Spatial Ecology of Fish in Toronto Harbour in Response to Aquatic Habitat Enhancement

by

Maxime A. N. Veilleux
B.Sc., University of Guelph, 2012

A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial fulfillment of the requirements for the degree of

Master of Science

in

Biology

Carleton University
Ottawa, Ontario

Abstract

Every year billions of dollars are being spent on rehabilitation activities in hopes of improving the state of degraded ecosystems. In this thesis, I considered the practical aspects of acoustic telemetry for studying habitat enhancement and investigated the effectiveness of habitat enhancement initiatives in Toronto Harbour by comparing fish habitat use of six species in two enhanced slips to two non-enhanced slips. During spring, Northern pike were found to spend more time in the enhanced slips compared to the non-enhanced slips. All other species did not spend significantly different amounts of times across the slips. When Largemouth bass and Northern pike were experimentally displaced in the enhanced slips, they left within 29 hours suggesting that the enhanced habitats did not provide substantial direct benefits to adult fish in this study. Overall, telemetry studies with good experimental designs are considered valid tools for management.

Acknowledgements

I would like to thank my supervisor Steven Cooke, my co-supervisor Susan Doka, and my mentors Nick Lapointe, and Jon Midwood for their help, guidance, support and patience. I would also like to thank my collaborators (Andrew Rous, Tyler Peat, Bodgan Hlevca, Mathew Wells, and Liset Cruz-Font) for helping with the overall Toronto Harbour project development. I would like to extend my sincerest appreciation to many employees from the Toronto and Region Conservation Authorities (TRCA) (Adam Weir, Pete Shuttleworth, Brian Graham, Rosss Davidson, Rick Portiss, and Emily Morton) and volunteers from the Fish Ecology and Conservation Physiology Laboratory (Robert Lennox, Tanya Prystay, Graham Raby, and Andrew Weatherhead) for assistance in the field. Finally, I would like to thank my family and friends for the continuous support and encouragement.

Co-Authorship

Chapter 2: Tracking Fish to Inform Habitat Management and Rehabilitation: A Case Study of the Toronto Harbour Area of Concern

M.A.N. Veilleux, J.D. Midwood, A. Rous, S.E. Doka, N.W.R. Lapointe, A. Weir, M. Wells, and S.J. Cooke

While the study is my own, the research was undertaken as part of a collaborative effort, and each co-author played a valuable role in its completion. The project was conceived by Veilleux, Midwood, Lapointe, and Cooke. Field work was completed by Veilleux, Lapointe, Midwood, Rous, and Weir. All writing was conducted by Veilleux. All co-authors provided comments and feedback on the manuscript. The manuscript is in preparation for submission to a peer-reviewed journal.

Chapter 3: Spatial ecology of adult fish relative to habitat enhancement activities in an urban freshwater harbour: a multi-species acoustic telemetry study

M.A.N. Veilleux, J.D. Midwood, S.E. Doka, N.W.R. Lapointe, A. Weir, R. Portiss, M. Wells, and S.J. Cooke

While the study is my own, the research was undertaken as part of a collaborative effort, and each co-author played a valuable role in its completion. The project was conceived by Veilleux, Midwood, Lapointe, and Cooke. Field work was completed by Veilleux, Lapointe, Midwood, Rous, and Weir. All data analysis was conducted by Veilleux. Data were interpreted by Veilleux, Midwood, and Cooke. All writing was conducted by Veilleux. All co-authors provided comments and feedback on the manuscript. The manuscript is in preparation for submission to a peer-reviewed journal.

Table of Contents

List of Tables

List of Figures

Glossary

AHT: Aquatic Habitat Toronto

AOC: Area of Concern

GTA: Greater Toronto Area

HPA: Hyperbolic Positioning Array

HPE: Horizontal Position Error

RAP: Remedial Action Plan

TRCA: Toronto and Region Conservation Authority

TTP: Tommy Thompson Park

VPS: Vemco Positioning System

Chapter 1: General Introduction

1.1 Background Information

Wetlands and coastal embayments are vital to the sustainability of many ecosystem services provided by the Laurentian Great Lakes and offer economic benefits to more than eight million Canadians and 35 million Americans (GLRC, 2005). Some of these services include water purification, food production, nutrient cycling, flood abatement, climate stabilization, coastal protection, and habitat for various fish species (Holmlund and Hammer 1999; Mayer *et al.* 2004; Zedler and Kercher 2005). It is estimated that about 50% of global wetlands have been lost as a result of anthropogenic activities (Keddy *et al.* 2009). The remaining 12.8 million km^2 represents 9% of the earth's land area (Zedler and Kercher 2005). The Laurentian Great Lakes contain 17,000 km of coastal habitat (Danz *et al.* 2007), which is critical to some life stages of 80% of native fishes (Chow-fraser and Albert 1999) including species at risk (Lapointe *et al.* 2010); however, majority of this habitat is threatened by human development (Niemi *et al.* 2007).

One coastal region of the Laurentian Great Lakes that has been subjected to major habitat alteration associated with urbanization is Toronto, Canada on the western end of Lake Ontario. Is it estimated that the Toronto Harbour had a historic maximum marsh area of 1,508 acres (610 ha) from 1789 to 1962 (Whillans 1982). By 1979, nearly 100% of the area had been lost (Whillans 1982) due to the urban development within the Great Toronto Area (GTA) which now exceeds a population of five million residents. Due to such habitat loss and degraded water quality, Toronto Harbour was listed as an area of concern (AOC) in 1987. Canada and the United States ratified the Great Lakes Water

Quality Agreement in 1987, which required the development of remedial action plans (RAPs) for each AOC. Various rehabilitation, naturalization, and habitat-creation projects have been put in place in hopes of restoring and protecting these AOCs and their corresponding biodiversity (Shields *et al.* 2003). In Toronto Harbour alone, there is currently $8 million being spent on rehabilitation activities with an additional $200 million to follow in the next five years with the aim of delisting this AOC by 2020 (http://www.torontorap.ca/).

Toronto Harbour has a long history of development starting in 1801, when it became a port-of-entry. By 1840, the waterfront was entirely owned by the government and merchant wharves. A deeper channel was dug in the western part of the harbour around 1906 to enable larger barges to pass through and six years later the whole harbour was dredged to a depth of 7.3 m (Wickson 2002). During this early period, in addition to dredging, up until the 1950s the northern shore of the inner harbour was gradually filled in with construction waste, such that it is now located 500 m south of its original location. Further expansion of the port facilities in the Outer Harbour in the late 1950s resulted in the creation of the Leslie Street Spit and finally, in 1972, the Eastern Gap was dredged and widened to allow the passage of larger commercial boats (TRCA 2000). In the early 1970s, dredged material was used to create Tommy Thompson Park (TTP) located on the Leslie Street Spit as an attempt to naturalize portions of Toronto Harbour. This habitat creation project was developed in order to help compensate for the loss of wetlands (610 ha) that were historically found in the area. This aquatic park projects five km out into Lake Ontario and covers a total area of approximately 500 ha. Through natural processes and habitat enhancement projects, TTP is now occupied by various plant and animal communities (TRCA 2000). Another smaller-scale project aimed at improving the harbour is the naturalization of the Spadina and Peter slips located in the Inner Harbour along the city's waterfront. Aquatic Habitat Toronto (AHT) improved the complexity of fish habitat in the slips by adding log structures, tree stumps, granular substrate, fieldstone, boulders, and submerged vegetation; a deck at the north end of the Spadina slip was also installed to provide shade for fish and provide access to the public. The Peter slip was also enhanced with various rocky substrates (i.e., gravel, cobble, and boulders). Although there is not broad literature support for the idea that habitat enhancement is effective, some studies have demonstrated that the addition of cover or supplemental structure such as logs can improve the reproductive success of Smallmouth bass and Largemouth bass (Vogele and Rainwater 1975; Hoff 1991; Hunt and Annett 2002). In fact, habitat complexity provides refuge for prey species (Crowder and Cooper 1982), and thus decreases foraging efficiencies of predators (e.g., Northern pike; Eklöv 1997).

There are various tools and approaches that enable researchers to study animal movements (e.g., mark-recapture approach, passive integrated transponders, radio telemetry, pop-up satellite archival tags, acoustic telemetry, and aerial surveys). Each method provides different benefits and can help answer different questions (reviewed in Lucas and Baras 2000) (reviewed in Lucas and Baras 2000). Some techniques provide insights on population-level measures (i.e., mark-recapture and aerial surveys) whereas others focus on the behaviour of individuals (i.e., radio telemetry, satellite tags, and acoustic telemetry). Traditional methods such as mark-recapture enable the monitoring of more individuals than more novel methods such as acoustic telemetry due to the costs associated with these "high-tech" methods. However, acoustic telemetry provides invaluable information on fine-scale movements of individuals through time whereas mark-recapture simply provides information on coarse-scale distribution and is biased against the detection of movement (Gowan and Fausch 1996).

Advances in electronic-tagging technologies provide a novel approach that could both inform rehabilitation activities and potentially enable better assessment of biological responses to rehabilitation efforts across a variety of spatial and temporal scales. A recent review revealed that this technology is underused compared to traditional approaches (e.g., measurement of abundance, richness, or community composition) to assess such responses in aquatic systems (Lapointe *et al.* 2013). Stationary acoustic telemetry arrays (see Heupel et al. 2006, Cooke et al. 2012) are a potential tool to assess biological responses to rehabilitation work as they enable the simultaneous monitoring of multiple individuals of various species on a fine scale or broad scale across all seasons for extended periods (transmitter batteries can last up to 10 years). For example, acoustic telemetry can be used to determine whether individuals are using areas more frequently after they have been rehabilitated. Over the past four decades, 25 studies have used electronic-tagging techniques to assess the effectiveness of aquatic rehabilitation projects (see Lapointe *et al.* 2013 for review). However, most of these studies were unable to provide conclusive results to determine the success or failure of rehabilitation activities for a variety of reasons including: small sample size, short tracking duration, no control habitat, no replications of rehabilitated sites, and no pre-rehabilitation data (Farrugia *et al.* 2011). Most evaluations of rehabilitation effectiveness have focused on monitoring changes in species richness, abundance, or community composition (Ford 1989).

However, it is also important to examine how such habitat management activities influence organismal health and condition (Cooke and Suski 2008), as well as understanding the spatial ecology of target animals across seasons (Herrick *et al.* 2006; Lindell 2008). Acoustic telemetry is growing rapidly in popularity (Heupel and Webber 2012) such that it will likely be increasingly used to inform habitat management in the coming years (Lapointe *et al.* 2013). For example, acoustic telemetry can provide information on i) whether fish are actually using the enhanced habitat more frequently than the habitat available before enhancement, ii) which microhabitats are preferred by tagged fishes, and iii) thermal and depth preferences of tagged fishes in varying areas.

To support the RAP process and inform habitat management activities of the (Toronto and Region Conservation Authorities) TRCA and their partners, a collaborative project based around acoustic telemetry technology was initiated. Broadly, the project objectives are to: 1) provide information on seasonal habitat requirements of different life stages of key native fishes in coastal embayments, 2) examine habitat partitioning in space and time between game species and an abundant non-native species, 3) determine the physical processes that control water circulation in various embayments of Toronto Harbour, and so estimate the relative importance of thermal exchange, seiche-driven flows, riverine flushing and wind forcing, 4) understand how fish movements and habitat selection are affected by limnological factors such as rapid drops in temperature associated with upwelling events due to variable flushing rates, and 5) assess fish community responses to multiple habitat rehabilitation activities. It is worth noting that the project objectives were co-created with partners and thus reflected science needs that had to be addressed to enable evidence-based habitat management.

Creation of TTP and the habitat-enhancement work in the waterfront slip contribute to the Toronto Harbour RAP goal of rehabilitating fish and wildlife habitat to ultimately create a self-sustaining fishery (http://torontorap.ca/). Additional goals include: eliminating discharges of toxic substances, improving water quality, improving sewage treatment, and reducing dredging; however, the focus of the Toronto Harbour Acoustic Telemetry Study is on evaluating the effectiveness of the fish-habitat creation and remediation efforts.

1.2 Research Objectives

The overall objective of my thesis is to provide insight on how to use telemetry data to inform habitat management. The Toronto Harbour area of concern was used as a biotelemetry case study to monitor community-level responses to habitat rehabilitation. Chapter 2 provides challenges and recommendations of implementing a large-scale acoustic telemetry study to inform fish-habitat management, serving as a framework for future aquatic-habitat tracking studies in other locales. Although there have been case studies on acoustic telemetry applications in other habitats (e.g., tropical coastal marine environments (Murchie *et al.* 2012), large high-flow rivers (Steig and Holbrook 2012), and estuaries (Whoriskey 2012)), there have not been any focused on freshwater wetlands, that extend across multiple seasons including winter (i.e., under ice), and habitat management. As such, this case study addresses an important void in the literature in that it occurs in an area that has abundant aquatic vegetation, extensive human activity (i.e., boat traffic) and ice in most winters, all which constrain telemetry study design and implementation. Chapter 3 assesses fish community responses to habitat enhancement in the Spadina and Peter slips to validate whether current rehabilitation activities increase fish habitat use relative to two adjacent slips that have not be enhanced. Understanding how different species respond to such habitat-enhancement projects is important in increasing the effectiveness of rehabilitation efforts.

Chapter 2: Tracking Fish to Inform Habitat Management and Rehabilitation: A Project Implementation Case Study of the Toronto Harbour Area of Concern

2.1 Abstract

Biotelemetry is now considered a common tool for fisheries research and has improved our understanding of the spatial ecology and movement of fishes. There are a number of articles that address specific technical aspects of telemetry studies such as receiver deployment, range testing, tag attachment, and data analysis; there are also case studies in various freshwater and marine systems that highlight specific applications. However, no case studies have focused on open nearshore freshwater areas in temperate regions that assess multiple species across all seasons, or focused on the specific needs of habitat management. In this paper, I use the Toronto Harbour Area of Concern to provide recommendations on the implementation of large-scale acoustic telemetry studies to inform fisheries and fish-habitat management, serving as a framework for future aquatic-habitat tracking studies in other locales. Recommendations are made regarding the choice of species, tagging methodology, receiver configuration, receiver deployment, range testing, and database management that will enable researchers to overcome the multiple challenges that may constrain the design and implementation of a telemetry study, especially in an urban setting. For example, the following issues must be considered in experimental design: open shallow areas with abundant aquatic vegetation, multiple species, multiple years, boat traffic, human activity, and ice formation. By sharing my experiences with other telemetry practitioners, they will be able to make informed

decisions regarding the use of acoustic telemetry for coastal habitat science and management and rehabilitation.

2.2 Introduction

Over the past few decades there have been many innovations in biotelemetry that have improved our understanding of the spatial ecology and movement of freshwater and marine fishes (Lucas and Baras 2000; Cooke and Thorstad 2012; Heupel and Webber 2012; Cooke *et al.* 2013a). Although biotelemetry used to be regarded as a specialized and cutting-edge high-tech tool, it is now a common part of the fisheries research toolbox (Cooke *et al.* 2012). Nonetheless, there remain many challenges with the effective use of biotelemetry to address diverse project objectives. There are some technical papers that address specific aspects of telemetry studies, such as receiver deployment (Domeier 2005), range testing (Kessel *et al.* 2014), tag attachment/implantation (Bridger and Booth 2003; Cooke *et al.* 2011) and data analysis (Rogers and White 2007). However, the diverse range of aquatic ecosystems and research objectives means that a "one size fits all" approach to telemetry is ineffective. To that end, there are a growing number of case studies, particularly related to acoustic telemetry, which is now arguably the most popular form of aquatic telemetry (Cooke and Thorstad 2012; Heupel and Webber 2012), in a diverse range of systems (e.g., tropical coastal marine environments [Murchie *et al.* 2012], large high-flow rivers [Steig and Holbrook 2012], and estuaries [Whoriskey 2012]). To date there have not been any case studies focused on open nearshore freshwater areas in temperate regions (nb. nearshore is here defined as the area beginning at the shoreline and extending offshore to the deepest depth where the thermocline intersects with the lakebed; Governments of Canada and USA 2009), especially where the case study extends across seasons, including winter (i.e., under ice), or focuses on practical management applications of the results.

The objective of this case study is to provide recommendations on how to overcome some of the specific challenges found in nearshore temperate freshwater systems, especially in an urban environment. Challenges addressed include: working in an open system, sheltered shallow areas with aquatic vegetation, experimental design of tagging multiple species and tracking them over multiple years, recreational and commercial boating activity (noise and physical damage), working in a densely-populated urban centre, and using telemetry in the winter (esp. including under ice) (Table 2-1). I accomplish this by discussing my approach and providing recommendations regarding species selection and tagging, receiver configuration and deployment, range testing, and finally database development. I focus on my experiences working with a multi-partner study on Toronto Harbour where research objectives were focused on informing and evaluating habitat rehabilitation activities; a research area for which biotelemetry is increasingly being applied (Lapointe *et al.* 2013).

2.3 Background

Wetlands and nearshore freshwater embayments are vital to many ecosystem services provided by the Laurentian Great Lakes and offer economic benefits to more than eight million Canadians and 35 million Americans (GLRC 2005). Urban development within the Greater Toronto Area (GTA) (population exceeding five million people) has led to a loss of over 600 hectares of wetland habitat (Whillans 1982). Due to such habitat loss and degraded water quality, Toronto Harbour was listed as an Area of Concern (AOC) in 1987 among many other sites in the Great Lakes. Canada and the United States ratified the Great Lakes Water Quality Agreement in 1987, which required the development of remedial action plans (RAPs) for each AOC. Various rehabilitation, naturalization, and habitat-creation projects have been put in place in hopes of restoring these AOCs and their correspondingly lost biodiversity (Shields *et al.* 2003). In Toronto Harbour alone, $8 million is being spent on rehabilitation activities with an additional $200 million expected to follow in the next five years, all with the aim of delisting this AOC by 2020 (http://www.torontorap.ca/). One of the RAP goals includes the rehabilitation and protection of fish and wildlife habitat to support self-sustaining fisheries. To date, however, rehabilitation efforts in Toronto Harbour have been based on "experiential and anecdotal evidence" rather than empirical site-specific scientific evidence of fish-habitat usage (either natural or constructed) and the ensuing potential for biodiversity and production improvements.

2.4 Site Information

Toronto Harbour (15 km^2) is connected to Lake Ontario and is often divided into the Inner Harbour and the Outer Harbour (Figure 2-1). The Inner Harbour is delineated by Toronto's waterfront and the Toronto Islands whereas the Outer Harbour is surrounded by Islands and Tommy Thompson Park (TTP). The eastern channel joins the two harbours and both harbours are directly connected to Lake Ontario (via the western channel and the mouth of the Outer Harbour). TTP, which is located on a man-made peninsula (previously known as Leslie Street Spit), was created from infill material in the early 1970s and modified in design in an attempt to naturalize portions of Toronto Harbour. This aquatic park projects five km out into Lake Ontario and covers a total surface area of approximately 500 ha with a depth range. To create a more structurally complex system, the aquatic portions of the park are functionally divided into three cells and four embayments (TRCA 2000; Figure 2-1). In addition to providing aquatic habitat, the cells in the park have continued to function as deposition sites for dredged material from the harbour. Currently, Cell 1 (8.2 ha) and Cell 2 (9.3 ha) have been filled to capacity, but Cell 3 (32.1 ha) continues to receive such material (TRCA 2000, 2002). Through natural processes and habitat enhancement projects, TTP is now occupied by various plant and animal communities (TRCA 2000). Another smaller-scale project aimed at improving the harbour is the naturalization of the Spadina and Peter slips located in the Inner Harbour along the city's waterfront. In 2008, habitat was created in the Spadina slip by adding log structures, boulders, and submerged vegetation; a deck at the north end of the slip was also installed to provide shade for fishes and provide waterfront access to the public (Goodfellow and Goodfellow 2012). The Spadina (5,620 m^2) and Peter (7,910 m^2) slips are located on the western side of the waterfront near the Western Channel whereas the Jarvis (11,550 m^2) and Parliament (11,270 m^2) slips are located on the eastern side of the waterfront near the mouth of the Don River (Figure 2-1).

2.5 Choice of Species

To date (June 2014), 300 individuals across eight species of fishes have been tagged with acoustic transmitters. Species were strategically chosen to represent various thermal and trophic guilds within the community, as well as native and non-native species. Northern pike (*Esox lucius*) were chosen as they are the dominant resident coolwater piscivores, having an optimum thermal range of 19-25ºC (Casselman 1978) and Largemouth bass (*Micropterus salmoides*) were selected as the dominant resident warmwater piscivores, having an optimum thermal range of 27-32ºC (Venables *et al.* 1978). Additionally, these two species were also selected since they are often targets for recreational fishers (Brownscombe *et al.* 2014). Common carp (*Cyprinus carpio*) were selected as the sole non-native fish for tagging; they are a warmwater species that is tolerant of poor water quality conditions and are considered benthic omnivores (Jackson *et al.* 2010). Walleye (*Sander vitreus*) are coolwater piscivores with an optimum thermal range of 11-25ºC (Lester *et al.* 2004). They have been identified as one of the targets for habitat and species remediation work since historically the Toronto waterfront supported a commercial Walleye fishery. Yellow perch (*Perca flavescens*) were included in the study since they are an important mid-foodweb prey species for many top predators and Brown bullhead (*Ameiurus nebulosus*), as benthic omnivores, are frequently used as indicators of sediment contamination (Pinkney *et al.* 2001). Finally, starting in the spring of 2013, Bowfin (*Amia calva*) and White suckers (*Catostomus commersonii*) were tagged as part of a pilot study to widen our community-level understanding and determine both the response of these species to tagging and some preliminary details on their spatial behaviour in the harbour. Overall, the bulk of tagging efforts focussed on two recreationally-important species (Largemouth bass and Northern pike) to help improve Toronto's fisheries and on a non-native species (Common carp) to gain a better understanding of their movements and behaviour so restoration could target habitats for native species. This information will be invaluable because we do not want to create habitats that will encourage this non-native species to outcompete native species.

