THE BEHAVIOUR OF LARGEMOUTH BASS IN LAKE OPINICON, ONTARIO: A BIOLOGICAL PERSPECTIVE FOR THE EVALUATION OF MURPHY BAY FISH SANCTUARY

by

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Abstract

This study provides a biological perspective on the potential of using year-round sanctuaries to protect largemouth bass (*Micropterus salmoides*). Although the Rideau Lakes bass sanctuaries have been present for more than 70 years, a lack of empirical rationale has resulted in a considerable debate regarding their usefulness. Using radio telemetry in Lake Opinicon, Ontario, the current study indicates that largemouth bass behaviour is influenced by the structural complexity of the habitats they occupy. In high-structure habitats, bass tend to have smaller utilization areas, displacement rates and radial displacements relative to those occupying low-structure habitats. All largemouth bass were captured and released (after transmitter implantation) in high-structure areas; however, more than half (12 of 23) of these individuals made spring (closed fishing season) relocations to low-structure areas where most (11 of 12) remained for the duration of the study. Behaviour is important to consider because of the influence it has on the level of sanctuary protection received by a largemouth bass. Twelve individuals began the study in the high-structure habitats of Lake Opinicon’s Murphy Bay fish sanctuary; however, only five remained in high-structure habitats throughout the study to receive full open season protection, two others received partial protection and four largemouth bass received no open season sanctuary protection because they made spring relocations to low-structure areas outside of the sanctuary. The results of this study provide an important biological perspective for the evaluation of year-round bass sanctuaries. Further research is needed to understand the specific causes of observed behaviours and to investigate how open and closed season protection of a year-round sanctuary translates into overall bass fishery benefits. Therefore, we recommend the maintenance of the Rideau Lakes bass sanctuaries as year-round regulations until there is sufficient empirical evidence to support their re-designation or removal.
Co-Authorship

This thesis conforms to the traditional format as outlined by the School of Graduate Studies and Research. The manuscript that is a direct result of this thesis and its coauthors are:

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<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
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<tr>
<td>APA</td>
<td>Aquatic protected area</td>
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<td>AR</td>
<td>Aspect ratio</td>
</tr>
<tr>
<td>CV</td>
<td>Likelihood method (smoothing parameter selection)</td>
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<tr>
<td>CWS</td>
<td>Coarse woody structure</td>
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<tr>
<td>DF</td>
<td>Degrees of freedom</td>
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<tr>
<td>FMZ</td>
<td>Fisheries management zone</td>
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<td>FPA</td>
<td>Freshwater protected area</td>
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<tr>
<td>GPS</td>
<td>Global positioning system</td>
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<tr>
<td>h</td>
<td>Smoothing parameter</td>
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<td>H-S</td>
<td>High-structure habitat type</td>
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<td>HB</td>
<td>Habitat use behaviour</td>
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<td>KDE/KUD</td>
<td>Kernel utilization distribution</td>
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<tr>
<td>L-S</td>
<td>Low-structure habitat type</td>
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<tr>
<td>LSCV</td>
<td>Least-squares cross-validation method (smoothing parameter selection)</td>
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<tr>
<td>MCP</td>
<td>Minimum convex polygon</td>
</tr>
<tr>
<td>MDPH</td>
<td>Minimum displacement per hour</td>
</tr>
<tr>
<td>MPA</td>
<td>Marine protected area</td>
</tr>
<tr>
<td>N</td>
<td>Number of replicates</td>
</tr>
<tr>
<td>ODGF</td>
<td>Ontario Department of Game and Fisheries</td>
</tr>
<tr>
<td>OMNR</td>
<td>Ontario Ministry of Natural Resources</td>
</tr>
<tr>
<td>p</td>
<td>Significance level</td>
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<tr>
<td>Abbreviation</td>
<td>Definition</td>
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<tr>
<td>PT</td>
<td>Pre-tracking habitat shift</td>
</tr>
<tr>
<td>QUBS</td>
<td>Queen’s University Biological Station</td>
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<tr>
<td>R²</td>
<td>Explanation of variance</td>
</tr>
<tr>
<td>SEM</td>
<td>Standard error of the mean</td>
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<tr>
<td>TL</td>
<td>Total length</td>
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<tr>
<td>VBCZ</td>
<td>Voluntary Bass Conservation Zone</td>
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<tr>
<td>WLEO</td>
<td>Warner Lake Ecological Observatory</td>
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Chapter 1

Introduction

A greater awareness of the overharvest and habitat destruction that is occurring in marine ecosystems has resulted in a focus of attention on the protected areas of the world’s oceans (Pauly et al. 1998; Jackson et al. 2001; Myers and Worm 2003). Despite considerable research and prominent global utilization of marine protected areas (MPA), their overall usefulness in fisheries management remains highly debated. Evidence of increases in biomass, density and size of species within protected areas illustrates their potential as a conservation tool (Halpern and Warner 2002; Halpern 2003; Micheli et al. 2004; Lester et al. 2009), although it remains unclear how these internal improvements translate into overall fishery benefits outside of its boundaries (Apostolaki et al. 2002; Sale et al. 2005; Lester et al. 2009).

Freshwater protected areas (FPA) are also commonly used, but have not received the same attention as MPAs. This is due in part to the fact that many global FPAs are not specifically designated and occur as incidental byproducts of large terrestrial protected areas (Keith 2000; Saunders et al. 2002; Cucherousset et al. 2007). In addition, much of the focus for FPAs relates to the protection of biodiversity within entire ecosystems or catchments (Saunders et al. 2002; Abell et al. 2007). Although resource-based FPAs that target a singles species are common (i.e. more than 600 listed in the 2010 Ontario Recreational Fishing Regulations Summary), there is a lack of research that examines their role in fisheries management. Some empirical evidence suggests that seasonal sanctuary protection may be beneficial for bass (Micropterus spp.); however, most current bass sanctuaries in Ontario are closed to fishing throughout the entire year. A large majority of these year-round bass sanctuaries can be found throughout the Rideau Lakes system.
in southeastern Ontario and were originally designated to protect largemouth bass (*M. salmoides*) over 70 years ago. Despite a longstanding presence, the role of year-round sanctuaries in bass management has not been thoroughly investigated and this has resulted in a debate over their usefulness. In November 2006, the Fish and Wildlife Branch (Fisheries Section) of the Ontario Ministry of Natural Resources (OMNR) released guidelines for bass management that included recommendations for bass sanctuaries. The proposal suggested that year-round bass sanctuaries are overly restrictive and should have a standardized date (May 15–June 30) if they are required at all. In addition to the recommendations there is recognition of the need to provide empirical rationale as the basis for any changes.

It is important to define ‘protection’ in the context of fisheries management, especially for year-round bass sanctuaries. Traditional fisheries management strategies such as size and season regulations protect a fish species during a unit of time. For example, size limits often protect a fish species during a time of its life that has the greatest potential importance to the population (i.e. larger females tend to have greater fecundity). Season regulations often protect a fish species during an important time of the year (i.e. spawning or nesting). On the other hand, creel limits attempt to protect a fish species by managing the number of individuals that are harvested from a population. Fish sanctuaries differ from these traditional strategies because they protect fish in a unit of area. In other words, fish sanctuaries are a type of spatial regulation and sanctuary protection is a form of spatial fisheries management. For largemouth bass, the specific objectives of a sanctuary are largely dependent on whether they aim to provide protection during the open or closed fishing season. Sanctuary protection can focus on the prevention of angling and harvest of adult largemouth bass during the open season, as well as incidental angling of
nesting bass during the closed season. Year-round bass sanctuaries attempt to achieve both closed and open season protection, which is a key consideration for their evaluation.

