites, although trends were only significant at four sites. Many nests were in very shallow areas; in fact, many nests were in areas that dried up shortly after spring freshet.

The reproductive success of male slimy sculpin as measured by the number of eggs in his nest averaged 239 eggs for tributaries of the Kennebecasis River. Larger males tended to obtain larger nest and larger males generally obtained more eggs, although there was no direct relationship
between number of eggs and size of the nest rock. This suggests that although males preferred larger nest, females selected males based on their size, not the nest size. Males of many cottid species have shown a preference for larger nest sites and larger males are often more successful in securing these sites (Downhower & Brown 1980, Brown 1981, Brown & Downhower 1982, Cole 1982, Marconato & Bisazza 1988, Natsumeda 2001). It is believed that females select larger males because they provide better parental care (Downhower & Brown 1980, Brown 1981, Brown & Downhower 1982, Marconato & Bisazza 1988). Parental care in cottid species is very important since eggs in abandoned nest are eaten immediately by conspecifics and other predators (Cole 1982, Marconato & Bisazza 1988, Bisazza et al. 1989).

5.3 Application of this Research

This PIT tag system has the potential to improve fisheries research by increasing the number of tagged individuals located, minimizing disturbance and providing researchers the ability to ask ecological and applied questions about small-bodied fishes. Application of this antenna may be restricted to species and sites that are consistent with the limitations of this technique. For example, Cucherousset et al. (2005) demonstrated that only 80% of age-0 brown trout (Salmo trutta) were detected with a similar portable PIT tag antenna. The difference is probably attributable to the behaviour of the study species. Cottid fishes like the slimy sculpin are ideal to study with the PIT tag antenna since they are cryptic, benthic fish with limited mobility (Gray 2003, see Chapter 2); they normally hide under stones and move only short distances when startled.
Results from salmonid research highlight a major limitation of portable PIT antennas when used on mobile stream fish that display pronounced escape behaviour (Roussel et al. 2000, Cucherousset et al. 2005).

The second major limitation for the antenna is related to water depth and instream habitat complexity. The presence of large rocks (boulders) and woody debris preclude effective coverage of all potential fish refugia with the antenna. Therefore, the field application of this method is currently restricted to shallow streams where the linear distance beneath complex habitat cover does not exceed the detection limits of the antenna.

Despite the limitations, the new portable PIT antenna represents an alternative tracking method when standard radiotelemetry is impossible because of small fish size. The data can be collected in conjunction with microhabitat measurements to provide information on habitat use by fish in shallow waters without having to physically disturb and remove individuals. In small streams (<5 m wide), the new portable PIT antennas can be efficiently operated at a pace that enables the coverage of long distances in a short period of time.

It has been suggested that sculpin would be an effective species to use for monitoring environmental effects due to their limited mobility (Gray et al. 2002, Gray 2003). This current study supports Gray’s (2003) conclusion that the movement of sculpin is low enough for them to reflect local conditions as bioindicators. In fact, this year-long research provided answers to several unknown questions about sculpin movement. First, movement was low throughout the year. Even during the spring, their most active time, only minor increases in movement were observed and most sculpin returned to their initial
location following spawning activity. Second, large movements to over-wintering habitat were not apparent even though these streams were at or near freezing for many months. Finally, with the increased precision of the PIT tag method, movement was still low and results were consistent among sites, suggesting these results would be applicable elsewhere.

5.4 Future Research

Sculpin movement during this study was normally monitored between the hours of 10am and 5pm. Slimy sculpin are considered a nocturnal species (Van Vliet 1964), so this sampling methodology could have resulted in biased results, if sculpin were making larger movements during the night. For the sculpin in this study, daytime and nighttime movement did not vary in June, when diel movements were considered; however, seasonal variability in diel movement was not determined in this study or considered in the past by other researchers monitoring sculpin movement. It is an assumption of this research that there was not a major seasonal difference, so more nighttime sampling may be needed in the future to elucidate this potential bias.

Movement of individual sculpin did not vary based on size; there was no relationship between length and movement. It is possible that this lack of relationship resulted from the limited range in total length of sculpin tagged. A major limitation of this study was that only sculpin >60 mm could be PIT tagged. Research needs to be conducted on young of the year and juvenile movement with another tagging technique to consider movement at these life history stages. Size may be more important to younger sculpin since intraspecific
competition and cannibalism have been shown to be important factors in the
distribution of sculpin (Downhower 1979).

The PIT system could be used in the future to address many additional
questions regarding sculpin ecology (e.g. natural growth, effects of temperature
stress, movement in response to contamination). As well, it would be interesting
to see how effective this PIT system is for ecological studies of other small-
bodied fishes.

5.5 Conclusions

In conclusion, 11.5 mm PIT tags had a minimal impact on the survival
and growth of PIT tagged sculpin and tag retention was very high. A portable
PIT tag antenna was developed with the ability to read PIT tags in fish at a
greater range than past PIT tag readers. The efficiency of this antenna was very
high (90%) when searches were conducted for tagged sculpin in closed sites.
Annual movement of PIT tagged adult sculpin was extremely low for all three
measures of movement. There were no differences in the movement observed
among the sites studied suggesting that these results may be consistent in
streams of similar size elsewhere. The PIT tag antenna was able to detect
(84.5%) of the sculpin at least once during the study and detected around 45%
of the sculpin each time the sites were searched. In addition, no bias was
observed in the size or sex of the sculpin detected. The PIT tag technology
used in this study provided the most precise estimate of home range and
movement described in the literature. The PIT tag system was also used to
provide new information about the reproductive ecology of the slimy sculpin.
Measurements of the available habitat and nest sites suggest that slimy sculpin prefer cobble habitat in shallow areas of the stream. Photographs provided an indication of the number of eggs in each nest. With this information, a strong relationship was identified between egg number and the size of the male. It appears that female sculpin are selecting nests based on the quality of the male rather than the nest; these results are consistent with research on other sculpin species.

5.6 Literature Cited


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CURRICULUM VITAE

Candidate’s full name:  Rachel Ann Keeler

Universities attended:
1998 – 2002  McMaster University, Hamilton, ON  
BSc – Biology and Environmental Science

Publications:


Conference Presentation:


Brasfield, S, Gray, M, Keeler, R and K. Munkittrick.  Investigating limitations and challenges to developing population-level ecological risk assessments for small