After analyzing preliminary data from 14 Brown bullhead tagged in 2012, I noticed that most individuals had limited detections and showed little evidence of movements within the Inner Harbour (only one individual moved across the Inner Harbour). The reason for these limited detections is unclear but could be linked to either procedural (e.g., issues with transintestinal expulsion of transmitters; Summerfelt and Mosier 1984) or behavioural (e.g., Brown bullhead favour extremely shallow vegetated areas where they cannot be detected). Regardless of the cause, tagging of Brown bullhead ceased allowing me to shift resources to other species of interest. In another instance, after obtaining preliminary results, I opted to only tag Common carp between 400 to 600 mm as individuals larger than 600 mm had a tendency to leave the harbour and not return. Understanding tag retention or detection limitations in Brown bullhead or Common carp helped to direct our interpretation of the data and refine our tagging strategy. However, when the level of tag retention is unclear (e.g., for Bowfin or White sucker) it can limit the ability to distinguish species' behaviour from tagging or detection issues. Ideally, tag-validation studies should be conducted for the more "unique" species of interest since Cooke *et al.* (2011) noted that tagging validations are still rather uncommon and tend to be focused on gamefish or others of direct commercial importance.

I therefore recommend integrating pilot studies into the design of a large-scale acoustic telemetry project. Tagging of a small number of individuals can help limit initial costs and can also determine which species are worthwhile to tag in greater numbers.

This type of pilot study can also help determine seasonal residency patterns (e.g., if all fish depart the study area it may be informative but negate the need for additional tagging) and species to target for future research. Overall, pilot studies can help determine the suitability of a species for telemetry by evaluating whether it survives the procedure, does not shed the transmitter, and does not leave the study area (if important for the study design).

2.6 Fish tagging

Information from literature on movements and habitat use derived from telemetry is readily available for all eight target species; particularly, Largemouth bass (e.g., Mesing and Wicker 1986; Cooke *et al.* 2005; Hanson *et al.* 2007), Northern pike (e.g., Cook and Bergersen 1988; Klefoth *et al.* 2008; Kobler *et al.* 2008), Walleye (reviewed in Landsman *et al.* 2011), and Common carp (e.g., Johnsen and Hasler 1977; Jones and Stuart 2007). Less is documented about the remaining four, although some research has been completed on Yellow perch (e.g., Zamora and Moreno-Amich 2002; Radabaugh *et al.* 2010), White suckers (e.g., Kelso 1977; Doherty *et al.* 2010), Brown bullhead (e.g., Kelso 1974; Sakaris *et al.* 2005), and Bowfin (e.g., Traslavina 2010). Regardless, only two studies were found that used telemetry to link the movement and behaviour of any of the eight target species with rehabilitation activities (Largemouth bass, Gent *et al.* 1995; Sammons *et al.* 2003). Additionally, there is a general lack of information on seasonal variation in movement and habitat use for most species, especially during the winter.

Fish in this study were captured via boat electrofishing, brought to shore for surgery, and released at their capture location. Many of the species tagged are targeted by anglers and therefore could not anesthetised with tricaine methanesulfonate (MS-222), which is a carcinogen and has a 21-day withdrawal period before the fish is considered safe for human consumption (Pirhonen and Schreck 2002). Instead, a portable electroanesthesia system (PES) (Smith-Root, Inc., Vancouver, WA) was used for sedations before tag-implant surgery (Vandergoot *et al.* 2011; Trushenski *et al.* 2012a,b; Trushenski and Bowker 2012; Table 2-2). Northern pike have been shown to respond well to electroanesthesia in the short term (e.g. zero mortality 24-hour post surgery) (Walker *et al.* 1994). However, preliminary data from the Toronto Harbour study for 18 Northern pike anesthetized using the PES unit in 2011 showed comparatively poor long-term survivorship (eight out of 18 died within the first month after being released). Consequently, after 2011, Northern pike were always anesthetized using a 60 ppm clove oil bath, which improved long-term survivorship (four out of 56 died or had malfunctioning transmitters within first month). To keep fish anesthetized during surgeries, a 30 ppm clove oil solution was continuously flooded through their gills. Surgeries were performed using methods similar to those described by Jepsen *et al.* (2002), Cooke *et al.* (2003), and Wagner *et al.* (2011). On average, surgeries lasted 4.45 minutes ± 1.92 minutes (median = 4.05 minutes). Twelve surgeries surpassed a length of eight minutes, mainly because novice surgeons performed some of the surgeries under the supervision of a more experienced surgeon. Although less than ideal, given the diversity of species being tagged it was not always possible to obtain fish for training purposes. The lengthier surgeries were also associated with efforts to identify the sex of the fish. One challenge associated with tagging a variety of species was interspecific variation in ventral body wall thickness and associated surgical challenges. For example, Common carp often have thick musculature that requires a deep incision (sometimes as much as 3 cm) to reach the coelomic cavity as well as large scales that can quickly dull scalpel blades. In contrast, the majority of the other target species have thinner musculature and small scales making surgery more straightforward. Surgeries were also challenging since some species (e.g., Bowfin) have rarely been the focus of telemetry studies; however, using a similar approach to tag Bowfin as other fish (e.g., Northern pike and Largemouth bass) seems to be appropriate with no apparent issues. Consequently, all incisions were made along the ventral line, with the exception of Common carp where they were offset from the ventral line because body wall thickness was thinner off the midline.

I recommend using electroanesthesia for sedations because it allows for a shorter induction period (three seconds) which results in overall shorter handling times, a relatively quick recovery from the surgery compared to other sedation methods (e.g., two-four minutes), and high survivorship (Vandergoot *et al.* 2011). Northern pike should be sedated with a 60-ppm clove oil bath since they seem to respond poorly to the PES unit in the long-term. In addition, electroanesthesia and eugenol appear to pose no health risks to humans (i.e., eugenol in the form of AQUI-S-20-E recently approved by US FDA for use on food fish without withdrawal; Bowker and Trushenski 2013) who may consume fish post-sedation. Nonetheless, additional research is needed to optimize electroanesthesia and evaluate its long-term consequences on fish health and survival. To improve the ability to assess fish sex, a surgeon should use a borescope to examine the body cavity instead of a blunt probe and light-emitting diode (LED) flashlight. The borescope required a smaller incision and was generally more effective. I recommend referring to the literature for appropriate surgical approaches (e.g., anesthesia, location of incision) when performing surgeries on commonly-studied species. Best practices, as outlined in Thiem *et al.* (2011) or Cooke *et al.* (2013b), should be followed to ensure optimal recovery and to limit any potential influences on the behaviour of the species.

2.7 Receiver Configuration & Fine-Scale Positioning

Previous telemetry studies have used large-scale acoustic arrays to evaluate fish movements, residency, home ranges, habitat utilization, habitat selection, site fidelity, diurnal movements, and diel activity (Heithaus *et al.* 2002; Lowe *et al.* 2003; Meyer *et al.* 2007). Some key considerations from these previous studies in terms of array design include using curtains at transition points (e.g., channels through which fish could depart the system) and over-lapping grids to increase detection probability. There are two different types of array deployments geared towards collecting either presence/absence data obtained by a single receiver or fine-scale positioning data (i.e. 1-m accuracy) obtained by three of more receivers in close proximity. A hyperbolic positioning array (HPA; Niezgoda *et al.* 2002) is a novel tool that allows researchers to continuously examine fine-scale movements and microhabitat use by fish. This technology is increasing in popularity and allows for finer-scale evaluation of residency, habitat use, home ranges, site fidelity, and behavioural patterns (Espinoza *et al.* 2011b,a; Baktoft *et al.* 2012; Dean *et al.* 2014).

While initially an over-lapping grid design was planned for the entirety of Toronto Harbour, the cost associated with this type of deployment as well as limitations due to shipping channels required a new approach. As such, receivers were strategically positioned throughout the harbour to monitor key areas of interest (e.g., cells and embayments in TTP, Toronto Islands, and rehabilitated areas) as well as key movement corridors between the areas (Figure 2-1). For example, receivers were deployed at transition points covering the two connections between the harbours and Lake Ontario (Western Channel and Outer Harbour Channel) as well as the connecting channel between the Inner and Outer Harbours (Eastern Channel) thus enabling us to determine residency within the different major sections of Toronto Harbour as a whole. At all transition points, receivers were deployed in pairs to determine movement direction (Heupel *et al.* 2006). Receivers were also deployed in areas that were presumed to be overwintering aggregation sites for key species (e.g., Largemouth bass) to collect sensor data (e.g., temperature and pressure) from a subset of the transmitters. The telemetry array for the current project has not been static; some receivers were added while others were removed based on an adaptive learning process and shifting project objectives, as well as the acquisition of funds to purchase additional telemetry infrastructure. Because fine-scale behaviour was also of interest in small habitat creation projects, receivers were deployed in a manner that provided the opportunity to use hyperbolic navigation to position fish in two dimensions. When identifying candidate sites for HPA deployments, I used both data collected from the larger array to identify highly used habitats (e.g., embayments) as well as input from resource managers (e.g., slips were identified as areas of restoration interest). Fine-scale positioning was ideally suited for work in the slips given the complex rehabilitation plans of the Spadina and Peter slips as well as the constrained nature of the slips themselves (i.e., only one entrance/exit); consequently HPA arrays were established in four slips to test hypotheses about their habitat structure and general usage (see Chapter 3). An HPA was also originally setup in Embayment D but had to be moved to Embayment C due to poor detection of the synctags as a result of interference from vegetation. HPAs require a high level of detection to function adequately. Thus, it is important to consider factors that affect detectability when setting up an HPA (e.g., abundant vegetation, code collisions, ambient noise).

Based on my experience with the development of the Toronto Harbour receiver array, it is important to be aware of boat traffic, public access, and ice formation patterns when designing the configuration of an array. I recommend consulting with the local port authorities regarding placement of receivers in areas that are considered navigable waters – indeed, it may be a legal requirement to do so. Although several areas in our study had deployment restrictions (e.g., shipping channels), in most cases deployments simply had to be modified such that they did not extend to within 3-m of the surface. I recommend doing a short pilot study to determine key hot spots and confirm residency of fish within the system. Locations of receivers can then be moved to improve the design of the array. However, an ever-changing array is not ideal since it will limit the ability to compare fish positions among years. Therefore, it is best to identify optimal array design as quickly as possible and then leave receiver locations as is for the duration of the study or until project objectives change. When designing an HPA, it is important to consider local boat traffic and the dynamic nature of aquatic vegetation. As such, I recommend conducting range testing (see range testing section below) during the summer months when boat traffic is at its highest and aquatic macrophytes are at their densest. Arrays surrounded by concrete walls can experience positioning issues as a result of echoes, therefore selection of appropriately sized synctags and transmitters are important to ensure proper array functioning. In addition, it is important to limit the number of fish tagged in the array since it will decrease the detection probability of each fish due to code collisions. Also, there are a variety of tools available to assist with selection of optimal delay periods between transmissions to minimize likelihood of overlap (Dale Webber, Vemco, Personal Communication).

2.8 Receiver Deployments and Retrievals

Although there are several papers that summarize various deployment methods (Domeier 2005; Titzler *et al.* 2010), none are specific to freshwater systems where soft substrates and winter surface ice occur. A variety of station designs were required to overcome Toronto Harbour's particular challenges (e.g., public access, boat traffic, wave action, ice cover, active dredging and deposition). Receivers located near shore in relatively shallow waters can be stationed with a sandbag, a half sewer grate, or a large cement block (i.e., methods 1-3, Table 2-3). All of these stations are positioned on the bottom and can be tethered to shore with aircraft cable (high-tensile steel cable that is coated to reduce corrosion). During the early stages of the Toronto Harbour project, I discovered that sandbags tended to disintegrate through time resulting in potential receiver loss. The half sewer grates were too heavy for the average person to lift by hand requiring deployment and retrieval using a winch and in general making them impractical for large-scale deployment. These challenges necessitated the design of 60 cm x 60 cm x 10 cm cement block stations (based on a design developed by Christopher Vandergoot, Ohio DNR) embedded with polyvinyl chloride (PVC) pipes to contain the receivers (Figure 2-2a). These stations did not disintegrate, were light enough to be lifted by a single person from a small vessel, yet heavy enough (30 kg) that they discouraged tampering and could not be moved by currents. The design of these stations reduced the likelihood of receiver loss since they were secured to the imbedded PVC pipe with bolts as opposed to being tied to a sandbag or half sewer grate with a rope (these can be cut by propellers or abraded against surrounding objects by waves as occurred with one of my receivers). Receivers located offshore in relatively shallow waters (<10 m) can be attached to a mooring buoy or stationed with a cement block that has a float attached. Stations attached to mooring buoys were located right below the surface with the hydrophone on the receiver facing downwards whereas stations attached to cement blocks with an attached float were positioned upward facing on the bottom. Neither of these station types were tethered to shore but were still within the public's reach. Floats attached to cement stations needed to be shallow enough so that they could be accessible to the research team, but deep enough to avoid getting caught in boat propellers or ice in the winter months (recommended depth of 1-m below surface). Both station types were light enough to be lifted by hand, which was useful for shallow areas where a larger boat with a mechanical winch cannot reach. However, these stations could be susceptible to theft and tampering because of their accessibility. Finally, receivers located offshore in deeper waters (>10 m) were stationed with two sewer grates that were connected with rope along lake bottom (i.e., they must be retrieved using a grapple). These stations were positioned on the bottom and were not tethered to shore. Stations weighed ~60 kg to ensure that they were not dislodged by strong currents. All of these aspects made it nearly impossible for members of the public to tamper with my stations. However, retrievals tended to be more technically challenging and time-consuming.

Finding and retrieving receiver stations can be challenging, making the collection of accurate GPS coordinates at the deployment location as well as the on-shore location where the station is secured critical. On-shore anchor points are very helpful and I recommend using them where possible (typically cannot be used in offshore locations or areas with high boat traffic) since they allow for easy retrieval of submerged equipment without the need for grappling. One important caveat of on-shore anchor points is that if seen, they may be tampered with or damaged. I therefore also recommend that consideration be given to the ease of public accessibility to the anchor-point locations; these areas should be hidden if possible either at or below the waterline. If the anchor points cannot be made discrete, the use of coated aircraft cable can make it difficult for curious individuals to lift the station since the line is too slippery (and heavy at ~30 kg) to pull by hand without gloves. When on-shore anchor points are not possible, stations can be retrieved by grappling the connecting rope and lifting the anchors using a davit and winch. The boat with the winch needs to be sufficiently large and stable to enable retrieval without listing and to be able to safely handle one or more heavy anchors once onboard. Despite my efforts to prevent receiver loss, abrasion and suspected vandalism resulted in the severing of some anchor-point cables. Fortunately, most of the lost receivers were retrieved with assistance from police SCUBA divers, who incorporated retrievals into their training program. By following these suggestions, I was able to retrieve all but two of my receivers throughout the entire project (i.e., Station 53 in Lake Ontario & Station 6b in Embayment D). Other researchers have used the acoustic release method which eliminates the need for surface buoys, cable bridle, and anchor taglines (Titzler *et al.* 2010). This method was not employed for my study due to the large quantity of macrophytes throughout the harbour that may have impaired function of acoustic releases. Fortunately, my team had the equipment and skills required to retrieve receivers manually.

Although receiver batteries for the units I deployed should last for ~15 months, I opted to download receivers at more frequent intervals (i.e., twice per year; spring and fall) and changed receiver batteries every 12 months to ensure continuous functionality. Thus, if a receiver went missing or malfunctioned, only data from the previous six months would be lost. Frequent retrievals also enabled me to both ensure that receiver locations had not changed and clean the receivers of fouling (e.g., algae, silt, and Dreissenid spp) (Figure 2-2b), which can reduce detection range (reviewed in Kessel *et al.* 2014). I did not treat the receivers with anti-fouling material and there was little evidence at 6-month intervals that biofouling was sufficient to affect hydrophone performance unlike many marine deployments (see Heupel *et al.* 2008). During retrievals I was also able to replace any rusted or corroded bolts, cables, or clamps to help prevent the loss of any stations in the future. Having access to more frequently collected data was an added benefit in that it enabled me to start analyzing the data earlier. This earlier access allowed me to quickly evaluate post-tagging survival of individual fish (e.g., if there was no evidence of movements or changes in depth from the tag then fish may have not survived or the tag was expelled) and adapt tagging procedures as needed or change tagging strategies as discussed previously for Brown bullhead and Common carp. In addition to providing information on individuals, frequent downloads were also helpful in refining the array design by identifying receivers that may not be situated for optimal detections and, in the case of 2-D positioning arrays, refining their placement to improve positional accuracy. Finally, given the collaborative nature of many large-scale telemetry projects, early access to data allowed me to share preliminary findings with partners and incorporate their feedback into my future array design and tagging strategies.

Overall, receivers should be deployed using appropriate methods depending on the surrounding habitat type, proximity to shore, local limiting factors, and depth of water column. In general, when selecting anchor types, it is important to balance the requirement for stations to remain stationary (e.g., sufficient mass to not be moved by currents or tampering) but to remain accessible (e.g., not so heavy they cannot be easily lifted for retrieval). In high boat-traffic areas and areas subject to ice cover, it is important to limit the height of the receiver and any associated floats. By working with a local partner (such as TRCA or Toronto Port Authority), it should be possible to fine-tune the positioning of receivers by determining areas of high traffic that should be avoided as well as appropriate depths wherein to deploy the receivers to avoid entanglement. When appropriate, stations should be affixed to shore with aircraft cable to facilitate station retrievals. Anchor points should be well hidden from the public to reduce chances of tampering. Lastly, receivers should be retrieved every six months to ensure continuous functionality, to minimize data loss, to ensure receiver locations have not changed, and to clean the receivers of any fouling.

2.9 Range Testing

Range testing in HPAs and open systems is essential for determining the detection range of a telemetry system (which varies widely) and should be performed to both inform array geometry and data analysis (Kessel *et al.* 2014). By doing so, researchers can avoid making false assumptions about their data (Payne *et al.* 2010). Horizontal position errors can be determined for HPAs by comparing the known location of a range-test tag to its location obtained through the HPA algorithm (Smith 2013). HPAs with high positioning error can be repositioned or array resolution increased to improve local accuracy.

Preliminary range testing performed in the Toronto waterfront slips demonstrated that V16-5H (165 dB) synctags often created code collisions between transmitters which reduced the performance of the system because they were too "loud". To reduce code collisions, V16-5H synctags were replaced with less powerful V13-1L (147 dB) synctags in November 2012. Further range testing demonstrated that some receivers (i.e., Spadina 3) within an HPA had lower detection efficiencies than others (Figure 2-3). Although the probability of a receiver detecting a range-test tag was variable among receivers, it was generally greater than 80%. In addition, range testing near the Outer Harbour channel demonstrated that the probability of detecting a range-test tag decreased with distance, dropping below 0.7 at approximately 400 m (Figure 2-4). However, some range-test tags had a probability of detection of 0.8 at ~1,000 m. This variability in detection probability is likely the result of the position of the range-test tag in the water column and its surrounding environment (e.g., dense macrophytes, deep grooves in surrounding structures) and further emphasizes the importance of testing the detection ranges for each receiver from multiple directions and depths (Kessel *et al.* 2014).

Although range testing can be tedious, it is absolutely necessary and should be done at the beginning of the project. When conducting range testing, it is important to cover various types of habitats (e.g., densely vegetated, different substrate types, submerged structures like logs, deep grooves in the substrate) in different environmental conditions (e.g., rain, high winds, various water temperatures, ice cover) to calculate the maximum and minimum detection probabilities as these environmental factors can affect signal detections (Gjelland and Hedger 2013). Range testing should also be conducted during summer months when boating and shipping activity are at their highest because environmental noise can create code collisions and reduce signal detections. Although range testing is crucial in HPAs, it is also important to perform range tests for open system arrays since receivers in different locations will have different detection ranges. Ideally, range tests and receiver performance would be evaluated continuously across seasons and habitat types (Figure 2-5).

2.10 Database Management

One of the biggest challenges in working with telemetry data is managing large datasets that can include millions of individual fish detections. The lack of user-friendly tools for the management of large and complex datasets limits the usefulness of data that is acquired from telemetry despite the high costs of acquisition (Coyne and Godley 2005). Some commonly used software have limitations that preclude their use for manipulating telemetry data (e.g., Microsoft Office Excel 2007-2013 limited to 1,048,576 rows and 16,384 columns of data). Some software is available directly from the receiver developers (e.g., VUE produced by VEMCO-Amirix, Bedford, NS); however, this type of software currently has limited functions for manipulating and analyzing data beyond simple filtering, visualization, and exporting. Common database management software can be used for large numbers of detections (e.g., SQL, Microsoft Access, Oracle) and telemetry-specific tools are being developed (e.g., Ocean Tracking Network Sandbox). In addition to handling large amounts of data from telemetry projects, databases also need to be able to filter incoming data to remove erroneous detections or non-fish detections (e.g., synctags or range-testing tags). Erroneous detections can occur in acoustic studies when the signals from two or more transmitters combine and mimic the signal of another transmitter (i.e., code collisions). It can be challenging to identify these types of incorrect detections since they may appear to be detections of actual fish and initially my approach was to vet them manually.