The evaluation of fisheries management has been traditionally based on population demographic models; however, this approach is largely ineffective for protected areas because these models do not adequately consider the behaviour of the target species (Babcock et al. 2005). Therefore, a behavioural perspective can provide an understanding of how an area can provide protection to the target species (Kramer and Chapman 1999; Griffiths and Wilke 2002) and is now considered to be an essential component in the design of protected areas (Roberts and Sargant 2002).

Many previous studies have examined largemouth bass movement and utilization of space; however, most research has occurred in tropical (or subtropical) regions, examined resource manipulation or focused on winter activity. In addition, many recent studies have occurred on small, private lakes with a low level of anthropogenic disturbance. Our research utilized radio telemetry to examine the behaviour and utilization of space by largemouth bass in Lake Opinicon, Ontario. This information was subsequently used to evaluate the open fishing season use of Lake Opinicon’s Murphy Bay fish sanctuary, as well as the overall potential of bass sanctuary protection. The investigation of largemouth bass behaviour within a lake that has a pre-existing bass sanctuary provides direct biological insight to be used during the evaluation and potential re-designation of Ontario’s bass sanctuaries.
Chapter 2

Literature Review

Driven by social and economic forces, mismanaged fishing has the potential to negatively impact fish populations. This can be observed in many marine stocks that have been overexploited or have collapsed in response to commercial fishing (Hutchings 2000; Jackson et al. 2001). Traditional fisheries management is often based on a single-species framework that uses stock assessments to determine a sustainable level of harvest (Beddington et al. 2007; Pitchford et al. 2007). Fishery stock assessments have become more sophisticated in recent years; however, resource mismanagement and overexploitation still occurs due to a high level of uncertainty (Botsford et al. 1997). Illegal harvest, incidental bycatch, insufficient stock data, environmental fluctuation and other factors contribute to stock assessment uncertainty (Pitchford et al. 2007).

2.1 Ecosystem-based Management

In recent years, multi-species and ecosystem-based models have been suggested as a potential solution to the uncertainty associated with traditional fisheries management (Agardy 2000; Roberts and Sargant 2002; Gell and Roberts 2003; Pikitch et al. 2004). These models focus on a more comprehensive consideration of ecological interactions that result in the management of ecosystems in addition to fishery yields (Babcock and Pikitch 2004). These approaches have theoretical advantages over single-species management; however, accurate modeling of the appropriate interactions often results in a similar level of uncertainty (Botsford et al. 1997).
APAs have been suggested as an ecosystem-based management approach because they attempt to protect the target species and their entire ecosystem within a unit of space. In other words, a protected area that targets a single species will also include protection for other species and habitats within its protective boundaries (Botsford et al. 1997; Zeller and Russ 1998). Depending on specific management objectives, an APA may allow for limited access to resources; however, most provide full spatial protection from resource-use. Non-designated areas of a waterbody are usually subject to regular fisheries management regulations (i.e. seasons, size limits, creel limits, etc.).

There are currently more than 5000 MPAs worldwide that protect approximately 2.58 million square kilometers or 0.65% of total marine area (International Union for Conservation of Nature 2008). Although APAs have become increasingly common in recent years, their objectives and overall usefulness are still highly debated. There are often many biological, social, economic and political factors that contribute to a wide range of specific management objectives, although APAs primarily serve a conservation- or resource-based function. Conservation protected areas focus on biodiversity, ecosystem or species conservation; whereas natural resource protected areas aim to improve natural fish stocks for human use (Boersma and Parrish 1999; Claudet and Pelletier 2004).

2.2 Freshwater Recreational Fisheries

The increasing awareness of overharvest and habitat destruction in marine ecosystems has focused public attention, scientific research and political agendas on spatial protection of the world’s oceans (Pauly et al. 1998; Jackson et al. 2001; Myers and Worm 2003). Recreational fisheries are not usually associated with the same destructive impacts as marine commercial
fishing (i.e. dredging, bycatch, etc.), although recent studies suggest that uncertainty may also have the potential to cause overexploitation in recreational fisheries (Post et al. 2002).

In Ontario, recreational fishery regulations are dependent on the target species, its current population status and geographic location. Combinations of creel, season and size regulations are used for each species across large regions known as fisheries management zones (FMZ). Within FMZs, there can be temporal (year-to-year) and spatial (waterbody-to-waterbody) variability in the biotic and abiotic factors across this broad diversity of populations that can result in variable management outcomes (Shuter et al. 1998). In an attempt to minimize the impact of broad management, Ontario implements many waterbody-specific exceptions to FMZ regulations. More than 600 of these exceptions are resource-based protected areas known as fish sanctuaries. The majority of fish sanctuaries in Ontario are seasonal regulations that protect a single species when it is highly vulnerable to exploitation; however, there is a small group of bass sanctuaries that have been fully closed to fishing for more than 70 years.

2.3 Bass and the History of Ontario’s Bass Sanctuaries

Season closures and creel limits had already been established to protect Ontario bass by the 1930s. At this time, bass were considered to be one of the province’s most important game fish and it was believed that current regulations would not sustain the demand of a growing fishery. Therefore, the Ontario Department of Game and Fisheries (ODGF) decided there was “no more promising method of bass conservation than the establishment of sanctuaries” (Ontario Department of Game and Fisheries Monthly Bulletin. 1939). Today, bass remain one of the most popular freshwater game fish in North America. Smallmouth bass (M. dolomieu) are a popular game fish throughout most of Ontario, while the largemouth bass fishery is most important in southern areas of the province, especially in the Rideau and Kawartha Lakes system (Scott and
Crossman 1973). The presence of ten year-round bass sanctuaries is likely a reflection of the importance of largemouth bass fishery in the Rideau Lakes system. Despite the presence of these sanctuaries for more than 70 years, there is limited evidence to support their role in bass management and this has lead to scrutiny in recent years. In response, the Fish and Wildlife Branch (Fisheries Section) of the Ontario Ministry of Natural Resources (OMNR) released guidelines for bass management in November 2006 that included the following proposed changes to bass sanctuaries:

1. Standardized sanctuary date of May 15 – June 30 where a sanctuary is required.
2. Year-round sanctuaries for bass are overly restrictive and should be reviewed to ensure they are still required.
3. Area-specific sanctuaries should only be used where there is sound biological rationale, otherwise closed seasons should be used to protect bass.

Although these recommendations include potential changes to current regulations, they also recognize a void in biological rationale that requires the evaluation of bass sanctuaries prior to re-designation.

2.4 Seasonal Bass Sanctuaries

Although there is no previous research on the Rideau lakes year-round sanctuaries, there has been evidence of seasonal bass sanctuary effectiveness in Ontario. The smallmouth bass fishery of Long Point, Lake Erie indicated a greater catch-per-unit effort during the open season in years when a seasonal sanctuary was employed (Sztramko 1985). Similarly, the designation of VBCZs in three eastern Ontario lakes showed a reduction of angling that resulted in increased reproductive success of bass within the protected area (Suski et al. 2002). The VBCZs were not
legally enforced as OMNR sanctuaries; however, it does illustrate the potential impact of seasonal spatial management of bass.