To speed-up the process of data vetting, a database and filtering system was developed in Microsoft Access that can iteratively search through the database and flag potential erroneous detections using the last known location for each tagged fish. By identifying consecutive receivers where a fish could be detected following detection at any given station, erroneous detections where a fish may appear to move large distances in an impossibly short time-frame can be removed. In addition, a filter was created to remove multiple receiver detections from a single tag ping (i.e. only the first detection of that ping is kept since it likely is the closest station). Unlike the previously described erroneous detections, these multi-detected pings can be used for other forms of analysis (e.g., centre of activity; Simpfendorfer *et al.* 2002), this filtering step therefore resulted in the creation of two databases, one with only the first detections and one containing multiple detections. The main utility of this type of tool is that once data have been filtered, data export is faster. A properly designed database management system allows queries by species, individual transmitter, receiver, a date range, or some combination of these factors. Breaking up the millions of records into more manageable components allows for easier analysis and it can enable users to rapidly respond to requests for results from project partners. For example, from the database for the Toronto Harbour project, I was able to quickly generate a summary of seasonal use of Cell 2, an area of rehabilitation priority, for all tagged fish species that included: timing of use, as well as depth and water temperature selection within the Cell. From this summary it became apparent that several species (e.g., Largemouth bass and Walleye) were using Cell 2 as overwintering habitat, particularly some of the deeper portions of the cell (10 m). As a result further rehabilitation plans to increase the complexity of Cell 2 to avoid cold water inundations were re-designed to provide deep-water habitat as well as the nearshore habitat features originally planned.

I recommend that telemetry data users select or create software that can manage large databases (including multiple species and seasons) quickly. Key features of the database should include filtering and exporting components. Additionally, it is important to include quality assurance and quality controls for data verification to eliminate potential errors.

2.11 Conclusions

Toronto Harbour poses various challenges for telemetry studies (e.g., open system, abundant coastal aquatic vegetation, multiple species tagged, multiple years, boat activity, human activity, ice cover). Based on my experience and using this as a case study, I provided recommendations to overcome such challenges that could be present in various other nearshore systems. After determining clear study objectives, the first step in developing a large-scale telemetry project is understanding the site and identifying key challenges associated with the environment and the study design required to address the objectives. Pilot studies should then be conducted to develop a preliminary understanding of the behaviour of your target species and their physical responses to tag implantations. This information will help you determine if certain species are well-suited for telemetry in your system, especially if documented information is lacking. Electroanesthesia appears to be an ideal method for sedation for tag implantation because it allows for immediate inductions, quick recoveries, high survivorships, and does not pose any health risks to anglers if fish are consumed post surgeries. However, it may not work for all species and additional experimentation is needed across a broad range of species to determine best practices. Appropriate tagging procedures should be selected based on species by referring to the literature (e.g., location of incision). As usual, best handling and surgical practices must be followed to ensure optimal recovery of individuals which will reduce any potential influences on their behaviour. To improve the ability to assign fish sex, surgeons should use a borescope instead of a blunt probe and LED flashlight. Before the beginning of receiver deployments, I recommend consulting with relevant authorities (e.g., coast guards, harbor masters, local resource managers) to familiarize yourself with deployment restrictions in your system (e.g., shipping channels, restricted zones). Locations of receivers can then be moved to improve the design of your array but should be kept constant afterwards to enable comparisons of fish movements across years. When designing an HPA, it is important to consider factors that will affect signal detections (e.g., dense macrophytes, boat traffic) and code collisions (e.g., synctag echoes from concrete walls, signals from other tagged fish). Receivers should be deployed using appropriate station types depending on the surrounding habitat type, proximity to shore, and depth of water. Stations must be sufficiently heavy so they remain stationary and are not subject to tampering, but must also be light enough so that they can be retrieved by researchers. In areas of high boat activity, it is important to limit the height of the receiver and its associated float. When appropriate, stations should be tethered to shore inconspicuously with aircraft cable to facilitate station retrievals and avoid grappling for submerged equipment or costly diving expenses. Receivers should be retrieved at least every six months to ensure continuous functionality, to ensure station locations have not changed, and to clean receivers of fouling. Range testing in HPAs and open systems should be performed at the beginning of the project in various types of habitats and environmental conditions to help improve the accuracy of your HPA, to determine the detection range of different receivers, and ultimately to avoid making false assumptions about your data. Finally, I recommend using a database that will remove erroneous detections, allow you to filter your data for easier analyses, and most importantly enable you to quickly generate summaries to share with stakeholders.

So far, few studies have used acoustic telemetry to assess the effectiveness of rehabilitation projects. In addition, only a subset of those studies had an appropriate experimental design (Lapointe *et al.* 2013). Telemetry studies with appropriate experimental designs can help stakeholders make informed decisions about habitat management and test some assumptions that are commonplace but unverified. I am hoping that my study in Toronto Harbour will identify preferred fish habitats across seasons including spawning sites associated with habitat selection. This knowledge will assist the development and enhancement of habitat that benefits local fish populations.

By following my recommendations, habitat managers can use acoustic telemetry data in addition to suite of typical information to achieve their habitat creation and rehabilitation goals and improve the prioritization of those activities.

2.12 Tables

Table 2-1 Challenges associated with acoustic telemetry studies in nearshore temperate freshwater systems such as Toronto Harbour, Lake Ontario, ON, CAN.

	Challenges	Recommendations
Open system	- Tagged individuals may leave the array and not return	- Perform pilot study to determine which species and which size classes are more likely to remain in your array if residency is important
Multiple species	- Tagging procedures can differ among species - Increases size of dataset	- Review literature to determine best practices for each species and surgeries should be performed by an experienced surgeon - Develop a database capable of dealing with large datasets
Multiple years	- Increases size of dataset - Increases difficulty of data analysis if receiver configuration changes through time	- Develop a database capable of dealing with large datasets - Revise receiver configuration after pilot study and keep stations in same place for remainder of study
Boat activity	- Noise can decrease detection range - Propellers can damage equipment	- Perform range testing during summer months when boat activity is high. Add more receivers if detection is low. - Ensure stations are at least 2 m below the surface
Human activity	- Theft and tampering of equipment - Anglers may catch tagged fish	- Ensure that stations are inconspicuous - Attach external floy tags to fish to promote catch and release
Abundant vegetation	- Decreases detection range	- Perform range testing during summer months to determine the area's detection range. Add more receivers if detection is low.
Winter	- Ice formation can damage equipment - Restricts access to stations	- Ensure that equipment is below ice cover - Retrieve receivers during the fall and spring

Table 2-2 Details of fish sedations using a portable electroanesthesia system (PES) (Smith-Root, Inc., Vancouver, WA). Electrode positions were determined based on the size of the fish (efforts were made to reduce the distance between electrodes for each individual).

Species	**Voltage (V)**	**Frequency (Hz)**	**Duty cycle (%)**	**Shock time (sec)**	**Electrode position (cm)**
Largemouth bass	75, 90 or 100	60, 90 or 100	25	3, 9 or 12	16 – 54
Common carp	90 or 100	90 or 100	25	3	34 – 86
Walleye	75, 90 or 100	60, 90 or 100	25	3 or 6	42 – 71
Yellow perch	100 or 240	90	25	3	15 – 28
Bowfin	90	100	25	3	56 – 74
White sucker	80 or 90	100	25	3	40 - 57
Northern pike	75	60	25	6, 9, or 12	52 - 97

Table 2-3 Pros and cons of various acoustic receiver station models.

	Sand bag with float	Half sewer grate with float	Cement block with PVC pipe	Hanging off float	Cement block with float	Two sewer grates
Materials needed	Sandbag, rope, float, aircraft cable	Half sewer grate, rope, float, aircraft cable	Cement block, PVC pipe, aircraft cable,	Rope, float	Cement block, PVC pipe, rope, float, aircraft cable	2 sewer grates, rope
Nearshore vs offshore	Near	Near	Near	Offshore	Offshore	Offshore
Tied to shore?	Yes	Yes	Yes	No	No	No
Substrate vs surface	Substrate	Substrate	Substrate	Surface	Substrate	Substrate
Accessible to public	Yes	Yes	Yes	Yes	Yes	No
Lightweight	Yes	No	Yes	Yes	Yes	No
Difficulty of retrieval	Easy	Intermediate	Easy	Easy	Difficult	Difficult
Chances of loosing receiver	Possible	Possible	Unlikely	Possible	Unlikely	Possible
Suction to bottom	No	No	Yes	No	Yes	No
Recommended	No	No	Yes	No	Yes	Yes

2.13 Figures

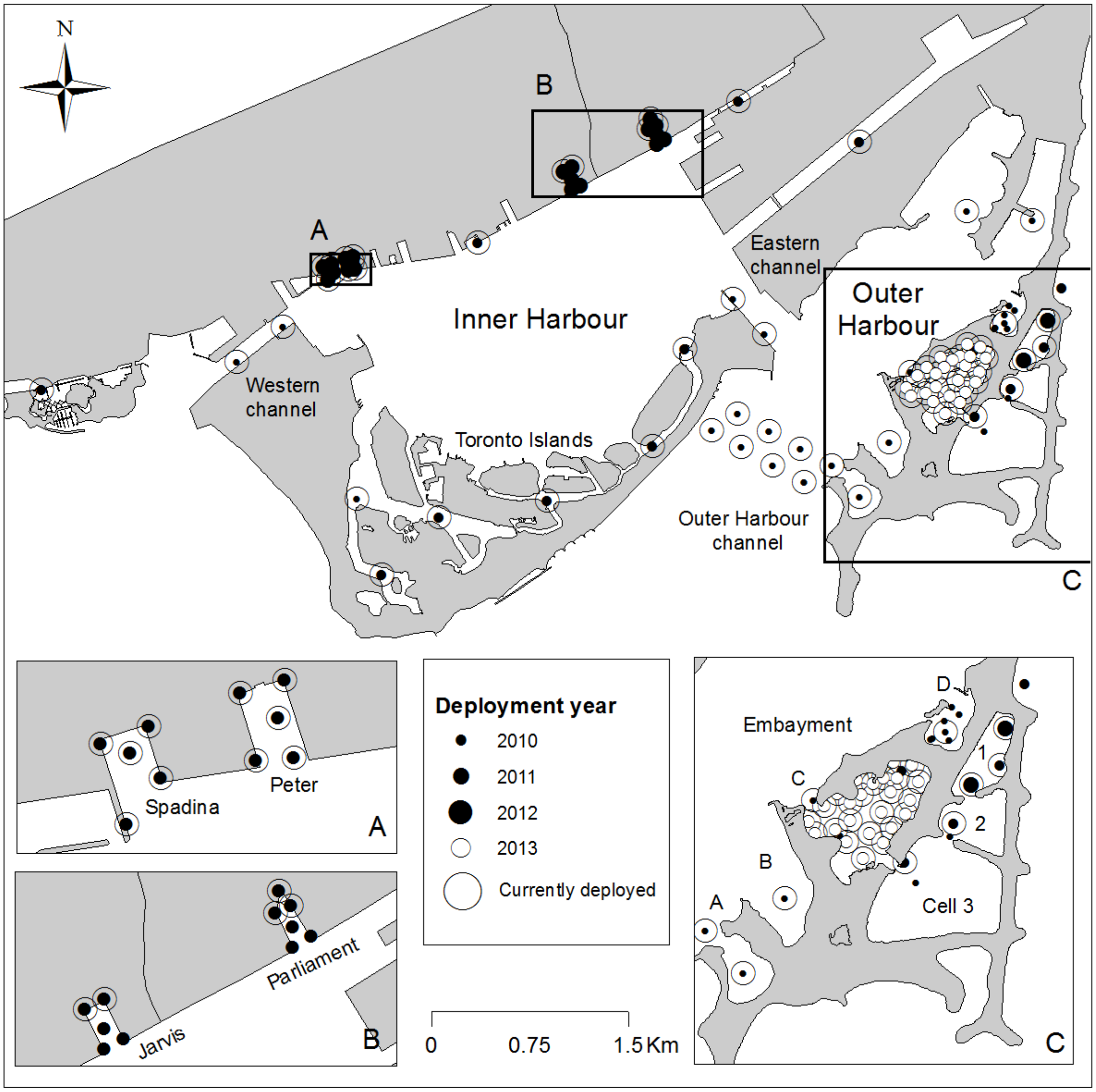


Figure 2-1 Map of acoustic telemetry study in Toronto Harbour from 2010-2014.

Figure 2-2 a) Custom-built cement station with embedded polyvinyl chloride PVC pipe and b) station covered with biofouling**.**

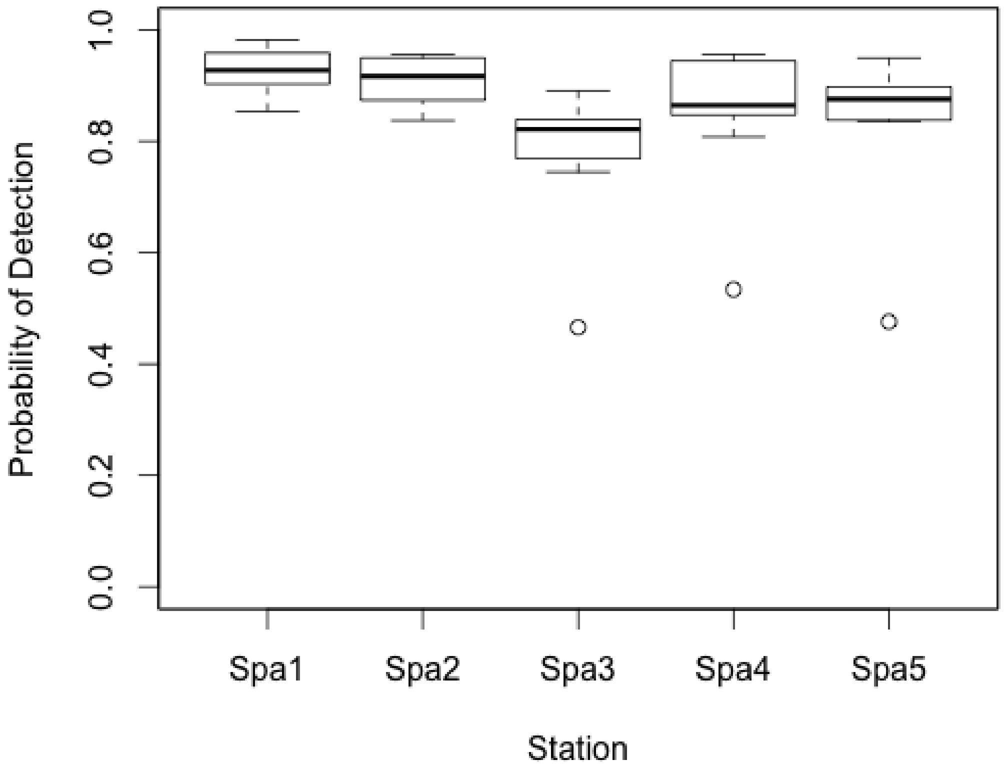


Figure 2-3 Probability of five receivers located in the Spadina slip to detect two V13-1x range-test tags (Vemco, 7 second delay) positioned at 10 nearby locations (5 bottom and 5 subsurface) for 10 minutes each. Each box on the figure represents the probability of detection of 10 different range-test tag locations from September 11, 2012. Each range-test tag emitted approximately 595 signals during each 10-minute period.

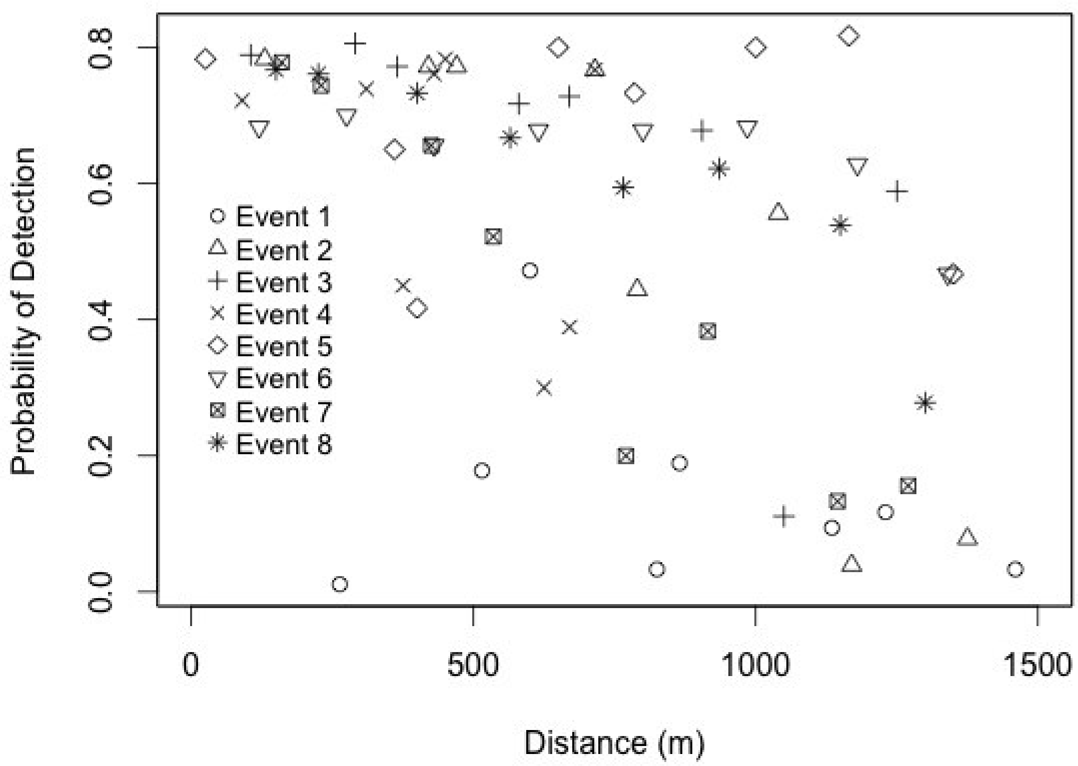


Figure 2-4 Probability of eight receivers located at the Outer Harbour channel to detect a V13-1x range-test tag (Vemco, 7 second delay) positioned at eight nearby locations for 30 minutes each. Each point on the figure represents the proportion of converted signals on a receiver (i.e., 8 range-test tag locations x 8 receivers). Data were obtained on October 25, 2011. The range-test tag emitted approximately 257 signals during each 30-minute period.

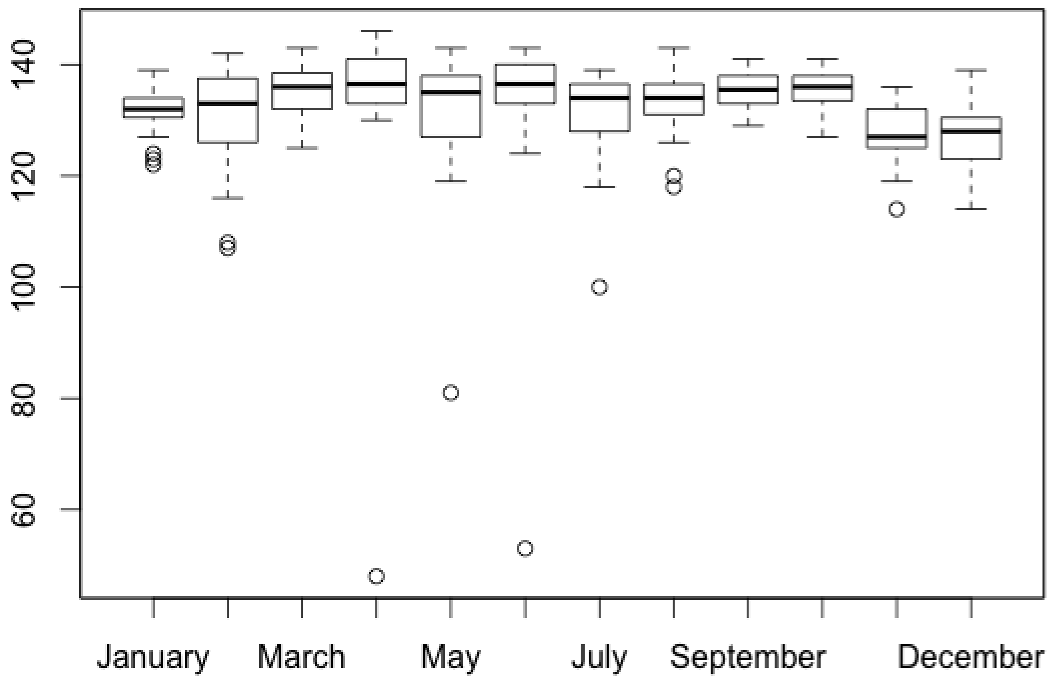


Figure 2-5 Probability of a receiver located in Spadina slip (i.e., Spadina 1) to detect a stationary V13-1x synctag (Vemco, 500-700 second delay) from November 12, 2012 to November 13, 2013. Each box represents the average daily number of synctag detections for a particular month. The expected maximum number of synctag transmissions per day is 144. Outliers represent days where receivers were pulled out of the water for data downloads.

Chapter 3: Spatial ecology of adult fish relative to habitat enhancement activities in an urban freshwater harbour: a multi-species acoustic telemetry study

3.1 Abstract

Freshwater ecosystems have been subject to various habitat rehabilitation projects in an attempt to address widespread habitat degradation. In Toronto Harbour, Ontario, habitat managers enhanced fish habitat in two waterfront boat slips (Spadina and Peter Slips) by increasing habitat complexity through the addition of aquatic vegetation, logs, gravel, and overhead cover. The main objective of this study was to determine if fish were using the enhanced habitat within Spadina and Peter more often than the non-enhanced habitats in the adjacent Jarvis and Parliament slips, which were comparatively devoid of complex habitat. Meso-scale habitat use of adult Largemouth bass, Northern pike, Common carp, Walleye, Brown bullhead, and Yellow perch were tracked with acoustic telemetry. Mean time per slip visit and mean total time spent within each slip were compared among slips across four seasons. Northern pike spent significantly more time per slip visit in Spadina compared to Jarvis and Parliament and spent significantly more time in total in Spadina and Peter compared to Jarvis and Parliament during spring. There is no evidence to support that Largemouth bass, Common carp, Walleye, Brown bullhead, or Yellow perch spent different amounts of time per slip visit or different amounts of time in total across the four slips during all seasons. Some Largemouth bass and Northern pike were displaced from their capture location and released into the two enhanced slips. This experiment revealed that at least in the short term (i.e., several weeks post displacement), the displaced fish did use habitats that had been enhanced but

eventually the fish left the slips. Overall, there was limited evidence to support the idea that the habitat enhancement work in Spadina and Peter increased habitat use of adult fish tagged in this study. However, it is possible that the enhanced habitat in Spadina and Peter provided suitable spawning habitat for Northern pike. Moreover, while not documented in the present study, there might have been indirect benefits (e.g., habitat use by juveniles, food production) and general improvements in habitat quality such that from a population perspective, the habitat enhancement might have been successful.

3.2 Introduction

Humans are a dominant force on Earth causing losses of habitat and alterations to most ecosystems (Vitousek *et al.* 1997). Although the human population continues to grow, there are increasing efforts to protect sensitive habitats (Hoekstra *et al.* 2005) and, when systems are degraded, various forms of ecological restoration (including enhancement, creation, rehabilitation, reclamation and true restoration; see Jackson *et al.* 1995; herein called "rehabilitation") are undertaken to move the system back towards a more desired state (Hobbs and Harris 2001; Benayas *et al.* 2009). Given that globally billions of dollars are spent annually on habitat rehabilitation activities, it is prudent to ensure that these resources are being used wisely and that rehabilitation efforts are meeting project objectives (Miller and Hobbs 2007). A recent meta-analysis (Benayas *et al.* 2009) of ecological restoration projects across a variety of biomes and ecosystem types revealed that ecological restoration increased biodiversity and the provision of ecosystem services by 44 and 25%, respectively. Interestingly, aquatic systems were inconsistent in their response between tropical and temperate systems with only biodiversity in temperate regions experiencing a significant increase associated with ecological restoration (Benayas *et al.* 2009).

Globally, freshwater fauna are disproportionately imperiled (Ritcher *et al.* 1997) and freshwater ecosystems among the most degraded (Dudgeon *et al.* 2006) so it is not surprising that they have been subject to much ecological rehabilitation – especially physical habitat alteration such as the placement of physical structures (e.g., logs or gravel beds). Many studies have examined the success of lotic physical habitat rehabilitation projects (both on small streams and larger rivers) on fish populations (typically salmonids; reviewed in Kondolf and Micheli 1995; Roni *et al.* 2002), but comparatively little is known about physical habitat rehabilitation success in lentic ecosystems (e.g., lakes, reservoirs, and wetlands; reviwed in Smokorowski and Pratt 2007).

Evaluating the success of rehabilitation activities is not a simple task and requires careful thought regarding experimental design and selection of relevant endpoints (Michener 1997). In recent years, electronic-tagging tools (e.g., radio telemetry, acoustic telemetry) have been increasingly used to monitor fish movements, residency, habitat use, home ranges, habitat selection, diel activity, swimming speeds, etc. (see Enders *et al.* 2007; Reynolds *et al.* 2010; D'Anna *et al.* 2011). Few studies though have used electronic-tagging technologies to assess the effectiveness of rehabilitation projects (see Lapointe *et al.* 2013 for review). The few that do, tend to focus on a single species and thus fail to examine multi-species responses to rehabilitation efforts (e.g., Makiguchi *et al.* 2008; Linnansaari *et al.* 2009; Espinoza *et al.* 2011). Lapointe *et al.* (2013) suggested that telemetry has great potential to inform and evaluate habitat restoration activities in aquatic systems and address long-standing questions regarding the effectiveness of such activities.

A number of habitat creation and habitat enhancement projects have taken place in Toronto Harbour (Ontario, Canada) in the past four decades in hopes of delisting this area of concern (AOC) by 2020 (Great Lakes Regional Collaboration 2005). Examples of such projects include the creation of Tommy Thompson Park and the enhancement of the various boat slips along Toronto's waterfront. In 2008, Aquatic Habitat Toronto increased habitat heterogeneity within the Spadina slip by creating 640 m^2 of enhanced aquatic habitat which consisted of logs, boulders, granular substrate, and submergent vegetation along the northern side of the slip. In 2006, the western and eastern sides of the Peter Street slip were also enhanced with gravel, cobble, and boulders. The goal of their efforts was to provide better-quality habitats for two recreationally-important fish species (i.e., Largemouth bass; *Micropterus salmoides* and Northern pike; *Esox lucius*). These slips were targets for enhancement efforts since they were considered highly-degraded habitats that were surrounded by hardened shorelines. Although fish had been found using Spadina and Peter pre-remediation, efforts were made to improve the diversity of habitat types so that they are more in-line with habitat requirements of local fish species (i.e., aquatic macrophytes, variable substrate sizes, complex structures, woody habitats, reduced fine substrates; reviewed in Smokorowski and Pratt 2007).

The first goal of this study was to assess the response of multiple fish species to habitat enhancement in the Spadina and Peter slips in order to validate whether rehabilitation activities increased fish habitat use relative to two other slips that had not been subject to habitat enhancement. A two-dimensional acoustic telemetry array was used as a tool to track the mean time per slip visit and the mean total time that tagged Largemouth bass, Northern pike, Common carp (*Cyprinus carpio*), Walleye (*Sander vitreus*), Brown bullhead (*Ameiurus nebulosus*), and Yellow perch (*Perca flavescens*) spent among the Spadina and Peter slips and two non-enhanced slips (Jarvis and Parliament) during four seasons. I plotted kernel density estimates (KDE) for each species (except for Brown bullhead and Yellow perch due to a lack of meso-scale data) in the four slips during four seasons to see if fish were preferentially selecting certain habitats (i.e., enhanced areas and overhead cover). The second goal of this study was to evaluate whether the two enhanced slips provided suitable habitat for tagged Largemouth bass and Northern pike that were experimentally released in these slips in May 2013. To answer this question, I calculated the time that individuals spent in their release slip before leaving, the total time that displaced fish spent in all slips during spring and summer, and the number of days it took displaced fish to return to their capture location. Finally, I also plotted KDE for displaced Largemouth bass and Northern pike in the four slips during spring and summer to see if fish were preferentially selecting certain habitats. Given that Largemouth bass and Northern pike are known to prefer complex littoral habitats (Inskip 1982; Cook and Bergersen 1988; Ahrenstorff *et al.* 2009), they were expected to prefer the enhanced habitats within Spadina and Peter compared to the homogeneous habitats in Jarvis and Parliament. In fact, it is expected that areas of improved habitat quality will have a higher species richness compared to non-enhanced areas. I am hopeful that these results will help habitat scientists and resource managers understand how different species respond to such rehabilitation activities and subsequently increase the efficiency of future efforts. Given that to my knowledge this is the first study to adopt a multi-species telemetry approach to habitat restoration evaluation in aquatic systems I also provide some brief yet candid commentary on the benefits and limitations associated with this approach.

3.3 Methods

3.3.1 Field Site/ Receiver Arrays

Vemco (Vemco-Amirix Inc, Halifax, NS) Positioning System (VPS) arrays were deployed in four waterfront boat slips (Spadina, Peter, Jarvis, and Parliament) within Toronto Harbour in August 2012. Spadina, Peter, and Jarvis were each equipped with five receivers while Parliament was equipped with six receivers due to its complex configuration (Figure 3-1). Each VPS array was also equipped with a Vemco V16 non-collocated synchronization transmitters (or synctag) and a V16 synctag collocated with the middle receiver. After performing some range testing and sending the data to Vemco for analysis, the powerful V16 synctags were replaced in November 2012 with weaker V13 synctags to minimize transmitter collisions. In June 2013, three receivers were removed from Jarvis and another three receivers were removed from Parliament. Based on results provided by Vemco, 90% of positions in each of Spadina, Peter, Jarvis, and Parliament had an average horizontal position error (HPE) estimate of 2.2, 3.3, 7.0, and 3.0. (relative, unitless estimate of how sensitive a calculated position is to errors in its inputs; Smith 2013). The slips also differed to some extent in physical characteristics and configuration (see Table 3-1). The Spadina slip is situated next to the human-made Spadina Quay Wetlands (2800 m^2) and the Peter slip is connected to a back basin. All four slips had some type of overhead cover. Part of the habitat enhancement project in

Spadina consisted of the addition of overhead cover in the form of a wooden wavedeck near the back of the slip to create better fish habitat. Overhead cover in Peter was provided by the large Fire Station dock located along the eastern side of the slip entrance and by the Queens Quay West Street that crosses over the back of the slip. Although Jarvis did not have any permanent overhead cover, there was a large shipping vessel (Puffin, ~200 m in length) that was frequently docked along the western wall. Finally, Parliament had a small floating dock in the back corner of the slip.

3.3.2 Fish Collection

Fish were collected using boat electrofishing (Smith-Root electrofishing boat model SR 18.EH; 250 V and 7 A for intervals of ~1,000 seconds). Fish were mostly captured in the Toronto Islands area, Embayment C, Cell 3, and Cell 2. Most fish were released at their capture location. However, in May 2013, 10 Largemouth bass were captured near the Toronto Islands and displaced in Spadina (six) and Peter (four; Table 3-2). In addition, six Northern pike were captured in the Inner Harbour (Keating Channel, York Key, or Toronto Islands) and displaced in Spadina (three) and Peter (three; Table 3-2). Two female (Walleye 423 & Walleye 504) and two male (Walleye 472 & Walleye 545) walleye originating from the Ontario Ministry of Natural Resources White Lake Fish Culture Station (Sharbot Lake, ON) and were released in the Outer Harbour Marina post surgery.

3.3.3 Surgical Procedures

Overall, 242 fish were tagged with acoustic transmitters of varying sizes (V7, V9, V9TP, V13, V13P, and V13TP) (Vemco-Amirix) (Table 3-3). As part of a harbour-wide acoustic telemetry study, from September 2010 to July 2013, a total of 83 Largemouth bass, 74 Northern pike, 49 Common carp, 12 Walleye, 14 Brown bullhead and 10 Yellow perch were tagged at different times of year (September 2010, June 2011, May 2012, September 2012, November 2012, May 2013, and July 2013) as funds were acquired. From 2010 to 2012, fish were held in a flow-through livewell (at ambient conditions) for 1-3 hours on the boat at the point of capture. Each individual was then placed in an anesthetic bath (60 ppm of clove oil) of harbour water until their opercular rate became slow and irregular (2-6 min). After 2012 all fish, except for Northern pike, were anesthetized using a portable electroanesthesia system (PES) (Smith-Root, Inc., Vancouver, WA) (Trushenski *et al.* 2012a,b; Trushenski and Bowker 2012) (Table 3-4). Following length and wet-mass measurements, fish were placed in a V-shaped surgical cradle and supplied with a continuous flow of water (30 ppm of clove oil) for gill irrigation. Transmitters (V7, 1.4 g 7 mm diameter x 18 mm; V9, 2.9 g, 9 mm diameter x 21 mm; V9TP, 4.6 g, 9 mm diameter x 39 mm; V13, 11 g, 13 mm diameter x 36 mm; V13P, 13 g, 13 mm diameter x 48 mm; V13TP, 13 g, 13 mm diameter x 48 mm) were inserted into the body cavity through a 1-3 cm mid-ventral incision, posterior to the pelvic girdle (anterior to the pelvic girdle for Northern pike). Incisions were closed with one or two independent monofilament absorbable sutures (PDS II – 3/0) tied with a double surgeons knot; four different surgeons performed the surgeries. All surgical equipment, including the transmitter, was cleaned with iodine between each surgery and rinsed with water. The incision site was not swabbed and antibiotics were not administered. The duration of each procedure took 1:20 – 11:51 min (note – the lengthier surgeries were caused by attempts to sex fish). Fish were placed in recovery bins until they regained equilibrium (4–6 min) and released 1–2 hours after surgery.

3.3.4 Statistical Analysis

For all analyses, the non-displaced and displaced fish were treated separately given that they were used to address two different questions. Mean time per slip visit and total time spent within each slip were calculated for each individual in all slips across all seasons. Two consecutive transmissions were considered part of the same slip visit if they were detected within 30 minutes of each other. To normalize the data and reduce heteroscedasticity, all values were log transformed after being increased by a value of one. Kruskal-Wallis and multiple comparisons tests were performed in R v 3.1.0 (R Development Core Team 2013) to determine differences in mean time per slip visit and mean total time spent for displaced and non-displaced individuals of each species between the four slips during four seasons. The four seasons were defined as follows, fall: 21 September 2012 to 20 December 2012, winter: 21 December 2012 to 20 March 2013, spring: 21 March 2013 to 20 June 2013, and summer: 21 June 2013 to 20 September 2013.

KDE figures were used to visualize the spatial distribution of displaced and non-displaced fish of each species in the four slips during the four seasons (with the exception of Brown bullhead and Yellow perch due to a lack of detection data in the arrays; see results). All positions were obtained from 21 September 2012 to 20 September 2013.

Since three receivers were removed from both Jarvis and Parliament in June 2013, no summer KDE figures were plotted for these two slips. Positioning data were weighted to ensure equal contribution of each individual to the figure. In addition, KDE maps were normalized for each species to enable proper visual comparisons among slips using the figures; therefore, direct comparisons should not be made among species. KDE figures were produced using ArcMap v. 10.2 (Esri Inc.; www.esri.com) with the output cell size set to 5 m and the search radius set to 25 m for all figures.

3.4 Results

Fish Habitat Use

Overall, species richness (assessed solely from telemetry data using the six species of tagged fish) among slips was relatively low across all seasons (i.e., 1/6 – 4/6 species) (Table 3-5). This is likely a result of the small portion (11%) of the total number of tagged fish that visited the slips voluntarily; 1/73 Largemouth bass, 17/68 Northern pike, 10/49 Common carp, 7/12 Walleye, 0/14 Brown bullhead, and 0/10 Yellow perch.

Largemouth bass were never present in Spadina, Peter or Jarvis and only one individual was found in Parliament during spring. There is no evidence to support that Largemouth bass spent more time per slip visit or more time in total in Parliament compared to the other slips during the spring (χ^2=3.00, DF=3, P=0.392, Figure 3-2, χ^2=3.00, DF=3, P=0.392, Figure 3-3, respectively). The sole non-displaced Largemouth bass detected in the slips was located in the back corner of Parliament during spring, possibly due to the available overhead cover (Figure 3-4).

During the fall and winter, Northern pike spent different amounts of time per slip visit in the different slips and also spent significantly different amounts of time in total across the four slips (fall; χ^2=17.48, DF=3, P<0.001, Figure 3-2, χ^2=17.65, DF=3, P<0.001, Figure 3-3, respectively; winter; χ^2=13.48, DF=3, P=0.004, χ^2=13.78, DF=3, P=0.003, respectively). However, further analysis of multiple comparisons after the Kruskal-Wallis test failed to reveal specific differences among slips. During the spring, Northern pike spent significantly more time per slip visit in Spadina compared to Jarvis & Parliament (χ^2=19.15, DF=3, P<0.001) and also spent significantly more time in total in Spadina and Peter compared to Jarvis and Parliament (χ^2=26.03, DF=3, P<0.001). During summer, Northern pike did not spent different amounts of time per slip visit in the different slips or different amounts of time in total across the four slips (χ^2=3.88, DF=3, P=0.274, χ^2=5.04, DF=3, P=0.169, respectively).

Northern pike used the enhanced habitat located at the back of the Spadina slip during fall, the entrance of the slip during winter, the entire slip with a preference for the center during spring, and the entire slip during summer (Figure 3-5). During all seasons, individuals appeared to used the back of Peter; specifically the back eastern corner during winter. Northern pike were not present in Jarvis during the fall and had no specific habitat preferences within the slip during winter and spring. Finally, Northern pike were only present in Parliament during the spring and were mainly found at the back and the center of the slip.

Common carp were not present in any of the slips during winter. There is no evidence to support that Common carp spent different amounts of time per slip visit in the different slips and different amounts of time in total across the four slips during fall

(χ^2=3.80, DF=3, P=0.284, Figure 3-2, χ^2=3.81, DF=3, P=0.283, Figure 3-3, respectively), spring (χ^2=6.14, DF=3, P=0.105, χ^2=5.09, DF=3, P=0.166, respectively), and summer (χ^2=1.77, DF=3, P=0.621, χ^2=3.94, DF=3, P=0.267, respectively).

Common carp used the enhanced habitat located at the back of the Spadina slip during fall and remained near the eastern side of the entrance during spring and summer (Figure 3-6). Fish were using the entirety of the Peter slip during fall, spring, and summer with an apparent preference for the back and the entrance of the slip. Individuals were only present in Jarvis during the spring and were found along the western side, possibly hiding under the moored vessel. Finally, they used the western side of Parliament during fall and aggregated in the back corner near a small dock during spring.

There is no evidence to support that Walleye spent different amounts of time per slip visit in the different slips and different amounts of time in total across the four slips during fall (χ^2=2.41, DF=3, P=0.491, Figure 3-2, χ^2=2.59, DF=3, P=0.459, Figure 3-3, respectively), winter (χ^2=0.67, DF=3, P=0.881, χ^2=0.80, DF=3, P=0.849, respectively), and summer (χ^2=2.12, DF=3, P=0.548, χ^2=2.19, DF=3, P=0.533, respectively). During spring, Walleye spent different amounts of time per slip visit in the different slips (χ^2=7.93, DF=3, P=0.047). However, further analysis of multiple comparisons after the Kruskal-Wallis test failed to reveal specific differences among slips. In addition, there is no evidence to support that Walleye spent different amounts of time in total across the four slips during spring (χ^2=7.76, DF=3, P=0.051).

Walleye were absent from Spadina during the fall, appeared to prefer the entrance of the slip during winter and summer, and used the entire slip during spring (Figure 3-7). Individuals used the western side of the Peter slip during fall, the eastern side near the entrance during winter, the entire slip during spring, and the back corner during summer. Walleye remained near the entrance of Jarvis during fall, and used the entirety of the slip during winter and spring. Finally, they used the entire Parliament slip during fall, winter and spring, with most detections occurring in the back corner near a small dock.

Displacement Experiment

On average, Largemouth bass released in Spadina remained in their release slip for 3.05 hours (ranging from 0.4 to 12.9 hours) before leaving (Table 3-2). During spring, these individuals spent on average 9.78 hours (ranging from 1.1 to 30.1 hours) in Spadina, 18.68 hours (ranging from 1.3 to 74.9 hours) in Peter, and 1.5 hours in Jarvis. During summer, these individuals spent on average 1.85 hours (ranging from 0.9 to 2.8 hours) in Spadina and 3.5 hours in Peter. Three out of these six displaced Largemouth bass returned to their capture location (Toronto Islands) within three weeks.

On average, Largemouth bass released in Peter remained in their release slip for 15.6 hours (ranging from 0.1 to 28.5 hours) before leaving. During spring, these individuals spent on average 62.3 hours (ranging from 40.2 to 113.2 hours) in Peter and 4.8 hours (ranging from 2.8 to 5.8 hours) in Spadina. During summer, none of the Largemouth bass that had been released in Peter were detected in the slips. Three out of these four displaced Largemouth bass returned to their capture location (Toronto Islands) within three weeks.

Displaced Largemouth bass did not show evidence of specific habitat selection within Spadina (Figure 3-8). Individuals used the entire Peter slip during spring with a preference for the back of the slip, and one individual was mostly found near the back eastern corner during summer. Finally, fish used the back eastern corner of Jarvis and the back corner of Parliament during spring. KDEs demonstrated that Largemouth bass were found in habitats with overhead cover in Spadina, Peter, and Parliament during spring.

On average, Northern pike released in Spadina remained in their release slip for 6.8 hours (ranging from 1.4 to 13.7 hours) before leaving (Table 3-2). During spring, these individuals spent on average 8.8 hours (ranging from 1.8 to 13.7 hours) in Spadina, 1.5 hours in Peter, 7.5 hours in Jarvis, and 31.95 hours (ranging from 20 to 43.9 hours) in Parliament. During summer, these individuals spent on average 2.1 hours (ranging from 1.7 to 2.4 hours) in Spadina. None of these three displaced Northern pike returned to their capture locations (Keating Channel or York Key in Inner Harbour) within six months. However, all three individuals visited the Toronto Islands within four weeks.

On average, Northern pike released in Peter remained in their release slip for 4.1 hours (ranging from 0.2 to 10.2 hours) before leaving. During spring, these individuals spent on average 18.4 hours (ranging from 0.2 to 53.1 hours) in Peter, 28.4 hours (ranging from 0.6 to 56.2 hours) in Spadina, and 1.1 hours in Jarvis. During summer, one individual spent 1.9 hours in Peter and 869.3 hours in Spadina. One out of three these displaced Northern pike returned to its capture location (Toronto Islands) within two days whereas the other two individuals did not return to their capture locations (Keating Channel and York Key in Inner Harbour) within six months. However, these two individuals visited the Toronto Islands within two weeks.

During spring, displaced Northern pike appeared to be using the entire Spadina slip (Figure 3-9). In Peter, displaced fish were mainly using the back corner and the eastern side of the entrance (which provided overhead cover). Similarly, displaced individuals appeared to be using the overhead cover provided on the western side in Jarvis and in the back corner of Parliament. During summer, displaced Northern pike were found near the entrance of Spadina and one individual was found in the center of Peter.

3.5 Discussion

Main Findings

The main objectives of this study were to determine if fish were using the enhanced habitats within the Spadina and Peter slips more often than the non-enhanced habitats in Jarvis and Parliament and to evaluate whether the two enhanced slips provided suitable habitat for Largemouth bass and Northern pike that were experimentally released into these slips. After data analysis, I determined that Northern pike was the only species that spent significantly different amounts of time among the slips. Moreover, that pattern was only evident in spring. Based on these telemetry-derived results, it is apparent that the enhanced habitat in Spadina and Peter was only preferred by one of the six study-species (Northern pike) during only one of the four seasons (spring). Furthermore, displaced Largemouth bass and Northern pike left their release slip within 29 hours and seven out of 16 individuals returned to their capture location within three weeks. This suggests that habitat enhancement efforts in Spadina and Peter did not provide substantial direct benefits in terms of habitat use by adults of six fish species throughout the year. It is possible that the enhanced habitat in Spadina and Peter might have provided suitable spawning habitat for Northern pike given that they are spring spawners (Raat 1988).