The seasonal success of bass sanctuaries is likely due to the reproductive ecology and behaviour of bass. Nest-guarding males are especially vulnerable to angling because they aggressively protect their brood from predation (Ridgway 1988; Ongarato and Snucins 1993; Philipp et al. 1997; Suski et al. 2003). Many fishing lures mimic potential brood predators and aggressive nest protection makes bass susceptible to angling (Philipp et al. 1997; Suski et al. 2002; Suski and Philipp 2004). If a guarding male is angled, it is likely that brood loss will occur even if the bass returns to his nest (Neves 1975; Kieffer et al. 1995; Philipp et al. 1997; Ridgway and Shuter 1997; Suski and Philipp 2004). In addition, physiological impairment caused by angling may lower the level of defense needed to provide adequate parental care leading to further brood loss (Kieffer et al. 1995; Cooke et al. 2000; Suski et al. 2003; Suski and Philipp 2004). Nest abandonment or even partial brood loss can lower an individual’s reproductive success (Coleman et al. 1985; Kieffer et al. 1995; Philipp et al. 1997) and it has been suggested that high angling pressure during the reproductive period could have population-level effects (Suski et al. 2002). Traditional bass season closures help to limit angling pressure during the reproductive period, although open-season angling for other species can result in the incidental capture of susceptible nest-guarding bass. Bass sanctuaries have the potential to eliminate non-targeted capture because fishing is prohibited for all species.

2.5 Freshwater Protected Areas Research

Despite the more than 600 resource-based protected areas (fish sanctuaries) in Ontario, there are few studies that have examined their role in fisheries management. Of the research on
Ontario fish sanctuaries, most has focused on the recovery of fish populations, such as lake trout in Lake Huron (Schram et al. 1995; Reid et al. 2001).

In other areas of the world, there is a similar absence of empirical studies that have examined the usefulness of FPAs. Spatial protection has resulted in improvements for a walleye population in northwestern Pennsylvania (Kocovsky and Carline 2001), European eels in northwest France (Cucherousset et al. 2007), but were determined to only protect northern pike while spawning in Northern Ireland (Rosell and MacOscar 2002). The void of literature regarding the performance of FPAs makes it difficult to draw conclusions or even establish a relevant standard for evaluation. To develop an evaluation framework, it is necessary to examine the more extensive literature that exists for MPAs.

2.6 Evaluation of Protected Areas

Although the success of spatial fisheries management is still debated, there has been considerable empirical evidence that shows increases in the density, biomass and size of fish within many MPAs (Halpern and Warner 2002; Halpern 2003; Micheli et al. 2004; Lester et al. 2009). The presence of a measureable improvement inside a protected area is known as a ‘reserve effect’ and is commonly used as indicator of performance (Afonso et al. 2009). Reserve effects often compare population demographics of a protected area to an unprotected area (Cote et al. 2001; Halpern 2003; Murawski et al. 2004). Although the presence of a reserve effect is generally a good indicator of protected area effectiveness, they are susceptible to type-I error. This may occur if a sanctuary is located in an area where localized resource availability is capable of supporting greater biomass than the comparison (control) area, so that an observed reserve effect may not actually be a direct result of the protection itself (Russ 1985; Willis et al. 2003; Sale et al. 2005:). To eliminate the potential confounding variables associated with control site selection,
many studies utilize a before-and-after approach at the same location (McClanahan and Graham 2005). This methodology is most useful during the initial design of a protected area or when a sufficient baseline of pre-closure data is available. This data is often missing for long-established protected areas and the age of any existing baseline knowledge is often difficult to utilize for comparison (McClanahan and Graham 2005). In addition, the overall evaluation of reserve effects has been shown to be more effective in areas where severe overharvest and habitat degradation has occurred due to commercial fishing (Lauck et al. 1998; Guénette and Pitcher 1999; Sladek-Nowlis and Roberts 1999; Apostolaki et al. 2002). The combination of these factors suggests that the long-established Ontario bass sanctuaries may not exhibit measurable reserve effects.

The successful maintenance or recovery of populations indicates that MPAs have the potential to achieve conservation goals (Pelletier and Mahévas 2005); however, it still remains unclear how these internal improvements can translate into fishery benefits (Apostolaki et al. 2002; Sale et al. 2005; Lester et al. 2009). Theoretically, the fishery benefits of spatial protection occurs when the buildup of reserve effects inside the protected area cause the dispersal of larvae (export) or adults and juveniles (spillover) into the fishery. Export is important for connecting and replenishing many marine sub-populations to enhance future recruitment (Murawski et al. 2004; Planes et al. 2009), although spillover is generally more important than export in freshwater aquatic systems where larval dispersal is limited (Gell and Roberts 2003). True spillover is considered to be a density-dependent process and can be typified by an abundance gradient that is highest within the reserve core and diminishes as it extends out into the fishery (Abesamis et al. 2006). Behavioural, ontogenetic, or environmentally influenced movement out of a protected area may appear like spillover (Murawski et al. 2004), making the contribution of true spillover to surrounding fisheries very difficult to assess (Willis et al. 2003).
The abovementioned evaluation methods are largely based on assessments of population demographics and can be inadequate for protected areas because they have limited spatial considerations (Babcock et al. 2005). Therefore the evaluation of a protected area requires an understanding how and why a fish utilizes space (Kramer and Chapman 1999; Griffiths and Wilke 2002). This type of behavioural perspective is now considered to be an essential component in the design and evaluation of protected areas (Roberts and Sargant 2002).

2.7 A Behavioural Perspective

In the 1940s, a mark-and-recapture study was carried out in Murphy Bay fish sanctuary of Lake Opinicon (Curran et al. 1947). This study determined that largemouth bass left the sanctuary after the nesting period and some moved great distances throughout the lake. Although this study provides potential insight into the behavioural use of a bass sanctuary, many environmental and physical changes have occurred in Lake Opinicon since the 1940s. Climate change, the introduction of zebra mussels and the change from an oligotrophic to a mesotrophic lake may have influenced largemouth bass ecology and behaviour. The age of the study and the potential of confounding factors limit its usefulness as a relevant baseline for the current research.

Since then, many studies have examined the spatial ecology of largemouth bass; however, a great majority of this research has focused on populations in southern latitudes (Mesing and Wicker 1986; Wildhaber and Neill 1992; Sammons and Maceina 2005; Slipke and Maceina 2007). Many of these studies have a specific focus on hydrological regimes (Rogers and Bergersen 1995; Furse et al. 1996; Havens et al. 2005) and vegetation removal (Colle et al. 1989; Bain and Boltz 1992; Brown and Maceina 2002; Sammons et al. 2003). While these studies may provide some perspective on largemouth bass spatial ecology and behaviour, there are many
important climatic and community structure differences that provide potential barriers for comparison.