Moreover, there may have been habitat use by other life stages (e.g., juveniles) or indirect benefits (e.g., food production) that I was unable to measure here.

Fish Habitat Use

Largemouth bass are known to exhibit different seasonal habitat preferences and variable seasonal activity levels (i.e., active in warmer seasons and quiescent in colder seasons; Hanson *et al.* 2007). Tagged Largemouth bass in Toronto Harbour did not appear to actively select habitats in the slips, despite being a target species of the rehabilitation work. In fact, they were completely absent from all slips, except for one individual in Parliament during spring. This suggests that regardless of enhancement efforts, slips with hardened shorelines are not suitable habitats for Largemouth bass.

Non-displaced Northern pike were mainly present in Spadina and Peter across all seasons, but were also present in Jarvis and Parliament during winter and spring. Cook and Bergersen (1988) found that overall Northern pike preferred vegetated littoral areas, and that home-range size varied seasonally. Northern pike are known to avoid shallow open waters in the littoral zone and pelagic areas during winter (Kobler *et al.* 2008) and have been found at mean depths of 1.2 m (Ross and Winter 1981). As previously mentioned, Northern pike spent significantly more time in total in Spadina and Peter compared to Jarvis and Parliament during spring. It is unlikely that Northern pike are spawning in either slip given that their preferred spawning habitat (i.e., shallow flooded emergent vegetation; Inskip 1982; Casselman and Lewis 1996) is not available in these slips. However, Northern pike have been found spawning in deeper areas that are less optimal (Farrell *et al.* 2006). Unfortunately, these deep littoral habitats are likely ecological sinks (Farrell *et al.* 2006). Therefore, Northern pike are most likely spawning in the adjacent Spadina Quay Wetland and subsequently spilling over to Spadina and Peter. Tagged Northern pike were found to use Spadina and Peter during summer, which is consistent with findings from Kobler *et al.* (2008) who determined that some Northern pike prefer areas with submerged macrophytes and avoid pelagic areas during summer.

Interestingly, Common carp were present in the slips during all seasons except for winter. These results are in agreement with findings of other studies which concluded that Common carp tended to overwinter in deep offshore areas that did not experience winterkills (García-Berthou 2001; Penne and Pierce 2008; Bajer and Sorensen 2009). Although Common carp are known to aggregate in shallow, vegetated areas for spawning (Swee and McCrimmon 1966; Lougheed *et al.* 1998; Penne and Pierce 2008), they were found to aggregate during the spawning season in Parliament, which is considered relatively poor habitat. They might have chosen this degraded habitat during the spawning season as they have been shown to spawn in shallow hypoxic areas, presumably to exploit habitats free of predators (Bajer and Sorensen 2009). Finally, individuals were found in Spadina and Peter in summer, which is expected since they are known to prefer shallow vegetated areas during summer (Penne and Pierce 2008).

Contrary to Common carp, Walleye were quite prevalent in the slips during winter. They were, however, found in all other slips during all seasons, with the exception of Spadina during the fall. Paragamian (1989) found that Walleye preferred habitats with gravel-cobble substrates at depths of 1.3 – 1.8 m during fall and overwintered in deep pools (1.5 – 3 m). Similarly, Ross and Winter (1981) determined that Walleye preferred depths of 3.5 m during winter. Walleye were predominantly found in Peter and Parliament during the spawning season. However, it is unlikely that they spawned in these slips since Walleye are known to spawn in tributaries or offshore reefs (Olson and Scidmore 1962; Todd and Haas 1993; Strange and Stepien 2007). In addition, Walleye seek spawning habitats with flowing water and silt-free substrates to ensure that their eggs will receive sufficient levels of dissolved oxygen once deposited (Johnson 1961; Corbett and Powles 1986); habitats unlikely to be found in slips. Walleye were less prevalent in the slips during summer months since they are known to seek deeper open waters to avoid warming summer water temperatures (Schlagenhaft and Murphy 1985; Paragamian 1989; Williams 2001). However, they have been found to use rocky shoreline habitats when deeper waters became hypoxic during summer months (Schlagenhaft and Murphy 1985). Overall, Walleye were found using the four slips. However, three of the seven individuals detected in the slips originated from a fish culture station and thus may not accurately reflect the behaviour of wild Walleye.

None of the 14 tagged Brown bullheads visited the slips during the study. This is likely attributed to the fact that tagged fish were captured and released around the Toronto Islands and are known to occupy small home ranges (mean 95% minimum area polygon of 4.5-19.7 ha; Sakaris *et al.* 2005). Likewise, none of the 10 tagged Yellow perch visited the slips during the study. These fish were all captured and released in Tommy Thompson Park and are also known to occupy small home ranges (0.54-2.20 ha; Fish and Savitz 1983).

Displacement Experiment

Largemouth bass are known to occupy small home ranges (<1.4 ha) (Winter 1977) that vary seasonally (small in winter, large in summer; Warden Jr and Lorio 1975). Additionally, displaced Largemouth bass have been shown to return to their capture locations within three months when released in the spring (Richardson-Heft *et al.* 2000). In this study, six out of 10 displaced Largemouth bass returned to their capture locations within three weeks. Clearly, these results demonstrate that none of the slips provided optimal habitats for Largemouth bass, as only one tagged non-displaced individual (out of 83) visited a slip, and none of the displaced individuals spent extensive time in the slips.

In this study, displaced Northern pike left their release slip within 14 hours. However, only one out of six displaced Northern pike returned to its capture location. This is likely because Northern pike are known to either occupy large home ranges (Ross and Winter 1981) or no distinct home ranges (Diana *et al.* 1977; Cook and Bergersen 1988). Furthermore, all displaced Northern pike visited the Toronto Islands within four weeks post release, thus suggesting that the Toronto Islands may provide more preferable habitats than the slips.

Factors that Influence Fish Distribution

There are many biotic and abiotic factors that influence how fish are distributed in space and time. In this study it was only possible to evaluate general patterns of habitat use relative to four different slips with differing habitat quality. Regional geography and physical configuration of the slips may have influenced the findings. For example, Jarvis and Parliament both have homogeneous silt substrate and are also exposed to higher amounts of suspended sediments and pollution flowing from the nearby mouth of the Don River relative to the other two slips. They are also located in a more industrial area compared to Spadina and Peter; there is heavy industry (manufacturing) located along the western side of Jarvis and a Merchant's Wharf on the western side of Parliament. This area also has a high density of boat traffic associated with these industries (e.g., shipping vessels, boats for the dredging of the Keating Channel). Furthermore, these two slips are located further from the connection to Lake Ontario as well as the more "natural" habitats associated with the Toronto Islands and the Spadina Quay Wetland. A spillover effect (defined as the net emigration of fish; Harmelinvivien *et al.* 2008) might explain why both Spadina and Peter are visited by comparable numbers of fish. There is a possibility that fish are preferentially selecting the enhanced habitat within Spadina and subsequently spillover to the adjacent Peter slip (120 m apart), or conversely, it is possible that fish are attracted to enhanced habitat in Peter and subsequently spillover to Spadina. This phenomenon was demonstrated with the displaced fish. Seven out of nine individuals that were released in Spadina eventually spilled over to Peter (Table 3-2). Similarly, five out of seven individuals that were released in Peter eventually spilled over to Spadina. Interestingly, only one Largemouth bass and two Northern pike spilled over to Jarvis (1,750 m from Peter) and only two Northern pike spilled over to Parliament (2,480 m from Peter).

Habitat preferences usually differ among size classes of the same species. For example, Wanjala *et al.* (1986) found that smaller Largemouth bass (<25 cm) preferred habitats in the littoral zone with cover, intermediate-sized individuals preferred habitats in the open limnetic zone, and larger individuals (>38 cm) preferred habitats near submerged structures. Although some efforts were made in 2013 to tag juvenile Largemouth bass and Northern pike, most tagged individuals in this study were adults. Unfortunately studying within species variability was beyond the scope of this study so I am restricted to constraining my conclusions to adult fish.

Fish might have spent more time in Peter because it was connected to a small enclosed basin at the back of the slip via a small channel that crossed under Queens Quay West Street. This small embayment likely provided a warm, shallow refuge for fish. KDEs revealed that Largemouth bass and Northern pike present in Peter remained at the back of the slip near the opening of the small embayment. Interestingly, displaced and non-displaced Largemouth bass and Northern pike were concentrated in greater numbers (N=9 and N=17, respectively) near this small basin during the spawning season compared to other seasons (N≤1 and N≤7, respectively), suggesting that this area might have provided habitat during the spawning season. Conversely, Common carp and Walleye did not appear to use this small basin.

Another important factor that affects fish habitat selection is the presence of overhead cover which provides protection from predators and shade (Lewis 1969; Sechnick and Carline 1986; Smokorowski and Pratt 2007). In general, all four species found in the slips tended to seek refuge below the available overhead cover within the slips. Overhead cover was of less relevance during winter months since the slips were covered with ice.

Study Limitations and Future Research

Due to the lack of pre-rehabilitation positioning data, I was unable to determine whether the habitat enhancement in Spadina and Peter had in fact increased fish habitat use. Given my results, I can only conclude that Spadina and Peter were used more frequently by tagged adult Northern pike compared to Jarvis and Parliament. There is no way of knowing whether Spadina and Peter were always superior to Jarvis and Parliament in terms of habitat quality and therefore the habitat enhancement had no effect on fish habitat use, or whether Spadina and Peter were previously as degraded as Jarvis and Parliament and the habitat enhancement did increase fish habitat use. In addition, more replicate enhanced and non-enhanced sites as well as longer study duration could help draw more robust conclusions. Given that only a small portion (11%) of the total number of tagged fish visited the slips voluntarily (1/73 Largemouth bass, 17/68 Northern pike, 10/49 Common carp, 7/12 Walleye, 0/10 Yellow perch, 0/14 Brown bullhead), it would be interesting to examine habitat selection among the six species across the entire harbour to determine if the slips even represent important habitats. It is likely that fish prefer more natural habitats that are not surrounded by hardened shorelines (Currin *et al.* 2010).

Management Implications & Conclusions

Although it was expected that Largemouth bass and Northern pike would prefer the complex littoral habitats provided in Spadina and Peter, there was limited evidence to support the idea that the habitat enhancement work in these slips increased habitat use of adult fish tagged in this study. However, Northern pike did spend significantly more time per slip visit in Spadina than Jarvis and Parliament, and spent significantly more time in total in Spadina and Peter compared to Jarvis and Parliament during their spawning season. Unfortunately, there is no way of knowing whether Northern pike have always used these slips during the spawning season, or whether use increased after the habitat enhancement work since there is no pre-enhancement telemetry data. Furthermore, displaced Largemouth bass and Northern pike left their release slip within 29 hours and seven out of 16 individuals returned to their capture locations within three weeks. This suggests that habitat enhancement efforts in Spadina and Peter did not provide substantial direct benefits in terms of habitat use by adults of six fish species. Regardless, habitat enhancement projects have been successful in the past (Vogele and Rainwater 1975; Hoff 1991; Hunt and Annett 2002) and should therefore continue to be undertaken. Indeed, not all habitat enhancement activities have direct benefit for adult fish. For example, there may have been indirect benefits to forage fish species as well as general improvements in habitat quality. In addition, other life stages (i.e., juveniles) of the species studied here may have used the habitats such that from a population perspective, the habitat enhancement was successful.

I submit that habitat managers should be aware of native and non-native seasonal habitat requirements (including spawning, nursery, and winter habitats) of multiple species of various size classes in order to design effective habitat enhancement projects. Additionally, habitat managers should be aware of system-specific habitat requirements of species because habitat preferences may differ across systems (Hunt *et al.* 2002). Combining telemetry monitoring with other techniques such as community-level and population-level surveys (using video, electrofishing, seine net, etc.) across life stages is likely the best approach for evaluating the ecological success of enhancement activities.

3.6 Tables

Table 3-1 Physical characteristics of the four waterfront slips in Toronto Harbour. Temperature data originate from Hobo (Onset Computer Corporation, Bourner, MA) temperature data loggers.

	Spadina	**Peter**	**Jarvis**	**Parliament**
Surface area (m^2)	5,620	7,910	11,550	11,270
Maximum depth (m)	12	12	12	12
Temperature range (ºC)	0.8 – 24.1	0.2 – 22.0	0.3 – 21.3	0.6 – 22.5
Substrate/ habitat type	Silt, rocky substrate, submergent vegetation	Silt, rocky substrate, submergent vegetation	Silt	Silt
Permanent overhead cover (Yes/No)	Yes	Yes	No	Yes

Table 3-2 Slip presence, time spent (hours) before leaving the release slip, total time spent (hours) during spring and summer, and number of days until return to capture location of displaced Largemouth bass and Northern pike in the four slips after being released in either Spadina or Peter on 7-8 May 2013.

Individual	Release slip	Time spent before leaving (hours)	Total time spent in spring (hours)	Total time spent in summer (hours)	# of days until return to capture location
Bass 356	Spadina	0.4	Spadina (30.1) Peter (13.3)	Spadina (2.8) Peter (3.5)	–
Bass 385	Spadina	1.0	Spadina (1.1) Peter (2.2)	–	17
Bass 430	Spadina	0.7	Spadina (3.4) Peter (2.6)	–	–
Bass 450b	Spadina	2.2	Spadina (3.8) Peter (1.3)	Spadina (0.9)	3
Bass 453	Spadina	1.1	Spadina (1.1) Peter (74.9) Jarvis (1.5)	–	–
Bass 480b	Spadina	12.9	Spadina (19.2)	–	3
Bass 364	Peter	17.2	Peter (113.2) Spadina (5.7)	–	20
Bass 466	Peter	16.6	Peter (50.0) Spadina (2.8)	–	–
Bass 470c	Peter	0.1	Peter (40.2) Spadina (5.8)	–	18
Bass 481	Peter	28.5	Peter (45.8)	–	6
Pike 592	Spadina	5.3	Spadina (11.0) Peter (1.5)	Spadina (1.7)	–
Pike 729	Spadina	13.7	Spadina (13.7) Jarvis (7.5) Parliament (20.0)	–	–
Pike 810	Spadina	1.4	Spadina (1.8) Parliament (43.9)	Spadina (2.4)	–
Pike 635b	Peter	10.2	Peter (53.1) Spadina (56.2)	–	2
Pike 770b	Peter	2.0	Peter (2.0) Jarvis (1.1)	Peter (1.9) Spadina (869.3)	–
Pike 901	Peter	0.2	Peter (0.2) Spadina (0.6)	–	–

Table 3-3 Total number, mean length (mm), minimum and maximum lengths of fish, and type of acoustic transmitter in Toronto Harbour by year tagged. T=temperature sensor, P=pressure sensor.

		2010	2011	2012	2013
Largemouth bass	**Number**	17	18	20	28
Micropterus salmoides	**Length (mm):**				
	Mean	436	444	445	337
	SD	66	56	68	117
	Minimum	301	305	307	156
	Maximum	497	500	535	481
	Tag type	V13P, V13TP	V13TP	V13TP	V7, V9TP, V13TP
Northern pike					
Esox lucius	**Number**	17	18	20	19
	Length (mm):				
	Mean	755	740	765	691
	SD	166	135	122	159
	Minimum	476	520	556	325
	Maximum	965	964	1003	901
	Tag type	V13P, V13TP	V13TP	V13TP	V9TP, V13TP
Common carp					
Cyprinus Carpio	**Number**	17	-	20	12
	Length (mm):				555
	Mean	706	-	631	
	SD	114	-	88	50
	Minimum	340	-	470	497
	Maximum	854	-	741	677
	Tag type	V13P, V13TP	-	V13TP	V13TP
Walleye					
Sander vitreus	**Number**	-	3	7	2
	Length (mm):				
	Mean	-	655	552	523
	SD	-	21	95.5	53
	Minimum	-	635	423	485
	Maximum	-	676	703	560
	Tag type	-	V13	V13, V13TP	V13TP
Brown Bullhead	**Number**	-	-	14	-
Ameiurus nebulosus	**Length (mm):**	-	-	364	-
	Mean				
	SD	-	-	30	-
	Minimum	-	-	312	-
	Maximum	-	-	408	-
	Tag type	-	-	V13	-
Yellow perch					
Perca flavescens	**Number**	-	-	10	-
	Length (mm):	-	-		-
	Mean			230	
	SD	-	-	25	-
	Minimum	-	-	177	-
	Maximum	-	-	271	-
	Tag type	-	-	V9	-

Table 3-4 Details of fish sedations using a portable electroanesthesia system (PES) (Smith-Root, Inc., Vancouver, WA). Electrode positions were determined based on the size of the fish (efforts were made to reduce the distance between electrodes for each individual). Brown bullhead and Yellow perch were sedated with a 60 ppm clove oil bath.

Species	Voltage (V)	Frequency (Hz)	Duty cycle (%)	Shock time (sec)	Electrode position (cm)
Largemouth bass	75, 90 or 100	60, 90 or 100	25	3, 9 or 12	16 – 54
Northern pike	75	60	25	6, 9, or 12	52 - 97
Common carp	90 or 100	90 or 100	25	3	34 – 86
Walleye	75, 90 or 100	60, 90 or 100	25	3 or 6	42 – 71
Brown bullhead	NA	NA	NA	NA	NA
Yellow perch	NA	NA	NA	NA	NA

Table 3-5 Species richness among four waterfront slips across four seasons (total of 6 species: Largemouth bass, Northern pike, Common carp, Walleye, Brown bullhead, and Yellow perch)

	Fall 2012	Winter 2013	Spring 2013	Summer 2013
Spadina	2/6 (Pike, Carp)	2/6 (Pike, Walleye)	3/6 (Pike, Carp, Walleye)	3/6 (Pike, Carp, Walleye)
Peter	3/6 (Pike, Carp, Walleye)	2/6 (Pike, Walleye)	3/6 (Pike, Carp, Walleye)	3/6 (Pike, Carp, Walleye)
Jarvis	1/6 (Walleye)	2/6 (Pike, Walleye)	3/6 (Pike, Carp, Walleye)	3/6 (Pike, Carp, Walleye)
Parliament	2/6 (Carp, Walleye)	1/6 (Walleye)	4/6 (Bass, Pike, Carp, Walleye)	3/6 (Pike, Carp, Walleye)

3.7 Figures

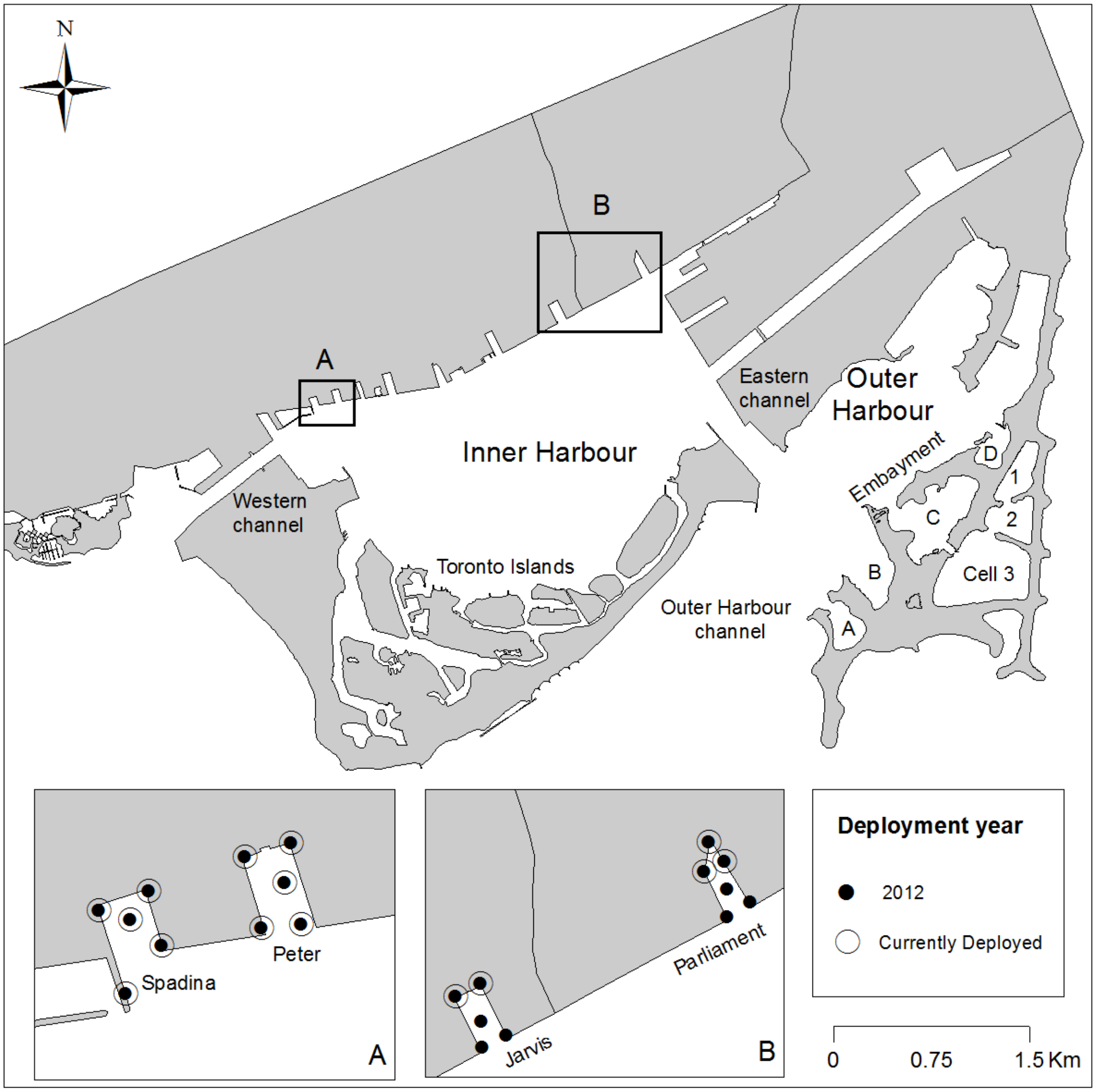


Figure 3-1 Map of Toronto Harbour acoustic telemetry array with insets of the meso-scale 2D positioning acoustic telemetry array in four waterfront slips.