In temperate areas, largemouth bass spatial biology studies have been limited to anthropogenic displacement (Hodgson et al. 1998; Ridgway 2002) or experimental manipulations of habitat (Ahrenstorff et al. 2009) and forage supply (Savitz and Treat 2007). Non-experimental studies of largemouth bass spatial behaviour have suffered from small sample sizes (Winter 1977; Demers et al. 1996) or focused on winter activity in a temperate climate (Carlson 1992; Gent et al. 1995; Raibley et al. 1997; Karchesky and Bennett 2004). The majority of recent research on temperate largemouth bass spatial biology has been derived from the whole-lake acoustic telemetry array used at the Warner Lake Ecological Observatory (WLEO) in eastern Ontario (Cooke et al. 2005). The associations among largemouth bass (Hasler et al. 2007), as well as the influence of water temperature (Hanson et al. 2007a; Hasler et al. 2009a), winter habitat (Hasler et al. 2009b), lunar cycles (Hanson et al. 2008b), morphological features (Hanson et al. 2007b), sex and reproductive status (Hanson et al. 2008a) have been examined relative to ecological behaviour. The WLEO is a small, private research lake (18 ha) with a high level of control over anthropogenic activities and a subsequently low level of disturbance. Recently it has been determined that human activities such as fishing, boating (Popper et al. 2003; Graham and Cooke 2008) and shoreline development (Christensen et al. 1996; Reed and Pereira 2009) can have a significant influence on the ecological behaviour of largemouth bass.

2.8 Research Rationale and Objectives

This research utilized radio telemetry to examine the behaviour and habitat use of largemouth bass in Lake Opinicon, Ontario (780 ha). This provides a temperate study site with moderate to high levels of anthropogenic activity including fishing, boating and shoreline
development. In addition to anthropogenic activity, Lake Opinicon may experience differences in physical, chemical and community dynamics relative to a smaller lake (i.e. WLEO), which may influence the overall behaviour of largemouth bass. Subsequently, the behaviour and habitat use of largemouth bass was used as an indicator of the protection potential of Lake Opinicon’s Murphy Bay fish sanctuary during the open fishing season. Ultimately, this behavioural perspective will provide an important component in the evaluation of Ontario’s bass sanctuaries.
Chapter 3

Methods

3.1 Study site

Located in southeastern Ontario, Lake Opinicon (44°30.8’N, 76°19.5’W; Figure 1) is a long (9.5km) and shallow (mean depth = 4.9 m; max depth = 9.2 m) mesotrophic lake naturally formed by the retreat of the last glaciations (Karst and Smol 2000) In the late 1820s, Lake Opinicon was flooded for navigation as a part of the Rideau Canal system. The flooding added considerable surface area (currently 780 ha) and is responsible for the ‘drowned land’ areas that contain large numbers of submerged and protruding stumps (Karst and Smol 2000).

There are two year-round fish sanctuaries in Lake Opinicon that are located in these areas of ‘drowned land’. Darlings Bay sanctuary (14.2 ha) is a narrow bay located at the southwest end of the lake with a relatively high level of anthropogenic disturbance due to boat traffic and cottages along the shoreline. Murphy Bay fish sanctuary (83 ha) is located at the northeast end of the lake and receives very little anthropogenic disturbance. The innermost area of Murphy Bay fish sanctuary is shallow (<1 m) with dense vegetation and is connected to the outer sanctuary and Lake Opinicon by a narrow inlet. This outermost portion of the sanctuary (adjacent to the boundary) has some areas with lower vegetation densities. Only Murphy Bay fish sanctuary was used in this study to maximize the sample size of telemetered fish in this location, as well as to enable a focusing of tracking efforts.

3.2 Capture and Transmitter Implantation

Twenty-three largemouth bass were captured by rod and reel angling for transmitter implantation between May 15 and May 22 (total length = 410.9 ± 21 mm; weight = 1022 ± 177
All fish were angled, landed and placed in a cooler of lake water as quickly as possible. The fish were subsequently transferred into an induction anesthetic bath (0.06 ml/L Clove Oil solution, Sigma-Aldrich Co., Missouri) on land. Once a fish lost equilibrium it was transferred to a surgical apparatus that positioned the fish for intraperitoneal implantation and delivered a continuous flow of re-circulated maintenance anesthetic (0.02 ml/L Clove Oil solution) over the gills. A small (10-15mm) incision, adjacent to the mid-ventral line, was made 20-30mm anterior to the urogenital pore. A Micro Coded Fish Transmitter (MCFT-3FM, Lotek Engineering Inc., Ontario) was inserted gently into the visceral cavity towards the pelvic girdle. The weight of transmitters (in air) were always less than 2% (1.02 ± 0.002%) of the fish’s body weight (Winter 1983; Mellas and Haynes 1985; Mesing and Wicker 1986; Table 1). Each transmitter was equipped with a whip antenna that was passed to the outside of the body using the shielded-needle technique (Ross and Kleiner 1982; Belanger and Rodriguez 2001; Bettinger and Bettoli 2004). The incision was closed using two or three monofilament absorbable sutures (PDS II 3-0, Ethicon Inc., New Jersey). Immediately following surgery, length and weight were measured and the fish were placed in a container of aerated lake water to recover. All surgical procedures (anesthesia, transmitter implantation, incision suturing) and fish processing were completed in less than ten minutes. Following surgery, all fish were released within five meters of the original capture site once they had regained equilibrium (mean recovery time = 64 minutes).

3.3 Monitoring fish locations

Fish were manually tracked by boat using a hand-held, Folding 3 Element Yagi Antenna (Model F150-3FB, AF Antronics, Illinois) and telemetry receiver (SRX 400A, Lotek Wireless Inc., Ontario). The locations of the fish were estimated using zero point tracking, which utilizes a method of successive gain reductions on the receiver. The receiver was initially set to the full
gain position (100) until a transmitter signal was detected. At this point the gain was gradually reduced (by increments of 5) as the signal strength intensified and the boat approached the fish. When a power reading (indicator of signal strength) was obtained at a low gain position (10), a hand-held GPS receiver (eTrex Legend H, Garmin Ltd., Kansas) was used to mark the location (~5m accuracy).

Two distinct areas were targeted for the original capture and subsequent tracking of largemouth bass. The first group were captured and released inside the boundaries of Murphy Bay fish sanctuary (hereafter referred to as the sanctuary group). The other bass were captured and released in similar habitats a considerable distance away from Murphy Bay fish sanctuary. Tracking occurred approximately every six days between June 2 and August 20, 2009. Fish were separated into sanctuary (N = 12) and non-sanctuary (N = 11) tracking groups based on where they were originally captured and released following surgery. This was done to ensure there was sufficient time to locate each fish five times within a single 24-hour period. Each location group was tracked approximately every 13 days. Additional 12-hour tracking periods were utilized to acquire supplementary location estimates for area utilization analyses and directional displacement rates. Three fish were lost during the study due to harvest (N=2) or unknown reasons (N = 1); however, the remaining fish were continuously monitored throughout the duration of the study (see Table 1).

Fish were monitored during all diel periods (dawn, day, dusk and night) to reduce the possibility of location bias (type-II error) associated with tracking fish exclusively during certain times of the day (i.e. only during daylight). Location estimates for an individual fish were observed at least four hours apart to avoid autocorrelation (non-independence) of successive locations, which is known to underestimate utilization distributions (Swihart and Slade 1985).
Longer time intervals between successive locations would increase the likelihood of independence between those locations, but would increase the time required to obtain an adequate number of location estimates. Seaman et al. (1999) has suggested using 30 to 50 locations to obtain accurate 95% kernel density estimates (KDE; explained below), but also determined that as few as 20 locations can be used with fixed kernel estimators. The number of locations used in the current analysis ranged between 27 and 41 (mean = 37).

3.4 Environmental Characteristics of Fish Locations

A suite of environmental characteristics were measured and recorded at the time of each location estimate. Water temperature and water depth were measured immediately on site. Water temperature was recorded 0.3 m below the surface with a temperature probe (Orion 3 Star Plus Dissolved Oxygen Meter, Thermo Fisher Scientific Inc., Massachusetts) and water depth was measured using a pre-measured sounding line attached to a float (to the nearest 0.15 m), taking care not to disturb the fish. Air pressure, air temperature, wind speed and wind direction values measured at ten minute intervals were obtained from the Queen’s University Biological Station (QUBS) located at Lake Opinicon (Figure 1). The interval closest to the time of the actual location estimate was used for analysis. Air pressure (kPa) was measured using a digital recording air pressure sensor (RM Young 61205V, Campbell Scientific Canada Corp., Alberta). Air temperature (°C) was measured using an air temperature probe (Model 107F, Campbell Scientific Canada Corp., Alberta). Solar radiation was measured using a pyranometer (LI-200SZ, Li-Cor Biosciences, Nebraska). Wind speed was measured using a rotating anemometer (Model 013A, Met One Inc., Oregon). Wind direction (DegTru) was measured using a wind direction sensor (Model 023A, Met One Inc., Oregon).
3.5 Habitat Types

The presence of coarse woody structure (CWS), dominant vegetation type and vegetation density were recorded by visual observation from a boat at each location estimate site. The same depth measurement was used as described above (see section 3.4). A location was considered to have CWS if submerged or emerging stumps, fallen trees or logs (Ahrenstorff et al. 2009) were a dominant form of structure within a 5m radius of the boat. A vegetation type (floating-leaf aquatic vegetation, submerged aquatic vegetation or emergent aquatic vegetation) was considered to be dominant if it made up more than 50% of the overall vegetation present within a 5m radius of the boat. The density of vegetation was determined by estimating the percentage of the water column (within 5m of the boat) that was occupied by submerged and emergent aquatic vegetation and the percentage of the water surface for floating-leaf aquatic vegetation. Locations were estimated as having low (0-35%), moderate (35-65%) or high (65-100%) vegetation densities. For example, locations with mats of floating-leaf aquatic vegetation or submerged aquatic vegetation that dominated the water column were considered to have high vegetation densities. The median depth, the percentage of locations with each vegetation density level (low to moderate or high) and percentage of locations with coarse woody structure present were used to determine the predominant habitat type for each fish (Table 2). High-structure habitats were characterized by shallow areas (median depth range = 0.76 – 1.30m) with CWS and/or high vegetation densities. Low-structure habitats were characterized by deeper areas (median depth range = 1.07 to 3.35m) without CWS and low to moderate vegetation densities (often a combination of aquatic vegetation and open water).
3.6 Area Utilization Analysis

3.6.1 Minimum Convex Polygon (MCP)

A minimum convex polygon (MCP) is one of the simplest methods to estimate home range size. To create an MCP, the outermost location estimates for an individual fish are connected to form the smallest possible convex polygon. The MCP outlines the entire lake area where a fish may potentially be located (or angled), based on the location estimates obtained in the current study. All MCP home range areas were estimated using the Hawth’s Tools (V3.27) extension in ArcGIS 9 (ArcMap V9.2, ESRI Inc., California).

3.6.2 Kernel Utilization Distribution (KUD)

Although an MCP provides an outer boundary for the home range of an individual, it ignores a large majority of the data (all inner location estimates) and assumes that a fish utilizes the space equally within these boundaries. The actual home ranges of many animals do not meet this assumption, making it necessary to determine the utilization of space within a home range by creating a utilization distribution (Seaman and Powell 1996; Seaman et al. 1999; Powell 2000). Kernel density estimates (KDE) use a sample of location estimates to produce a probability density estimate of utilization. The KDE can be interpreted as a kernel utilization distribution (KUD), which estimates the smallest area that explains a given percentage of total use (Powell 2000; Topping et al. 2005). In this study, a 95% KUD was used to describe the total area of utilization and a 50% KUD was also used to determine the core area representing the smallest area that accounts for 50% of total utilization by largemouth bass in Lake Opinicon (Powell 2000; Jones 2005). These methods apply a grid to the data and use the mean influence of all location estimates at each grid intersection to create the utilization density contours (Silverman 1986; Seaman and Powell 1996). Each location will have a varying degree of influence on a single grid
intersection point depending on the smoothing factor (h; explained below) and the proximity of
the locations to that point. In other words, grid intersections with high densities of location
estimates in close proximity will have the greatest influence on the estimate.

All KUDs were calculated using the Hawth’s Tools (V3.27) extension in ArcGIS 9
(ArcMap V9.2, ESRI Inc., California). For all utilization area estimates, terrestrial environments
(including islands) were removed prior to analysis because fish are not able to use these habitats
and therefore should not be included area use estimates (Espeland et al. 2008). In addition,
individual location estimates were omitted from analysis if they resulted in a greater than 75%
increase in home range size (Burt 1943; Ables 1969; Mesing and Wicker 1986).

3.6.3 Choosing the Smoothing Factor (h)

One of the most important, yet difficult tasks in kernel estimation is the selection of an
appropriate smoothing factor (Powell 2000; Jorgensen et al. 2007). The smoothing factor adjusts
the variance of location estimates, which in turn influences the magnitude of contribution they
have on the density estimates at each grid intersection. Many studies recommend using a
smoothing factor that is calculated by the LSCV (least-squares cross-validation) method (Seaman
and Powell 1996; Seaman et al. 1999; Powell 2000), although it has been known to underestimate
utilization distributions in studies with small sample sizes (Seaman et al. 1999; Girard et al. 2002;
Horne and Garton 2006), clustered locations (Hemson et al. 2005) or linear home ranges
(Blundell et al. 2001; Kernohan et al. 2001). For linear home ranges, underestimation of the
utilization distribution often results in fragmentation (Blundell et al. 2001; Kernohan et al. 2001).
This occurs because LSCV is designed to examine utilization distributions of animals that have a
relatively unrestricted use of space (i.e. many terrestrial and avian species). These species are
generally not confined by a geographical barrier, and are thus more likely to have spherical home
ranges centered on a core area (Blundell et al. 2001). Alternatively, many fish species have home ranges that are restricted by a geographical barrier (i.e. a shoreline) that causes the LSCV method to undersmooth the data (by calculating a small h). Smoothing parameter selection should be reflective of study objectives, sample size and study species.

Many largemouth bass in Lake Opinicon illustrated home range fragmentation when the LSCV method was used to smooth home range data. This fragmentation was likely caused by the relatively small sample size (N = 27 to 41), clustered locations, and home range linearity of the current study. Home range linearity was confirmed by calculating aspect ratios (AR) of the proportion of maximum polygon width (perpendicular to maximum length) relative to the maximum polygon length for the MCP of each fish (Eristhee and Oxenford 2001). An AR closer to one represents a more circular home range, whereas an AR closer to zero represents a more elongated (or linear) home range (Eristhee and Oxenford 2001). Only three largemouth bass had an AR greater than 0.5, suggesting that the most MCPs were relatively linear with the majority being more than twice as long as they were wide (Table 8).