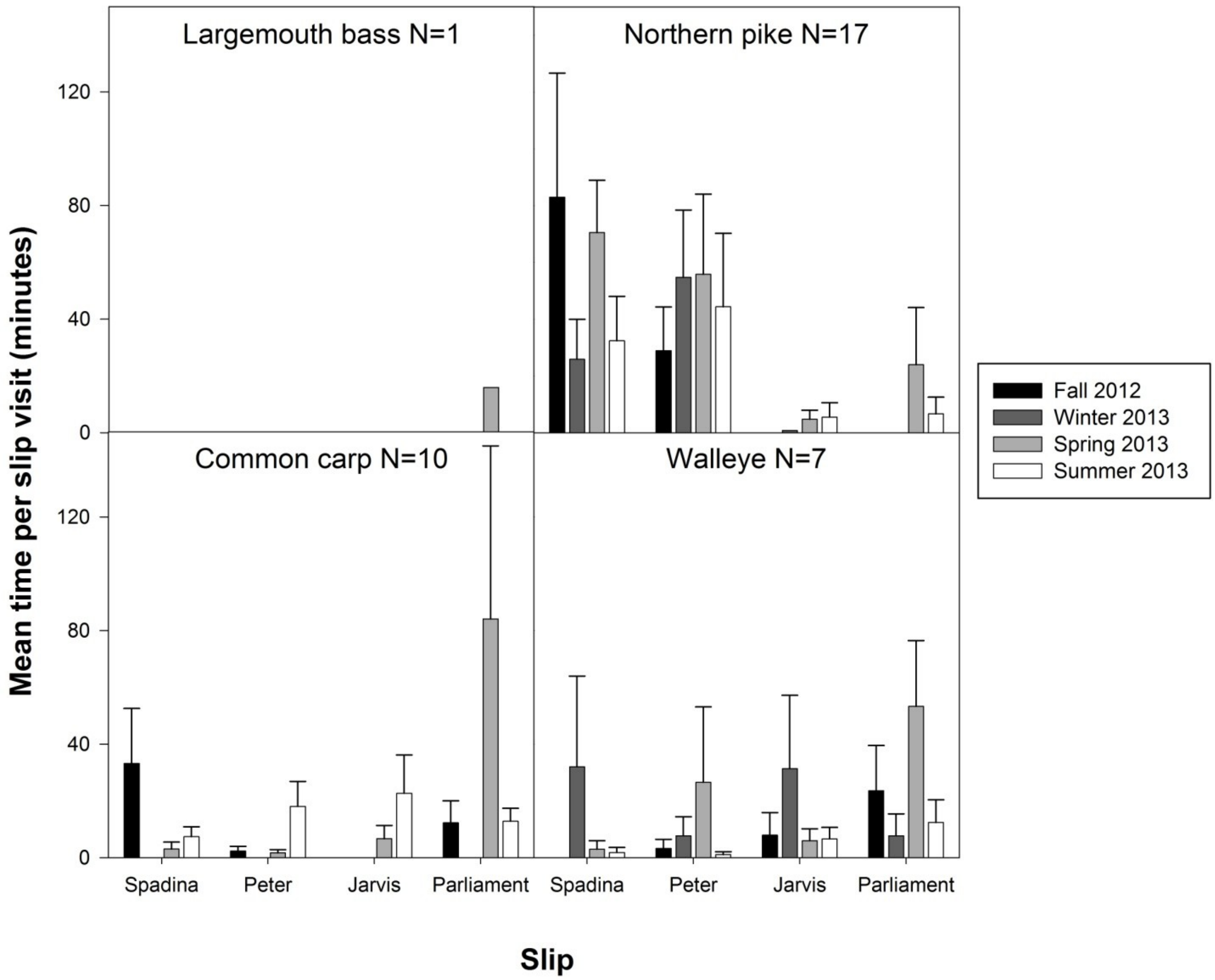


Figure 3-2 Mean time fish spent per slip visit (minutes) in four waterfront boat slips during four seasons. No Yellow perch or Brown bullhead were detected in the slips. Bars represent standard error.

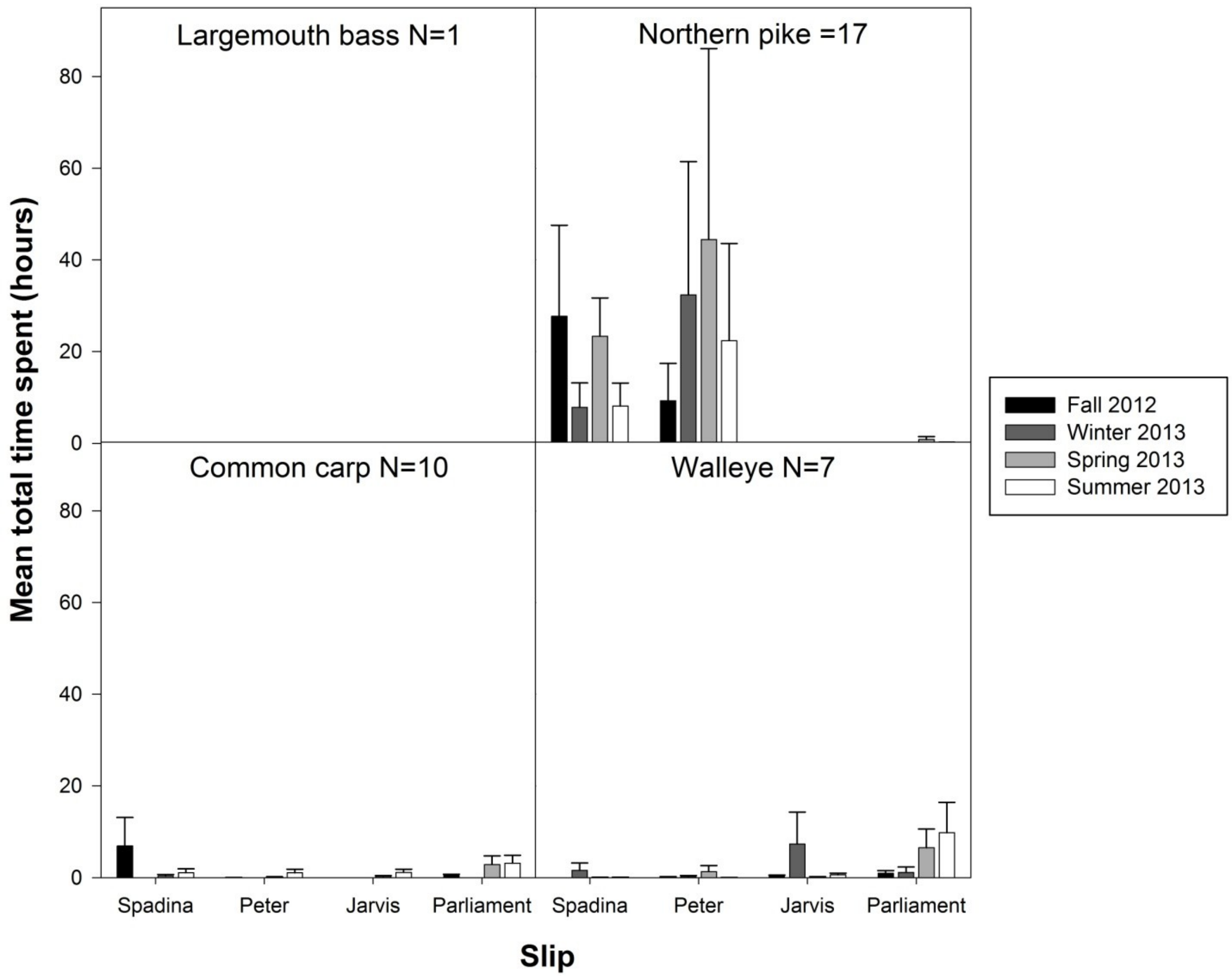


Figure 3-3 Mean total time (hours) fish spent in four waterfront boat slips during four seasons. No Yellow perch or Brown bullhead were detected in the slips. Bars represent standard error.

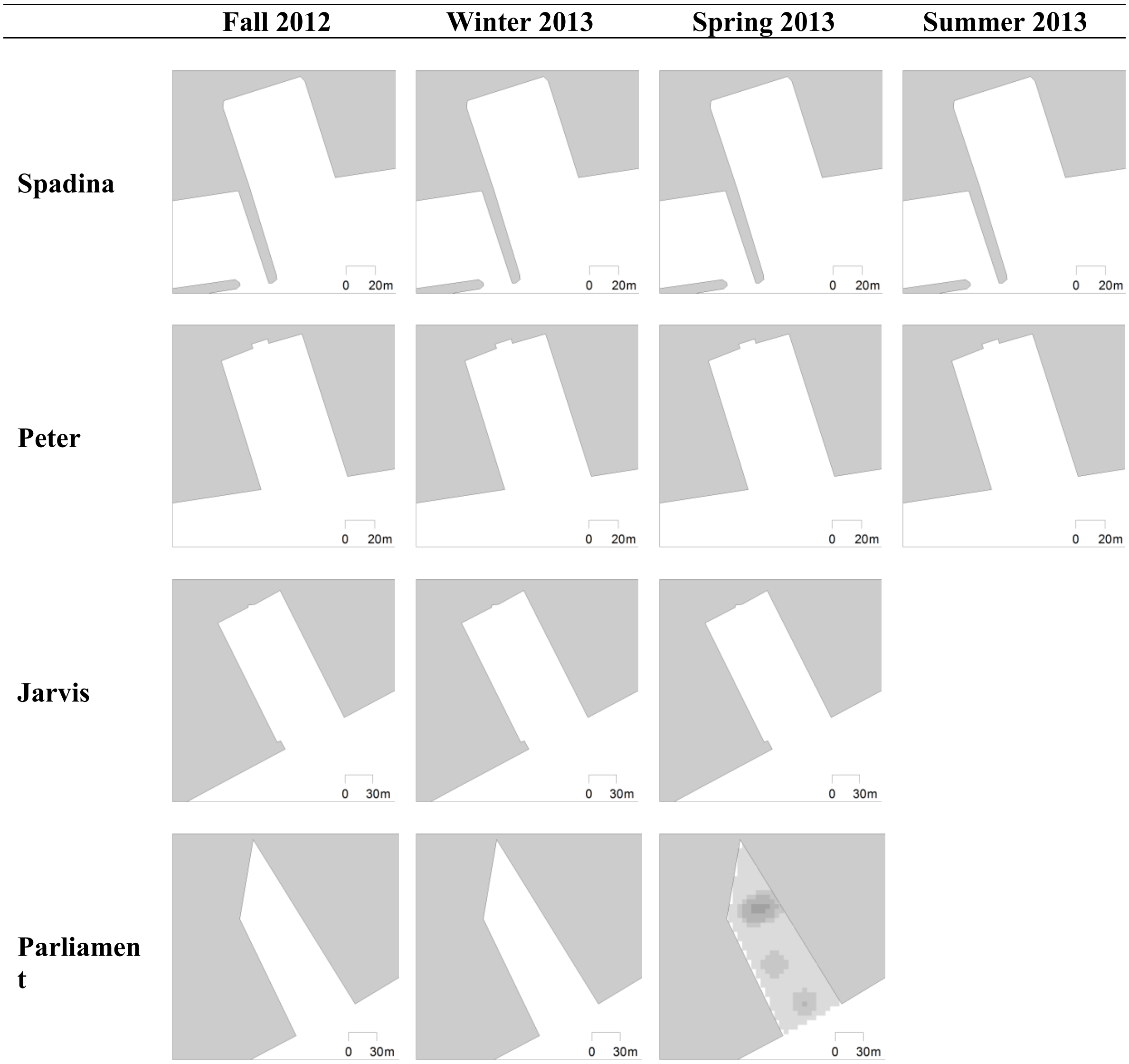


Figure 3-4 Kernel density estimates of Largemouth bass in four boat slips located in Toronto Harbour, ON, during four seasons (low KDEs are shown in light colours and high KDEs are shown in dark colours). Sample sizes from left to right: Spadina = 0, 0, 0, 0; Peter = 0, 0, 0, 0; Jarvis = 0, 0, 0; Parliament = 0, 0, 1. No meso-scale data available in Jarvis and Parliament after June 2013.

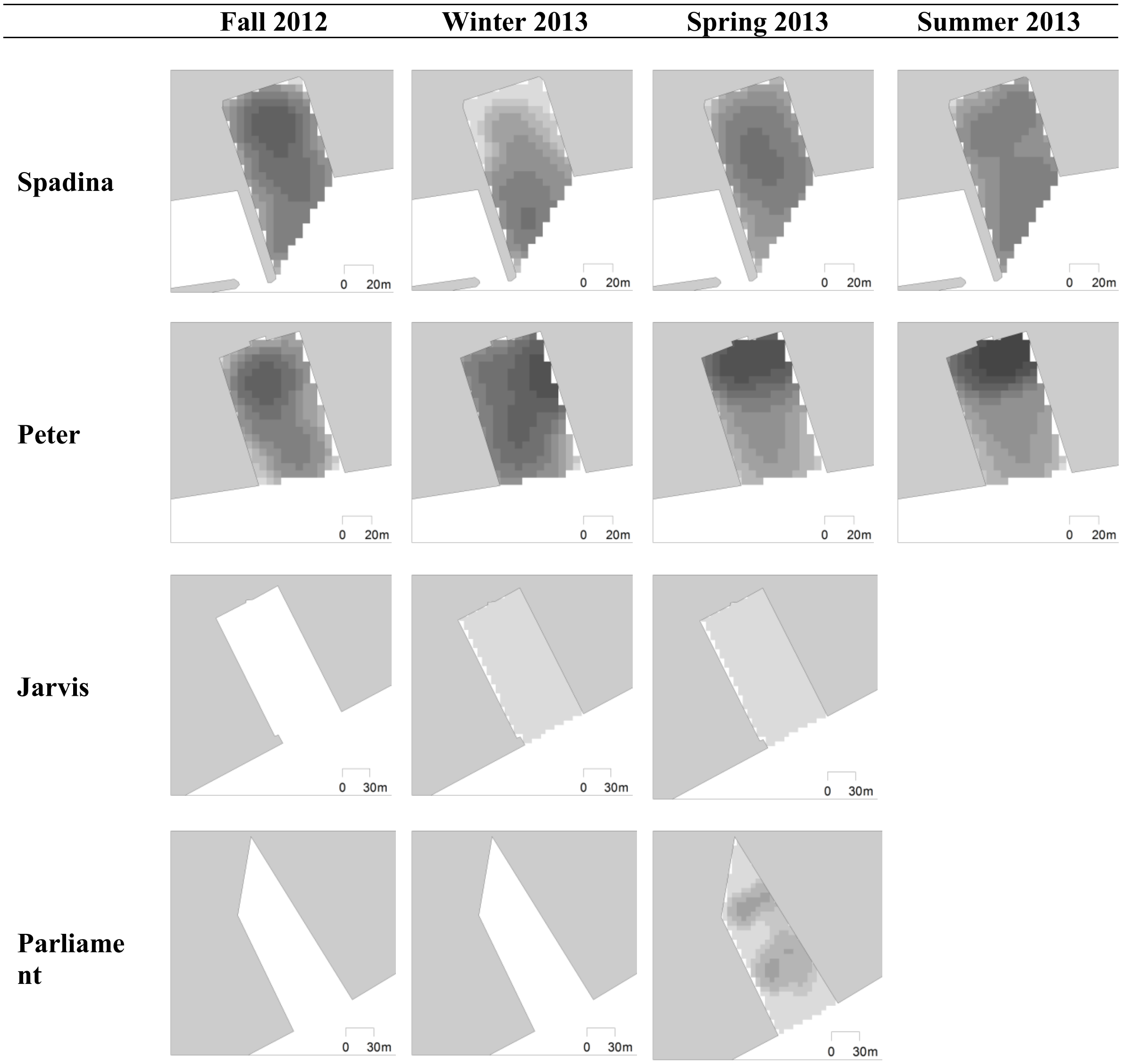


Figure 3-5 Kernel density estimates of Northern pike in four boat slips located in Toronto Harbour, ON, during four seasons (low KDEs are shown in light colours and high KDEs are shown in dark colours). Sample sizes from left to right: Spadina = 8, 6, 13, 6; Peter = 6, 7, 13, 4; Jarvis = 0, 1, 5; Parliament = 0, 0, 2. No meso-scale data available in Jarvis and Parliament after June 2013.

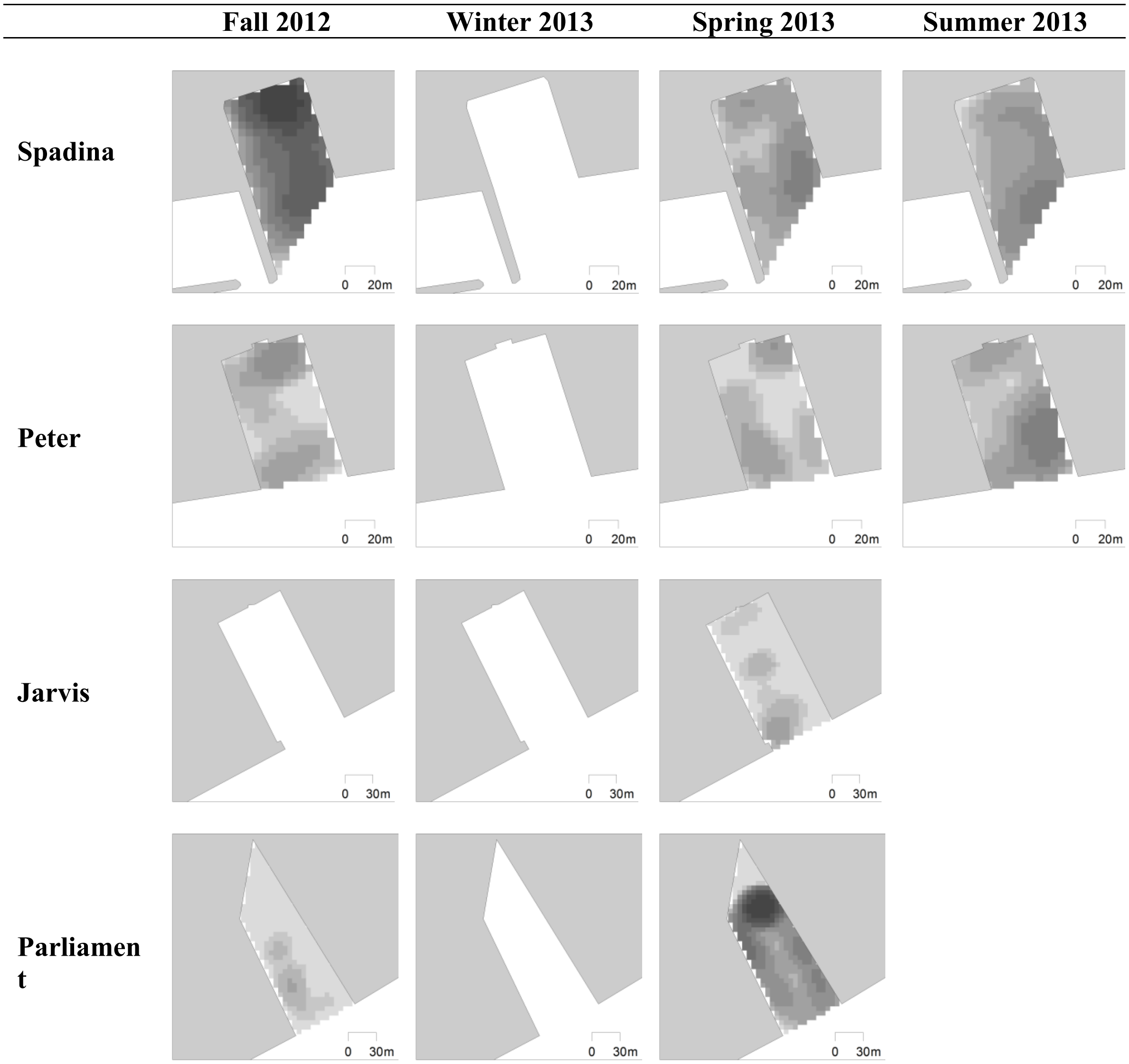


Figure 3-6 Kernel density estimates of Common carp in four boat slips located in Toronto Harbour, ON, during four seasons (low KDEs are shown in light colours and high KDEs are shown in dark colours). Sample sizes from left to right: Spadina = 3, 0, 2, 6; Peter = 2, 0, 2, 5; Jarvis = 0, 0, 1; Parliament = 3, 0, 3. No meso-scale data available in Jarvis and Parliament after June 2013.