Due to the inconsistencies of LSCV-based home ranges, a fixed-KDE (constant h) was utilized with the likelihood (CV) method for smoothing parameter selection. The CV method has been shown to be successful for home ranges with linearity, clustered locations and small sample sizes (Moser and Garton 2007). The Animal Space Use Software (V1.2) was used to determine the CV\textsubscript{h} for each individual fish (Horne and Garton 2007). The median CV\textsubscript{h} (h = 22.2) for all fish was used as the smoothing factor when determining KDEs (Churchill et al. 2002; DeVault et al. 2004).
3.7 Displacement Analysis

Directional displacement was calculated by measuring the distance (in meters) between successive location estimates using the Measure Tool of ArcGIS 9 (ArcMap V9.2, ESRI Inc., California). These measurements were divided by the number of hours between successive locations to calculate the minimum displacement per hour (MDPH). All directional displacements were considered to be minimum metrics because they only measure a straight-line distance without knowing the true path between successive location estimates (Rogers and White 2007; Kobler et al. 2008).

A continuous tracking schedule during a 24-hour period resulted in five successive location estimates. The daily displacement rate was calculated by dividing the total displacement (sum of consecutive directional displacements for a single tracking period) by the total duration of a tracking day. The daily displacement rate provides an average displacement rate for a tracking period, but does not describe the nature of the movement relative to the other occupied locations for that day. In other words, a fish moving back and forth over the same area may have a disproportionately large daily displacement rate reflecting the general activity of a fish, but not an accurate representation of daily space use.

To illustrate the daily outward movement of a fish for each tracking period, minimum radial displacement was utilized. This methodology measured the displacement between a single location estimate and all other locations for an individual fish during a single tracking period. This was accomplished using the ‘distance between points’ function of Hawth’s Tools (V3.27) extension in ArcGIS 9 (ArcMap V9.2, ESRI Inc., California). The mean radial displacements for all five locations within a single tracking period were then averaged to provide the mean daily radial displacement for each fish.
Fish locations were categorized into three diel time periods: night-dawn, day, dusk-night. Dawn was defined as the period beginning two hours prior to sunrise until two hours after sunrise. Similarly, dusk was defined as the period beginning two hours prior to sunset until two hours after sunset. Day was defined as the time between dawn and dusk and night was the time between dusk and dawn (Bauer et al. 2009). To ensure that each diel period had adequate directional displacements for analysis, night measurements were incorporated into the closest crepuscular period (dawn or dusk).

The daily habitat use behaviour of each individual largemouth bass was also examined to determine if any general behaviour trends could be identified. Each fish was assessed to see if there were any obvious relationships between their spatial behaviour and diel periods or their overall occupation of specific habitat types. It is important to note that all largemouth bass were originally captured in high-structure shallow areas; however, capture locations were not used in analyses (i.e. only radio tracking location estimates were used). Shifts in location or habitat utilization were considered to be long-term if they occurred for more than one 24-hour tracking period.

3.8 Spatial Utilization of Murphy Bay fish sanctuary

The spatial utilization of Murphy Bay fish sanctuary was only measured for those largemouth bass that were in the ‘sanctuary’ location group (i.e. originally captured inside Murphy Bay fish sanctuary). The utilization of Murphy Bay fish sanctuary in Lake Opinicon was assessed by examining the proportions of total and core utilization areas, as well as the number of location estimates and open season days that occurred within the sanctuary boundaries. This information coupled with the spatial behaviour analysis was utilized to help determine the potential protective capacity of Murphy Bay fish sanctuary.
3.9 Statistical Analysis

For all area utilization and displacement analyses, individual fish were used as the sampling unit. Only those fish with sufficient data points were used for analysis. These statistical analyses were performed using SPSS Statistics 17.0 software (SPSS Inc., Illinois). Log\(_{10}\) transformations were performed to ensure that data satisfied the assumption of normality. The level of significance (\(\alpha\)) for all tests was 0.05, and all means report ± standard error mean (SEM) where appropriate.

3.9.1 Regression Analyses

Total lengths (mm) of individual fish were linearly regressed against the mean of each log\(_{10}\) transformed variable used in the study (MCP, 95% KUD, 50% KUD, directional displacement rate, daily directional displacement rate, daily radial displacement).

Environmental variables (water depth, water temperature, air temperature, air pressure, solar radiation, wind speed, wind direction) were calculated averages of the values from the two location estimates corresponding to the MDPH. The environmental variables most influencing the directional MDPH were determined using forward-loading stepwise multiple regression. The minimal model was run through the standard least squares regression tool to determine model effects and measures of significance for individual sources of variation. Partial residual plots were used to determine the relationship between each source of variation and the directional MDPH while controlling for all other variables in the model. All regression analyses were performed using the statistical package JMP version 8.0 (SAS Institute Inc., North Carolina).

3.9.2 Area Utilization between Habitat Types

Log\(_{10}\) transformed values of all home range and area utilization estimates (MCP, 95% KUD, 50% KUD) were normally distributed with equal variances at \(p > 0.05\) for both habitat
types. An independent t-test was used to compare area utilization estimates between the habitat types.

3.9.3 Directional Displacement Rates between Diel Periods and Habitat Types

Individual displacements for a fish were averaged to produce a mean of individual means that were used for analyses. The minimal sample size, assumption of normality (based on skewness and kurtosis of the repeated measures), assumption of homogeneity of variance (Levene’s test for equality of variances) and assumption of sphericity (Mauchly’s test) were all satisfied. Thus, a mixed-model analysis of variance (ANOVA) with repeated measures in one factor (diel period) was used to analyze the potential interaction of diel- and habitat-based displacements. Bonferroni post-hoc tests were used to evaluate differences in MDPH between diel periods (dawn-night, day, dusk-night) and habitat types (high-structure and low-structure). A repeated measures analysis was utilized because the same individuals were analyzed across three different time periods.

3.9.4 Daily Displacement Rates and Radial Displacements between Habitat Types

Daily displacement rates and daily radial displacements were averaged for individual fish to produce a mean of individual means that were used for analyses. Log_{10} transformed values of daily MDPH and radial displacement were normally distributed with equal variances at P > 0.05 in both habitat types. An independent t-test was used to compare mean daily displacement rates and mean radial displacements between habitat types.
3.9.5 Spatial Biology between Locations

Similar analyses to those comparing habitat types (as described above – see 3.9.2 through 3.9.4) were used to evaluate compare sanctuary and non-sanctuary groups to ensure observed differences in behaviour were not a result of sanctuary protection.
Figure 1. A bathymetry map of Lake Opinicon. The northeast end of Lake Opinicon is magnified to show Murphy Bay fish sanctuary in more detail. Dashed line represents the Murphy Bay fish sanctuary boundary. The star (★) represents the Queen’s University Biological Station (QUBS).
Table 1. The total length (TL; mm), percentage of transmitter mass (in air) relative to total fish mass (% of TM), capture date, capture location, tracking duration, total number of location estimates and reason for removal (if applicable) of telemetered largemouth bass in Lake Opinicon.

<table>
<thead>
<tr>
<th>Fish</th>
<th>TL</th>
<th>% of TM</th>
<th>Capture Date</th>
<th>Capture Location</th>
<th>Tracking Duration</th>
<th>Total Estimates</th>
<th>Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>398</td>
<td>1.1%</td>
<td>May 15</td>
<td>Sanctuary</td>
<td>May 29 – Aug 18</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>421</td>
<td>0.9%</td>
<td>May 19</td>
<td>Sanctuary</td>
<td>June 11 – Aug 18</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>417</td>
<td>0.9%</td>
<td>May 22</td>
<td>Non-sanctuary</td>
<td>May 26 – Aug 20</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>446</td>
<td>0.7%</td>
<td>May 22</td>
<td>Sanctuary</td>
<td>May 29 – Aug 18</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>414</td>
<td>1.0%</td>
<td>May 21</td>
<td>Non-sanctuary</td>
<td>May 26 – Aug 20</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>415</td>
<td>1.1%</td>
<td>May 15</td>
<td>Sanctuary</td>
<td>June 3 – Aug 5</td>
<td>27</td>
<td>Harvest</td>
</tr>
<tr>
<td>7</td>
<td>380</td>
<td>1.2%</td>
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<td>Non-sanctuary</td>
<td>May 29 – June 16</td>
<td>10</td>
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</tr>
<tr>
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<td>416</td>
<td>1.1%</td>
<td>May 21</td>
<td>Non-sanctuary</td>
<td>May 26 – Aug 20</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>390</td>
<td>1.3%</td>
<td>May 22</td>
<td>Non-sanctuary</td>
<td>May 26 – Aug 20</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>433</td>
<td>0.8%</td>
<td>May 19</td>
<td>Sanctuary</td>
<td>May 29 – Aug 18</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>423</td>
<td>0.9%</td>
<td>May 22</td>
<td>Sanctuary</td>
<td>June 3 – Aug 18</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>420</td>
<td>1.0%</td>
<td>May 13</td>
<td>Sanctuary</td>
<td>May 29 – Aug 18</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>410</td>
<td>1.0%</td>
<td>May 21</td>
<td>Non-sanctuary</td>
<td>June 2 – Aug 12</td>
<td>30</td>
<td>Harvest</td>
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<tr>
<td>14</td>
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<td>0.9%</td>
<td>May 22</td>
<td>Non-sanctuary</td>
<td>May 26 – Aug 20</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>358</td>
<td>1.4%</td>
<td>May 15</td>
<td>Sanctuary</td>
<td>May 29 – Aug 18</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>420</td>
<td>0.9%</td>
<td>May 22</td>
<td>Sanctuary</td>
<td>May 29 – Aug 18</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>437</td>
<td>0.8%</td>
<td>May 20</td>
<td>Non-sanctuary</td>
<td>May 29 – Aug 20</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>446</td>
<td>0.7%</td>
<td>May 15</td>
<td>Sanctuary</td>
<td>May 29 – Aug 18</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>388</td>
<td>1.1%</td>
<td>May 19</td>
<td>Sanctuary</td>
<td>May 29 – Aug 18</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>412</td>
<td>1.0%</td>
<td>May 20</td>
<td>Non-sanctuary</td>
<td>May 29 – Aug 20</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>395</td>
<td>1.2%</td>
<td>May 13</td>
<td>Sanctuary</td>
<td>June 3 – Aug 18</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>404</td>
<td>1.1%</td>
<td>May 22</td>
<td>Non-sanctuary</td>
<td>May 26 – Aug 20</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>390</td>
<td>1.2%</td>
<td>May 21</td>
<td>Non-sanctuary</td>
<td>May 26 – Aug 20</td>
<td>37</td>
<td></td>
</tr>
</tbody>
</table>

|     |    |        |               |                  |                   |       |         |
| Mean| 410| 1.0%   |               |                  |                   |       | 37.1    |
| Min | 358| 0.7%   |               |                  |                   |       | 27      |
| Max | 446| 1.4%   |               |                  |                   |       | 41      |
Table 2. A summary of the habitat characteristics for locations occupied by telemetered largemouth bass in Lake Opinicon, including median depth (m), % occurrence of vegetation density (low to moderate or high), % occurrence of coarse woody structure (CWS) and predominant habitat type (high-structure or low-structure).

<table>
<thead>
<tr>
<th>Fish</th>
<th>Habitat Type</th>
<th>Depth</th>
<th>Vegetation</th>
<th>CWS</th>
</tr>
</thead>
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<td></td>
<td></td>
<td></td>
<td>Low-Mod</td>
<td>High</td>
</tr>
<tr>
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<td>High-structure</td>
<td>0.91</td>
<td>21.2%</td>
<td>77.8%</td>
</tr>
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<td>Low-structure</td>
<td>1.92</td>
<td>91.2%</td>
<td>8.8%</td>
</tr>
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<td>High-structure</td>
<td>1.07</td>
<td>16.7%</td>
<td>83.3%</td>
</tr>
<tr>
<td>4</td>
<td>High-structure</td>
<td>0.76</td>
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<td>81.1%</td>
</tr>
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<td>Low-structure</td>
<td>2.59</td>
<td>91.9%</td>
<td>8.8%</td>
</tr>
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<td>Low-structure</td>
<td>3.35</td>
<td>100%</td>
<td>0%</td>
</tr>
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<td>7</td>
<td>High-structure</td>
<td>1.14</td>
<td>63.9%</td>
<td>36.1%</td>
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<td>8</td>
<td>Low-structure</td>
<td>1.37</td>
<td>91.4%</td>
<td>8.6%</td>
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<tr>
<td>9</td>
<td>High-structure</td>
<td>0.76</td>
<td>21.6%</td>
<td>78.4%</td>
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<td>10</td>
<td>High-structure</td>
<td>0.76</td>
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<td>81.6%</td>
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<tr>
<td>11</td>
<td>Low-structure</td>
<td>1.52</td>
<td>74.4%</td>
<td>25.6%</td>
</tr>
<tr>
<td>12</td>
<td>Low-structure</td>
<td>3.20</td>
<td>100.0%</td>
<td>0%</td>
</tr>
<tr>
<td>13</td>
<td>High-structure</td>
<td>0.76</td>
<td>2.8%</td>
<td>97.2%</td>
</tr>
<tr>
<td>14</td>
<td>High-structure</td>
<td>0.76</td>
<td>32.4%</td>
<td>67.6%</td>
</tr>
<tr>
<td>15</td>
<td>High-structure</td>
<td>0.76</td>
<td>18.9%</td>
<td>81.1%</td>
</tr>
<tr>
<td>16</td>
<td>High-structure</td>
<td>0.91</td>
<td>24.3%</td>
<td>75.7%</td>
</tr>
<tr>
<td>17</td>
<td>Low-structure</td>
<td>1.07</td>
<td>77.1%</td>
<td>22.9%</td>
</tr>
<tr>
<td>18</td>
<td>High-structure</td>
<td>1.30</td>
<td>45.9%</td>
<td>54.1%</td>
</tr>
<tr>
<td>19</td>
<td>Low-structure</td>
<td>2.74</td>
<td>100%</td>
<td>0%</td>
</tr>
</tbody>
</table>
Chapter 4