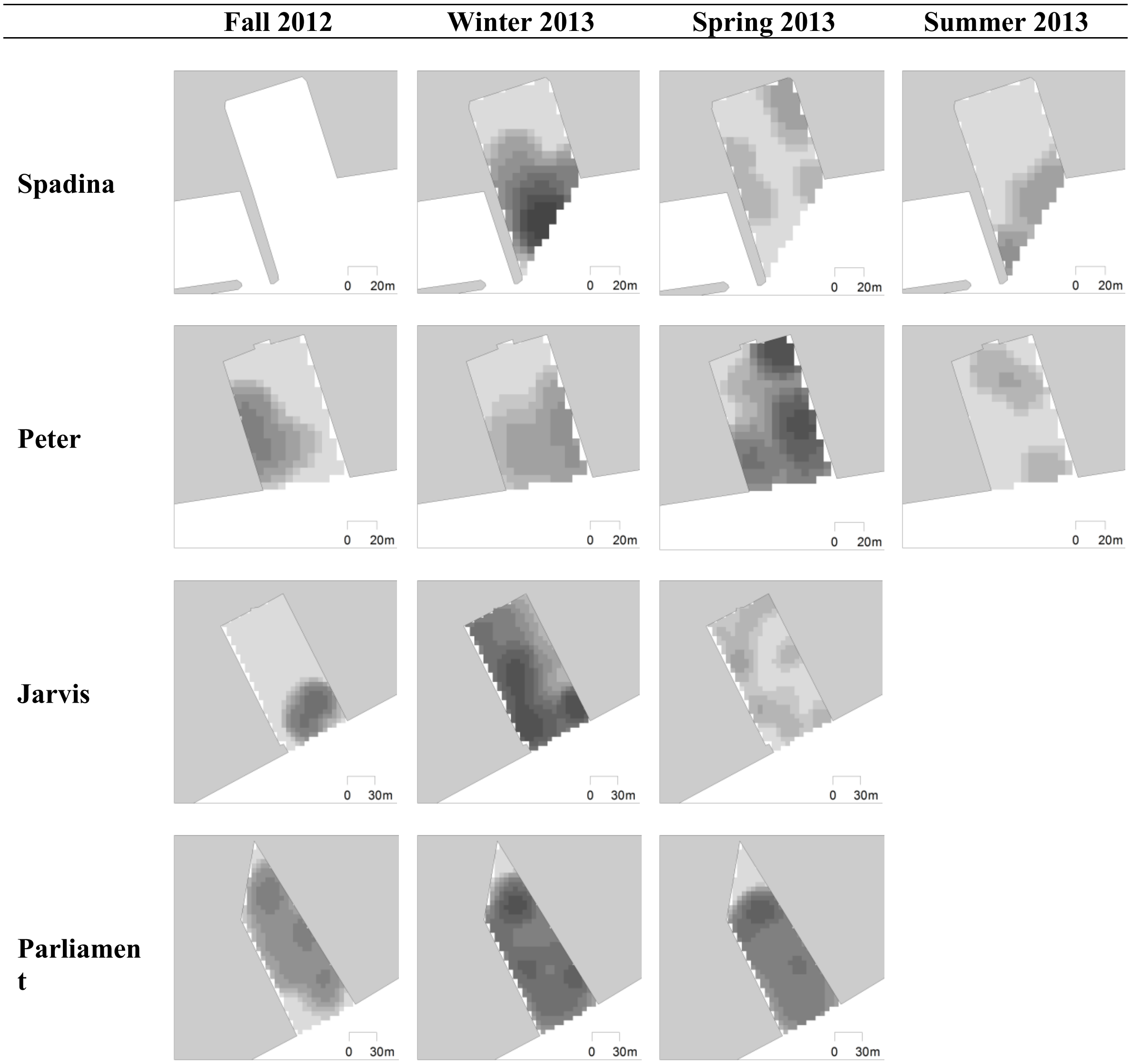


Figure 3-7 Kernel density estimates of Walleye in four boat slips located in Toronto Harbour, ON, during four seasons (low KDEs are shown in light colours and high KDEs are shown in dark colours). Sample sizes from left to right: Spadina = 0, 1, 1, 1; Peter = 1, 2, 1, 1; Jarvis = 1, 2, 2; Parliament = 2, 1, 5. No meso-scale data available in Jarvis and Parliament after June 2013.

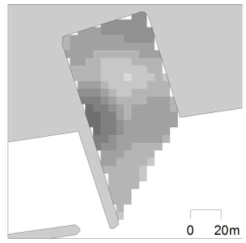
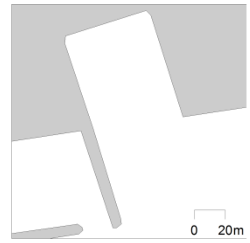
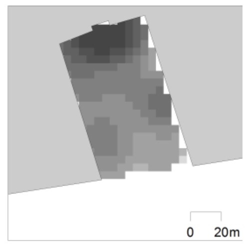
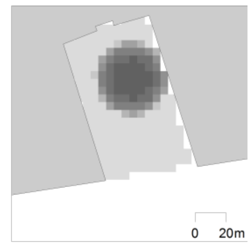
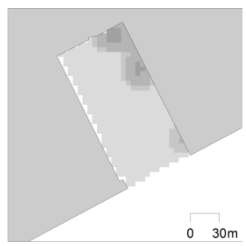
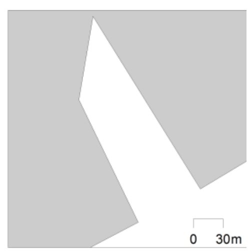
	Spring 2013	Summer 2013
Spadina		
Peter		
Jarvis		
Parliament		

Figure 3-8 Kernel density estimates of displaced Largemouth bass in four boat slips located in Toronto Harbour, ON, during four seasons (low KDEs are shown in light colours and high KDEs are shown in dark colours). Sample sizes from left to right: Spadina = 9, 0; Peter = 9, 1; Jarvis = 1; Parliament = 0. No meso-scale data available in Jarvis and Parliament after June 2013.

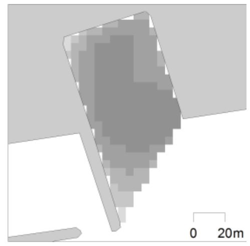
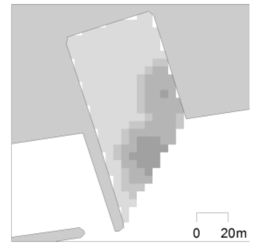
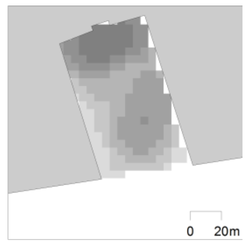
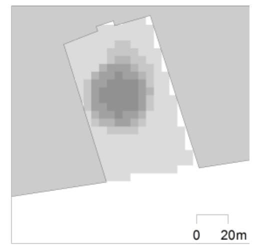
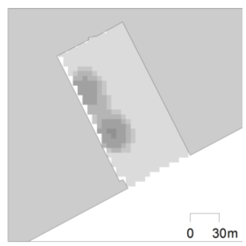
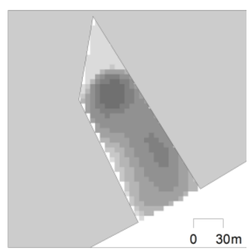
	Spring 2013	Summer 2013
Spadina		
Peter		
Jarvis		
Parliament		

Figure 3-9 Kernel density estimates of displaced Northern pike in four boat slips located in Toronto Harbour, ON, during four seasons (low KDEs are shown in light colours and high KDEs are shown in dark colours). Sample sizes from left to right: Spadina = 5, 2; Peter = 4, 1; Jarvis = 2; Parliament = 2. No meso-scale data available in Jarvis and Parliament after June 2013.

Chapter 4: General Discussion

The purpose of this thesis was to provide insight on how to use acoustic telemetry data to inform habitat management, using the Toronto Harbour AOC as a case study. Chapter 2 considered challenges of implementing a large-scale acoustic telemetry study to inform fish-habitat management, serving as a framework for future aquatic-habitat tracking studies in other locales. In Chapter 3, I assessed responses of multiple fish species to habitat enhancement in the Spadina and Peter slips compared to two non-enhanced slips to validate whether current rehabilitation activities increased fish habitat use.

4.1 Findings and Implications

Although there have been acoustic telemetry case studies in other habitats (e.g., tropical coastal marine environments (Murchie *et al.* 2012), large high-flow rivers (Steig and Holbrook 2012), and estuaries (Whoriskey 2012)), there have not been any focused on freshwater wetlands or that extend across multiple seasons including winter, and focus on habitat management. As such, the case study presented in Chapter 2 addresses an important void in the literature in that it occurs in an area that has abundant aquatic vegetation, ice cover, and extensive human and boat activity, all which constrain telemetry study design and implementation. Recommendations regarding species selection and tagging, receiver configuration and deployment, range testing and database development will help stakeholders use telemetry data to make informed decisions about habitat management.

Until now, few researchers have assessed the effectiveness of habitat rehabilitation projects using biotelemetry tools (see Lapointe *et al.* 2013 for review). Moreover, available studies rarely provide conclusive results regarding the success or failure of such rehabilitation efforts as a result of poor experimental designs. In Chapter 3, I used fine-scale acoustic telemetry to compare the average time per slip visit and the total time spent per slip of adult Largemouth bass, Northern pike, Common carp, Walleye, Yellow perch, and Brown bullhead among the enhanced and non-enhanced slips across all seasons. I also examined whether the two enhanced slips provided suitable habitat for tagged Largemouth bass and Northern pike that were experimentally released in these slips. Northern pike were found to spend significantly more time in total in the Spadina and Peter slips compared to Jarvis and Parliament during spring. In addition, displaced Largemouth bass and Northern pike left their release slip within 29 hours and seven out of 16 displaced individuals returned to their capture locations within three weeks. These results suggest that habitat enhancement efforts in Spadina and Peter did not increase habitat use of adult fish tagged in this study. However, there might have been indirect benefits to adult fish such as habitat use by other life stages, food production, and general improvements of habitat quality that we were unable to measure here. Therefore, from an ecosystemic perspective, the habitat enhancement might have been successful. When designing habitat enhancement projects, habitat managers should be aware of native and non-native seasonal habitat requirements of multiple species of various size/age classes of fish. Telemetry is considered a valid tool for management as long as the study is developed with a good experimental design and provides a long-term sustained evaluation. Overall, combining telemetry with other techniques such as community-level surveys is likely the best approach for evaluating the ecological success of habitat enhancement projects.

4.2 Conclusions

In conclusion, my results from Chapter 2 and Chapter 3 suggest that acoustic telemetry is a valuable tool to assess the success of habitat rehabilitation projects. Researcher and managers should follow recommendations provided in Chapters 2 and 3 when considering the use of large-scale acoustic telemetry arrays to evaluate the effectiveness of aquatic habitat rehabilitation efforts.

4.3 Future Directions

This thesis contributed important information on habitat use of Largemouth bass, Northern pike, Common carp, and Walleye among enhanced and non-enhanced slips across multiple seasons. This is the first step towards assessing the effectiveness of habitat enhancement work in Toronto Harbour. Unfortunately, I was unable to determine whether the habitat enhancement in the Spadina and Peter slips in fact increased fish habitat use because pre-rehabilitation data was not collected. When possible, future studies should include before and after data in addition to control and impact data (i.e., BACI design). In fact, a BACI design was developed to assess habitat enhancement efforts in Embayment D. Post-enhancement data are still being collected, and as such, analyses will be performed in the future. Pre- and post-enhancement data from Embayment D will be compared to three control sites (i.e., Embayments A, B, and C).

Results from this study should provide science advice regarding the effectiveness of habitat enhancement efforts in embayments.

Given that only a fraction of the total number of tagged fish visited the slips, it would be interesting to explore fish distributions across the harbour as a whole to determine the level of use among slips compared to other available habitats. If the slips are not considered important habitats for fish (e.g., as a result of shoreline hardening; Currin *et al.* 2010), then it might be a better investment to improve habitats that they are actually using. There are an increasing suite of biotelemetry tools including some that would work with very small species or life-stages. Doing so would extend the tool-set here to the fish community level to consider various life-stages. To get a better sense of community-level responses to habitat enhancement work, more species of fish should be tagged and monitored. In fact, we did tag some Brown bullhead (n=14) and Yellow perch (n=10) starting in the spring of 2012 but none of these individuals were found in the slips. In addition, 10 Bowfin and 10 White suckers were tagged in the spring of 2013 but were excluded from analyses since they were not present at the beginning of the study. Other species of the local community that could be tagged and monitored include: Pumpkinseed, Bluegill, Channel catfish, Smallmouth bass, Rock bass, Freshwater drum, and Gizzard shad. It would be interesting to analyze data across multiple years to see if seasonal habitat preferences remain the same through time.

As previously mentioned, various environmental factors (e.g., temperature, dissolved oxygen, turbidity, pH, water currents) can play important roles in fish distributions and habitat selection. It would therefore be interesting to integrate positioning data with these environmental factors. Fortunately, our collaborators have been collecting temperature data in the slips since the beginning of the project, but those data are not yet available. Future efforts should focus on the collection of environmental data, and exploring their effects on fish distributions.

Literature Cited

Ahrenstorff, T.D., Sass, G.G. and Helmus, M.R. (2009) The influence of littoral zone coarse woody habitat on home range size, spatial distribution, and feeding ecology of largemouth bass (Micropterus salmoides). *Hydrobiologia* **623**, 223–233.

Bajer, P.G. and Sorensen, P.W. (2009) Recruitment and abundance of an invasive fish, the common carp, is driven by its propensity to invade and reproduce in basins that experience winter-time hypoxia in interconnected lakes. *Biological Invasions* **12**, 1101–1112.

Baktoft, H., Aarestrup, K., Berg, S., et al. (2012) Seasonal and diel effects on the activity of northern pike studied by high-resolution positional telemetry. *Ecology of Freshwater Fish* **21**, 386–394.

Benayas, J.M.R., Newton, A.C., Diaz, A. and Bullock, J.M. (2009) Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. *Science* **325**, 1121–1124.

Bowker, J. and Trushenski, J. (2013) Fish drug questions answered by the FDA. *Fisheries* **38**, 549–552.

Bridger, C.J. and Booth, R.K. (2003) The effects of biotelemetry transmitter presence and attachment procedures on fish physiology and behavior. *Reviews in Fisheries Science* **11**, 13–34.

Brownscombe, J.W., Bower, S.D., Bowden, W., Nowell, L., Midwood, J.D., Johnson, N. and Cooke, S.J. (2014) Canadian recreational fisheries: 35 years of social, biological, and economic dynamics from a national survey. *Fisheries* **39**, 251–260.

Casselman, J.M. (1978) Effects of environmental factors on growth, survival, activity, and exploitation of northern Pike. *American Fisheries Society Special Publication 11* **11**, 114–128.

Casselman, J.M. and Lewis, C.A. (1996) Habitat requirements of northern pike (Esox lucius). *Canadian Journal of Fisheries and Aquatic Sciences* **53**, 161–174.

Chow-fraser, P. and Albert, D.A. (1999) Biodiversity investment areas, coastal wetland ecosystems: identification of “eco-reaches” of Great Lakes coastal wetlands that have high biodiversity values. In: *State of the Lake ecosystem conference 1998*. .

Cook, M.F. and Bergersen, E.P. (1988) Movements , habitat selection , and activity periods of northern pike in Eleven Mile Reservoir , Colorado. *Transactions of the American Fisheries Soctiety* **117**, 495–502.

Cooke, S., Hinch, S., Lucas, M. and Lutcavage, M. (2012) Biotelemetry and biologging. In: *Fisheries Techniques*. (eds A. Zale, D. Parrish and T. Sutton), Third. American Fisheries Society, Bethesda, Md, pp 819–860.

Cooke, S. and Thorstad, E.B. (2012) Is radio telemetry getting washed downstream? The changing role of radio telemetry in studies of freshwater fish relative to other tagging and telemetry technology. *American Fisheries Society Symposium* **76**, 1–22.

Cooke, S.J., Graeb, B.D.S., Suski, C.D. and Ostrand, K.G. (2003) Effects of suture material on incision healing, growth and survival of juvenile largemouth bass implanted with miniature radio transmitters: case study of a novice and experienced fish surgeon. *Journal of Fish Biology* **62**, 1366–1380.

Cooke, S.J., Midwood, J.D., Thiem, J.D., et al. (2013a) Tracking animals in freshwater with electronic tags: past, present and future. *Animal Biotelemetry* **1**, 1–19.

Cooke, S.J., Nguyen, V.M., Murchie, K.J., et al. (2013b) To tag or not to Tag: animal welfare, conservation, and stakeholder considerations in fish tracking studies that use electronic tags. *Journal of International Wildlife Law & Policy* **16**, 352–374.

Cooke, S.J., Niezgoda, G.H., Hanson, K., Suski, C.D., Phelan, F.J.S., Tinline, R. and Philipp, D.P. (2005) Use of CDMA Acoustic Telemetry to Document 3-D Positions of Fish : Relevance to the Design and Monitoring of Aquatic Protected Areas. *Marine Technology Society Journal* **39**, 17–27.

Cooke, S.J. and Suski, C.D. (2008) Ecological Restoration and Physiology: An Overdue Integration. *BioScience* **58**, 957–968.

Cooke, S.J., Woodley, C.M., Brad Eppard, M., Brown, R.S. and Nielsen, J.L. (2011) Advancing the surgical implantation of electronic tags in fish: a gap analysis and research agenda based on a review of trends in intracoelomic tagging effects studies. *Reviews in Fish Biology and Fisheries* **21**, 127–151.

Corbett, B.W. and Powles, P.M. (1986) Spawning and larva drift of sympatric walleyes and white suckers in an Ontario stream. *Transactions of the American Fisheries Society* **115**, 41–46.

Coyne, M.S. and Godley, B.J. (2005) Satellite Tracking and Analysis Tool (STAT): an integrated system for archiving , analyzing and mapping animal tracking data. *Marine Ecology Progress Series* **301**, 1–7.

Crowder, L.B. and Cooper, W.E. (1982) Habitat structural complexity and the interaction between bluegills and their prey. *Ecology*, 1802–1813.

Currin, C.A., Chappell, W.S. and Deaton, A. (2010) Developing alternative shoreline armoring strategies: the living shoreline approach in North Carolina. *Puget Sound*

Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop, 91–102.

D'Anna, G., Giacalone, V.M., Pipitone, C. and Badalamenti, F. (2011) Movement pattern of white seabream, Diplodus sargus (L., 1758) (Osteichthyes, Sparidae) acoustically tracked in an artificial reef area. *Italian Journal of Zoology* **78**, 255–263.

Danz, N.P., Niemi, G.J., Regal, R.R., et al. (2007) Integrated measures of anthropogenic stress in the U.S. Great lakes basin. *Environmental management* **39**, 631–47.

Dean, M.J., Hoffman, W.S., Zemeckis, D.R. and Armstrong, M.P. (2014) Fine-scale diel and gender-based patterns in behaviour of Atlantic cod (Gadus morhua) on a spawning ground in the Western Gulf of Maine. *ICES Journal of Marine Science: Journal du Conseil*, 1–16.

Diana, J.S., Mackay, W.C. and Ehrman, M. (1977) Movements and habitat preference of northern pike (Esox lucius) in Lac Ste . Anne , Alberta. *Transactions of the American Fisheries Society* **106**, 560–565.

Doherty, C.A., Curry, R.A. and Munkittrick, K.R. (2010) Doherty , Chad A ., R . Allen Curry , and Kelly R . Munkittrick . " Spatial and temporal movements of white sucker : implications for use as a sentinel species ." Transactions of the American Fisheries. *Transactions of the American Fisheries Soctiety* **139**, 2010.

Domeier, M.L. (2005) Methods for the deployment and maintenance of an acoustic tag tracking array: an example from California' s Channel Islands. *Marine Technology Society Journal* **39**, 74–80.

Dudgeon, D., Arthington, A.H., Gessner, M.O., et al. (2006) Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological reviews* **81**, 163–182.

Eklöv, P. (1997) Effects of habitat complexity and prey abundance on the spatial and temporal distributions of perch (Perca fluviatilis) and pike (Esox lucius). *Canadian Journal of Fisheries and Aquatic Sciences* **54**, 1520–1531.

Enders, E.C., Smokorowski, K.E., Pennell, C.J., Clarke, K.D., Sellars, B. and Scruton, D. a. (2007) Habitat use and fish activity of landlocked Atlantic salmon and brook charr in a newly developed habitat compensation facility. *Hydrobiologia* **582**, 133–142.

Espinoza, M., Farrugia, T.J. and Lowe, C.G. (2011a) Habitat use, movements and site fidelity of the gray smooth-hound shark (Mustelus californicus Gill 1863) in a newly restored southern California estuary. *Journal of Experimental Marine Biology and Ecology* **401**, 63–74.

Espinoza, M., Farrugia, T.J., Webber, D.M., Smith, F. and Lowe, C.G. (2011b) Testing a new acoustic telemetry technique to quantify long-term, fine-scale movements of aquatic animals. *Fisheries Research* **108**, 364–371.

Farrell, J.M., Mead, J.V. and Murry, B.A. (2006) Protracted spawning of St Lawrence River northern pike (Esox lucius): simulated effects on survival, growth, and production. *Ecology of Freshwater Fish* **15**, 169–179.

Farrugia, T.J., Espinoza, M. and Lowe, C.G. (2011) Abundance, habitat use and movement patterns of the shovelnose guitarfish (Rhinobatos productus) in a restored southern California estuary. *Marine and Freshwater Research* **62**, 648–657.

Fish, P.A. and Savitz, J. (1983) Variations in home ranges of largemouth bass, yellow perch, bluegills, and pumpkinseeds in an Illinois lake. *Transactions of the American Fisheries Society* **112**, 147–153.

Ford, J. (1989) The effects of chemical stress on aquatic species composition and community structure. In: *Ecotoxicology: problems and approaches*. Springer New York, pp 99–144.

García-Berthou, E. (2001) Size- and depth-dependent variation in habitat and diet of the common carp (Cyprinus carpio). *Aquatic Sciences* **63**, 466–476.

Gent, R. (Iowa D. of N.R., Pitlo, J.J. (Iowa D. of N.R. and Boland, T.I.D. of N.R. (1995) Largemouth bass response to habitat and water quality rehabilition in a backwater of the upper Mississippi River. *North American Journal of Fisheries Management* **15**, 784–793.

Gjelland, K.Ø. and Hedger, R.D. (2013) Environmental influence on transmitter detection probability in biotelemetry: developing a general model of acoustic transmission. *Methods in Ecology and Evolution*, 1–25.

Goodfellow, M. and Goodfellow, P. (2012) *A Guidebook to Contemporary Architecture in Toronto*. Douglas & McIntyre.

Governments, of C. and the U. (2009) Nearshore areas of the Great Lakes. 1–112 pp.

Gowan, C. and Fausch, K.D. (1996) Mobile brook trout in two high-elevation Colorado streams : re-evaluating the concept of restricted movement. *Canadian Journal of Fisheries and Aquatic Sciences* **53**, 1370–1381.

Great Lakes Regional Collaboration (2005) Great Lakes regional collaboration strategy to restore and protect the Great Lakes. 1–70 pp.

Hanson, K.C., Cooke, S.J., Suski, C.D., Niezgoda, G., Phelan, F.J.S., Tinline, R. and Philipp, D.P. (2007) Assessment of largemouth bass (Micropterus salmoides) behaviour and activity at multiple spatial and temporal scales utilizing a whole-lake telemetry array. *Hydrobiologia* **582**, 243–256.

Harmelinvivien, M., Ledireach, L., Baylesempere, J., et al. (2008) Gradients of abundance and biomass across reserve boundaries in six Mediterranean marine protected areas: Evidence of fish spillover? *Biological Conservation* **141**, 1829–1839.

Heithaus, M.R., Dill, L.M., Marshall, G.J. and Buhleier, B. (2002) Habitat use and foraging behavior of tiger sharks (Galeocerdo cuvier) in a seagrass ecosystem. *Marine Biology* **140**, 237–248.

Herrick, J.E., Schuman, G.E. and Rango, A. (2006) Monitoring ecological processes for restoration projects. *Journal for Nature Conservation* **14**, 161–171.

Heupel, M.R., Reiss, K.L., Yeiser, B.G. and Simpfendorfer, C.A. (2008) Effects of biofouling on performance of moored data logging acoustic receivers. *Limnology and Oceanography: Methods* **6**, 327–335.

Heupel, M.R., Semmens, J.M. and Hobday, A.J. (2006) Automated acoustic tracking of aquatic animals : scales, design and deployment of listening station arrays. *Marine and Freshwater Research* **57**, 1–13.

Heupel, M.R. and Webber, D.M. (2012) Trends in acoustic tracking: where are the fish going and how will we follow them. *American Fisheries Society Symposium* **76**, 1–14.

Hobbs, R.J. and Harris, J.A. (2001) Restoration ecology: repairing the Earth ' s ecosystems in the new millennium. *Restoration Ecology* **9**, 239–246.

Hoekstra, J.M., Boucher, T.M., Ricketts, T.H. and Roberts, C. (2005) Confronting a biome crisis: global disparities of habitat loss and protection. *Ecology Letters* **8**, 23–29.

Hoff, M.H. (1991) Effects of increased nesting cover on nesting and reproduction of smallmouth bass in northern Wisconsin lakes. In: *Proceedings of the first international smallmouth bass symposium*, Vol. 1. (ed D.C. Jackson). Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, pp 39–43.

Holmlund, C.M. and Hammer, M. (1999) Ecosystem services generated by fish populations. *Ecological Economics* **29**, 253–268.

Hunt, J. and Annett, C.A. (2002) Effects of habitat manipulation on reproductive success of individual largemouth bass in an Ozark reservoir. *North American Journal of Fisheries Management* **22**, 1201–1208.

Hunt, J., Bacheler, N., Wilson, D. and Videan, E. (2002) Enhancing Largemouth bass spawning, behavioral and habitat considerations. *American Fisheries Society Symposium* **31**, 277–290.

Inskip, P.D. (1982) Habitat suitability index models, northern pike.pdf. 40 pp.

Jackson, L.L., Lopoukhine, N. and Hillyard, D. (1995) Ecological restoration: A definition and comments. *Restoration Ecology* **3**, 71–75.

Jackson, Z.J., Quist, M.C., Downing, J.A. and Larscheid, J.G. (2010) Common carp (Cyprinus carpio), sport fishes, and water quality: Ecological thresholds in agriculturally eutrophic lakes. *Lake and Reservoir Management* **26**, 14–22.

Jepsen, N., Koed, A., Thorstad, E.B. and Baras, E. (2002) Surgical implantation of telemetry transmitters in fish : how much have we learned ? In: *Aquatic Telemetry*, Vol. 483. Springer Netherlands, pp 239–248.

Johnsen, P.B. and Hasler, A.D. (1977) Winter aggregations of carp (Cyprinus carpio) as revealed by ultrasonic tracking. *Transactions of the American Fisheries Socitety* **106**, 1977.

Johnson, F.H. (1961) Walleye egg survival during incubation on several types of bottom in Lake Winnibigoshish , Minnesota , and connecting waters. *Transactions of the American Fisheries Society* **90**, 312–322.

Jones, M.J. and Stuart, I.G. (2007) Movements and habitat use of common carp (Cyprinus carpio) and Murray cod (Maccullochella peelii peelii) juveniles in a large lowland Australian river. *Ecology of Freshwater Fish* **16**, 2007.

Keddy, P. a., Fraser, L.H., Solomeshch, A.I., Junk, W.J., Campbell, D.R., Arroyo, M.T.K. and Alho, C.J.R. (2009) Wet and Wonderful: The World's Largest Wetlands Are Conservation Priorities. *BioScience* **59**, 39–51.

Kelso, J.R.M. (1977) Density, distribution, and movement of Nipigon Bay fishes in relation to a pulp and paper mill effluent. *Journal of the Fisheries Board of Canada* **34**, 1977.

Kelso, J.R.M. (1974) Influence of a thermal effluent on movement of brown bullhead (Ictalurus nebulosus) as determined by ultrasonic tracking. *Journal of the Fisheries Board of Canada* **31**, 1507–1513.

Kessel, S.T., Cooke, S.J., Heupel, M.R., Hussey, N.E., Simpfendorfer, C. a., Vagle, S. and Fisk, a. T. (2014) A review of detection range testing in aquatic passive acoustic telemetry studies. *Reviews in Fish Biology and Fisheries* **24**, 199–218.

Klefoth, T., Kobler, a. and Arlinghaus, R. (2008) The impact of catch-and-release angling on short-term behaviour and habitat choice of northern pike (Esox lucius L.). *Hydrobiologia* **601**, 99–110.

Kobler, a., Klefoth, T., Wolter, C., Fredrich, F. and Arlinghaus, R. (2008) Contrasting pike (Esox lucius L.) movement and habitat choice between summer and winter in a small lake. *Hydrobiologia* **601**, 17–27.

Kondolf, M.G. and Micheli, E.R. (1995) Evaluating stream restoration projects. *Environmental Management* **19**, 1–15.

Landsman, S.J., Nguyen, V.M., Gutowsky, L.F.G., et al. (2011) Fish movement and migration studies in the Laurentian Great Lakes: Research trends and knowledge gaps. *Journal of Great Lakes Research* **37**, 365–379.

Lapointe, N.W.R., Corkum, L.D. and Mandrak, N.E. (2010) Macrohabitat associations of fishes in shallow waters of the Detroit River. *Journal of fish biology* **76**, 446–66.

Lapointe, N.W.R., Thiem, J.D., Doka, S.E. and Cooke, S.J. (2013) Opportunities for Improving Aquatic Restoration Science and Monitoring through the Use of Animal Electronic-Tagging Technology. *BioScience* **63**, 390–396.

Lester, N.P., Dextrase, A.J., Kushneriuk, R.S., Rawson, M.R. and Ryan, P.A. (2004) Light and temperature: key factors affecting Walleye abundance and production. *Transactions of the American Fisheries Soctiety* **133**, 588–605.

Lewis, S.L. (1969) Physical factors influencing fish populations in pools of a trout stream. *Transactions of the American Fisheries Soctiety* **98**, 14–19.

Lindell, C. a. (2008) The Value of Animal Behavior in Evaluations of Restoration Success. *Restoration Ecology* **16**, 197–203.

Linnansaari, T., Alfredsen, K., Stickler, M., Arnekleiv, J.O.V., Harby, A. and Cunjak, R.A. (2009) Does ice matter ? Site fidelity and movements by Atlantic salmon (Salmo salar L .) parr during winter in a substrate enhanced river reach. *River Research and Applications* **25**, 773–787.

Lougheed, V.L., Crosbie, B. and Chow-fraser, P. (1998) Predictions on the effect of common carp (Cyprinus carpio) exclusion on water quality , zooplankton , and submergent macrophytes in a Great Lakes wetland. *Canadian Journal of Fisheries and Aquatic Sciences* **55**, 1189–1197.

Lowe, C.G., Topping, D.T., Cartamil, D.P. and Papastamatiou, Y.P. (2003) Movement patterns , home range , and habitat utilization of adult kelp bass Paralabrax clathratus in a temperate no-take marine reserve. *Marine Ecology Progress Series* **256**, 205–216.

Lucas, M.C. and Baras, E. (2000) Methods for studying spatial behaviour of freshwater fishes in the natural environment. *Fish and Fisheries* **1**, 283–316.

Makiguchi, Y., Nii, H., Nakao, K. and Ueda, H. (2008) Migratory behaviour of adult chum salmon, Oncorhynchus keta, in a reconstructed reach of the Shibetsu River, Japan. *Fisheries Management and Ecology* **15**, 425–433.

Mayer, T., Edsall, T. and Munawar, M. (2004) Factors affecting the evolution of coastal wetlands of the Laurentian Great Lakes: An overview. *Aquatic Ecosystem Health & Management* **7**, 171–178.

Mesing, C.L. and Wicker, A.M. (1986) Home range , spawning migrations , and homing of radio- tagged Florida largemouth bass in two central Florida lakes. *Transactions of the American Fisheries Soctiety* **115**, 286–295.

Meyer, C., Holland, K. and Papastamatiou, Y. (2007) Seasonal and diel movements of giant trevally Caranx ignobilis at remote Hawaiian atolls: implications for the design of Marine Protected Areas. *Marine Ecology Progress Series* **333**, 13–25.

Michener, W.K. (1997) Quantitatively evaluating restoration experiments: research design, statistical analysis, and data management considerations. *Restoration Ecology* **5**, 324–337.

Miller, J.R. and Hobbs, R.J. (2007) Habitat restoration — Do we know what we 're doing? *Restoration Ecology* **15**, 382–390.

Murchie, K.J., Danylchuk, A.J., Cooke, S.J., et al. (2012) Considerations for tagging and tracking fish in tropical coastal habitats: lessons from bonefish, barracuda, and sharks tagged with acoustic transmitters. In: *Telemetry techniques: a user guide for fisheries research*. (eds N.S. Adams, J.W. Beeman and J.H. Eiler). American Fisheries Society, Bethesda, Maryland, pp 389–412.

Niemi, G.J., Kelly, J.R. and Danz, N.P. (2007) Environmental indicators for the coastal region of the North American Great Lakes: introduction and prospectus. *Journal of Great Lakes Research* **33**, 1–12.

Niezgoda, G., Benfield, M., Sisak, M. and Anson, P. (2002) Tracking acoustic transmitters by code division multiple access (CDMA)-based telemetry. In: *Aquatic Telemetry*. Springer Netherlands, pp 275–286.

Olson, D.E. and Scidmore, W.J. (1962) Homing behavior of spawning walleyes. *Transactions of the American Fisheries Society* **91**, 355–361.

Paragamian, V.L. (1989) Seasonal habitat use by walleye in a warmwater river system , as determined by radiotelemetry. *North American Journal of Fisheries Management* **9**, 392–401.

Payne, N., Gillanders, B., Webber, D. and Semmens, J. (2010) Interpreting diel activity patterns from acoustic telemetry: the need for controls. *Marine Ecology Progress Series* **419**, 295–301.

Penne, C.R. and Pierce, C.L. (2008) Seasonal distribution, aggregation, and habitat selection of Common carp in Clear Lake, Iowa. *Transactions of the American Fisheries Society* **137**, 1050–1062.

Pinkney, A.E., Harshbarger, J.C., May, E.B. and Melancon, M.J. (2001) Tumor prevalence and biomarkers of exposure in brown bullheads (Ameiurus nebulosus) from the tidal Potomac River, USA, watershed. *Environmental Toxicology and Chemistry* **20**, 1196–1205.

Pirhonen, J. and Schreck, C.B. (2002) Effects of anaesthesia with MS-222, clove oil and CO2 on feed intake and plasma cortisol in steelhead trout (Oncorhynchus mykiss). *Aquaculture* **220**, 507–514.

Raat, A.J. (1988) *Synopsis of biological data on the northern pike: Esox lucius Linnaeus, 1758*. Food and Agriculture Organization of the United Nations.

Radabaugh, N.B., Bauer, W.F. and Brown, M.L. (2010) A Comparison of Seasonal Movement Patterns of Yellow Perch in Simple and Complex Lake Basins. *North American Journal of Fisheries Management* **30**, 179–190.

Reynolds, B.F., Powers, S.P. and Bishop, M.A. (2010) Application of acoustic telemetry to assess residency and movements of rockfish and lingcod at created and natural habitats in Prince William Sound. *PloS one* **5**, e12130.

Richardson-Heft, C.A., Heft, A.A., Fewladd, L. and Brandt, S.B. (2000) Movement of largemouth bass in northern Chesapeake Bay: relevance to sportfishing tournaments. *North American Journal of Fisheries Management* **20**, 493–501.

Ritcher, B.D., Braun, D.P., Mendelson, M.A. and Master, L.L. (1997) Threats to imperiles freshwater fauna. *Conservation Biology* **11**, 1081–1093.

Rogers, K.B. and White, G.C. (2007) *Analysis of movement and habitat use from telemetry data*. American Fisheries Society, Bethesda, Maryland.

Roni, P., Beechie, T.J., Bilby, R.E., Leonetti, F.E., Pollock, M.M. and Pess, G.R. (2002) A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific northwest watersheds. *Fisheries* **22**, 12–24.

Ross, M.J. and Winter, J.D. (1981) Winter movements of four fish species near a thermal plume in northern Minnesota. *Transactions of the American Fisheries Society* **110**, 14–18.

Sakaris, P.C., Jesien, R. V. and Pinkney, A.E. (2005) Brown bullhead as an indicator species : seasonal movement patterns and home ranges within the Anacostia River , Washington , DC. *Transactions of the American Fisheries Soctiety* **134**, 2005.

Sammons, S.M., Maceina, M.J. and Partridge, D.G. (2003) Changes in Behavior , Movement , and Home Ranges of Largemouth Bass Following Large-scale Hydrilla Removal in Lake Seminole , Georgia. *Journal of Aquatic Plant Management* **41**, 31–38.

Schlagenhaft, T.W. and Murphy, B.R. (1985) Habitat use and overlap between adult largemouth bass and walleye in a west Texas reservoir. *North American Journal of Fisheries Management* **5**, 465–470.

Sechnick, C.W. and Carline, R.F. (1986) Habitat selection by Smallmouth bass in response to physical characteristics of a simulated stream. *Transactions of the American Fisheries Soctiety* **115**, 314–321.

Shields, F.D., Cooper, C.., Knight, S.S. and Moore, M.. (2003) Stream corridor restoration research: a long and winding road. *Ecological Engineering* **20**, 441–454.

Simpfendorfer, C.A., Heupel, M.R. and Hueter, R.E. (2002) Estimation of short-term centers of activity from an array of omnidirectional hydrophones and its use in studying animal movements. *Canadian Journal of Fisheries and Aquatic Sciences* **59**, 23–32.

Smith, F. (2013) Understanding HPE in the VEMCO Positioning System (VPS). 1–31 pp.

Smokorowski, K.E. and Pratt, T.C. (2007) Effect of a change in physical structure and cover on fish and fish habitat in freshwater ecosystems – a review and meta-analysis. *Environmental Reviews* **15**, 15–41.

Steig, T. and Holbrook, C. (2012) Use of Acoustic Telemetry to Evaluate Survival and Behavior of Juvenile Salmonids at Hydroelectric Dams : a Case Study from Rocky Reach Dam , Columbia River , USA. In: *Telemetry techniques: a user guide for fisheries research*. (eds N.S. Adams, J.W. Beeman and J.H. Eiler). American Fisheries Society, Bethesda, Maryland, pp 361–387.

Strange, R.M. and Stepien, C.A. (2007) Genetic divergence and connectivity among river and reef spawning groups of walleye (Sander vitreus vitreus) in Lake Erie. *Canadian Journal of Fisheries and Aquatic Sciences* **64**, 437–448.

Summerfelt, R.C. and Mosier, D. (1984) Transintestinal expulsion of surgically implanted dummy transmitters by channel catfish. *Transactions of the American Fisheries Soctiety* **113**, 760–766.

Swee, B.U. and McCrimmon, H.R. (1966) Reproductive biology of the carp , Cyprinus carpio L ., in Lake St . Lawrence , Ontario. *Transactions of the American Fisheries Society* **95**, 372–380.

Thiem, J.D., Taylor, M.K., McConnachie, S.H., Binder, T.R. and Cooke, S.J. (2011) Trends in the reporting of tagging procedures for fish telemetry studies that have used surgical implantation of transmitters: a call for more complete reporting. *Reviews in Fish Biology and Fisheries* **21**, 117–126.

Titzler, S.P., McMichael, G.A. and Carter, J.A. (2010) Autonomous acoustic receiver deployment and mooring techniques for use in large rivers and estuaries. *North American Journal of Fisheries Management* **30**, 853–859.

Todd, T.N. and Haas, R.C. (1993) Genetic and tagging evidence for movement of walleyes between Lake Erie and Lake St. Clair. *Journal of Great Lakes Research* **19**, 445–452.

Traslavina, R.P. (2010) Principles of aquatic anesthesia , surgery and telemetry employed in a field study on the bowfin (Amia calva).

TRCA (2002) Tommy Thompson Park Master Plan Design Project. 1–62 pp.

TRCA (2000) Tommy Thompson Park public urban wilderness habitat creation and enhancement projects 1995-2000. 1–46 pp.

Trushenski, J.T. and Bowker, J.D. (2012) Effect of voltage and exposure time on fish response to electrosedation. *Journal of Fish and Wildlife Management* **3**, 276–287.

Trushenski, J.T., Bowker, J.D., Gause, B.R. and Mulligan, B.L. (2012a) Chemical and electrical approaches to sedation of hybrid striped bass: induction, recovery, and physiological responses to sedation. *Transactions of the American Fisheries Soctiety* **141**, 455–467.

Trushenski, J.T., Bowker, J.D., Mulligan, B.L. and Gause, B.R. (2012b) Induction, recovery, and hematological responses of largemouth bass to chemo-and electrosedation. *North American Journal of Aquaculture* **74**, 214–223.

Vandergoot, C.S., Murchie, K.J., Cooke, S.J., Dettmers, J.M., Bergstedt, R. a. and Fielder, D.G. (2011) Evaluation of two forms of electroanesthesia and carbon dioxide for short-term anesthesia in walleye. *North American Journal of Fisheries Management* **31**, 914–922.

Venables, B.J., Fitzpatrick, L.C. and Pearson, W.D. (1978) Laboratory measurement of preferred body temperature of adult largemouth bass (Micropterus salmoides). *Hydrobiologia* **58**, 33–36.

Vitousek, P.M., Mooney, H.A., Lubchenco, J. and Melillo, J.M. (1997) Human domination of Earth 's ecosystems. *Science* **277**, 494–499.

Vogele, L.E. and Rainwater, W.C. (1975) Use of brush shelters as cover by spawning black basses (Micropterus) in Bull Shoals Reservoir. *Transactions of the American Fisheries Society* **104**, 264–269.

Wagner, G.N., Cooke, S.J., Brown, R.S. and Deters, K. a. (2011) Surgical implantation techniques for electronic tags in fish. *Reviews in Fish Biology and Fisheries* **21**, 71–81.

Walker, M.K., Yanke, E.A. and Gingerich, W.H. (1994) Use of electronarcosis to immobilize juvenile and adult Northern pike. *The Progressive Fish-Culturist* **56**, 237–243.

Wanjala, B.S., Tash, J.C., Matter, W.J. and Ziebell, C.D. (1986) Food and habitat use by different sizes of largemouth bass (Micropterus salmoides) in Alamo Lake , Arizona. *Journal of Freshwater Ecology* **3**, 359–369.

Warden Jr, R.L. and Lorio, W.J. (1975) Movements of largemouth bass (Micropterus salmoides) in impounded waters as determined by underwater telemetry. *Transactions of the American Fisheries Society* **104**, 696–702.

Whillans, T.H. (1982) Changes in Marsh Area Along the Canadian Shore of Lake Ontario. *Journal of Great Lakes Research* **8**, 570–577.

Whoriskey, F.G. (2012) Ontogeny of a sonic telemetry program for Atlantic salmon Salmo salar. In: *Telemetry techniques: a user guide for fisheries research*. (eds N.S. Adams, J.W. Beeman and J.H. Eiler). American Fisheries Society, Bethesda, Maryland, pp 413–424.

Wickson, T. (2002) *Reflections of Toronto Harbour: 200 years of port activity and waterfront development*.

Williams, J.D. (2001) Walleye movement, distribution, and habitat use in Laurel River Lake, Kentucky. *Proceedings of the fifthy fith Annual Conference of the Southeastern Association of Fish and Wildlife Agencies*, 257–269.

Winter, J.D. (1977) Summer home range movements and habitat use by four largemouth bass in Mary Lake , Minnesota. *Transactions of the American Fisheries Society* **106**, 323–330.

Zamora, L. and Moreno-Amich, R. (2002) Quantifying the activity and movement of perch in a temperate lake by integrating acoustic telemetry and a geographic information system. *Hydrobiologia* **483**, 209–218.

Zedler, J.B. and Kercher, S. (2005) Wetland resources: Status, trends, ecosystem services, and restorability. *Annual Review of Environment and Resources* **30**, 39–74.