Results

4.1 Role of Environmental Variables

Multiple regression analysis indicates that water depth was the best indicator of largemouth bass directional MDPH when all other sources of variation in the model were controlled for. Water depth explained the greatest amount of variation associated with directional MDPH ($R^2 = 0.094$; Table 3). Other environmental factors (water temperature, air temperature and solar radiation) contributed significantly to directional MDPH, but accounted for smaller proportions of the variance in the all fish model (Table 3). When habitat type was considered (water depth was removed as a potential source of variation), multiple regression analyses revealed that air temperature was the best indicator of largemouth bass directional MDPH when all other sources of variation in the model were controlled for (Table 3). Air temperature explained the greatest amount of variation associated with directional MDPH for low-structure ($R^2 = 0.025$; Table 3) and high-structure ($R^2 = 0.032$; Table 3) habitat models. Solar radiation was also found to correlate significantly to directional MDPH for the low-structure habitat model, but accounted for a slightly smaller proportion of the variance. Due to the lack of variation explained by these variables and the difficulty of spatially quantifying them, they will not be further utilized in the current study. However, the variable (depth) explaining the greatest variation in MDPH is considered in the habitat-based quantification of largemouth bass spatial biology below.

4.2 Area Utilization

The home range and area utilization for each individual largemouth bass are described in Appendix A. The MCP areas utilized by largemouth bass in Lake Opinicon did not differ between
habitat types \( (t = -1.680, df = 20, p = 0.109; \text{Figure 2}) \). Largemouth bass occupying low-structure habitats had 1.9-fold larger total utilization areas (95% KUD) relative to those in high-structure habitats \( (t = -3.016, df = 20, p = 0.007; \text{Figure 3}) \). Mean core utilization areas (50% KUD) of largemouth bass occupying low-structure habitats were more than double (2.3-fold) that of bass occupying high-structure habitats \( (t = -3.912, df = 20, p = 0.001; \text{Figure 4}) \). There was no significant relationship between the total length of telemetered largemouth bass in Lake Opinicon and area utilization (or any other measured variables; Table 4).

4.3 Directional Displacement

The mean total, night-dawn, day and dusk-night MDPH values of individual largemouth are shown in Appendix A. There was no significant interaction between diel period and habitat type \( (F_{(2, 40)} = 0.296, p = 0.745) \). In other words, the pattern of directional displacement rates throughout the diel time periods was the same for fish occupying low-structure and high-structure habitats. Largemouth bass occupying low-structure habitats had double the directional displacement rates of bass occupying high-structure habitats \( (F_{(1, 20)} = 6.509, p = 0.019; \text{Figure 5}) \). The directional displacement rates between diel periods were significantly different \( (F_{(2, 40)} = 7.171, p = 0.002; \text{Figure 6}) \), with Bonferroni post-hoc tests revealing that directional displacement rates during night-dawn were double those during the day \( (p = 0.001) \), but only 1.2-fold greater than dusk-night \( (p = 1.000) \). Directional displacement rates during dusk-night were 1.7-fold greater than those during the day, but were not significantly different \( (p = 0.100) \).

4.4 Daily Displacement Rate and Daily Radial Displacement

The daily displacement rate and daily radial displacements of each tracking period are shown for individual largemouth bass in Appendix A. The mean daily displacement rate (Figure 7) and mean daily radial displacement (Figure 8) of largemouth bass occupying low-structure
habitats were almost double (1.9-fold) those occupying high-structure habitats (daily displacement rate: $t = -2.631$, df = 20, $p = 0.016$; daily radial displacement: $t = -2.674$, df = 20, $p = 0.015$).

### 4.5 Effect of Capture Location

There were no significant effects of capture location (sanctuary or non-sanctuary) on the spatial biology of largemouth bass in Lake Opinicon. See Table 9 for descriptive statistics of location analyses. Similar to the habitat, directional displacement differed between diel periods (Table 5).

### 4.6 Largemouth Bass Habitat Use Behaviour

The behaviour of individual largemouth bass was examined with respect to their occupation of habitat types during a single tracking period. The habitat use behaviour and the number of times it was observed are included in Table 6. An assessment of individual behaviours indicated that largemouth bass habitat use was specific (one habitat) or flexible (both habitat types). The majority of largemouth bass in Lake Opinicon ($N = 19$) exclusively used a single habitat type throughout the study. Six largemouth bass (Fish 1, 3, 4, 14, 15, 17) remained exclusively in areas of high-structure (i.e. Figure 9). Fish 1 remained in high-structure areas throughout the study, although a diel location shift was observed between two discrete areas. One location was utilized at night and then Fish 1 would return to the previously occupied area the following day (Figure 10).

Nine individuals (Fish 2, 5, 6, 9, 13, 20, 21, 22 and 23) made a pre-tracking habitat shift to low-structure areas where they remained for the duration of the study (i.e. Figure 11). Four individuals (Fish 11, 12, 16, 18) used a low-structure channel in Murphy Bay fish sanctuary during early tracking periods (late May to early June), but made late spring location shifts. Fish
11 and Fish 16 shifted their habitat utilization to high-structure areas where they remained for the duration of the study (Figure 12), while Fish 12 and Fish 18 continued to use the same habitat type in a distinctly different location (Figure 13).

Three largemouth bass (Fish 8, 10, 19) utilized both habitat types during the study. Fish 19 made two long-term location shifts that were also associated with changes in habitat utilization. Fish 19 made a pre-tracking habitat shift to a low structure area and a subsequent mid-study (July 9) habitat shift to a high-structure area. Despite these shifts, the radial displacements of Fish 19 were relatively consistent throughout the study (Appendix A). Fish 10 used high-structure habitats throughout the majority of the study prior to making a habitat shift to a low-structure area on August 5 (Figure14a). Despite spending the majority of the study in high-structure areas, there is a wide range in daily radial displacements for Fish 10 (Appendix A). Fish 8 made short-term diel-dependent habitat utilization shifts during four consecutive tracking days (July 3 – August 18). High-structure habitats were predominantly occupied during the day (75%) and dusk (100%) periods, but low-structure habitats were exclusively utilized during night and dawn periods (Figure 15b).

4.7 Protection

The proportion of location estimates, total areas, core areas and open season days are described for each largemouth bass in Table 7. Of the largemouth bass originally captured in Murphy Bay fish sanctuary, 62.1% of location estimates, 59.8% of total areas, 63.0% of core areas and 59.2% of open season days were within the protective boundaries on average (Table 7). Largemouth bass predominantly occupying high-structure habitats had 90.9% of location estimates, 87.6% of total areas, 91.9% of core areas and 93.0% of open season days within the protective boundaries on average (Table 7). Individuals that predominantly occupied low-
structure habitats had 21.8% of location estimates, 20.9% of total areas, 22.5% of core areas and 0% of open season days were within the protective boundaries on average (Table 7).

All five largemouth bass (Fish 1, 4, 11, 15, 16) that received full protection (100%) of their total and core utilization areas occupied high-structure habitats (i.e. Figures 9a, 10 and 12). The two largemouth bass (Fish 6, 21) that did not receive any protection during the tracking period made location shifts to an area outside Murphy Bay fish sanctuary prior to the onset of tracking. The remaining five largemouth bass (Fish 2, 10, 12, 18 and 19) were provided varying levels of partial protection for their total (8.8 to 67%) and core (16.4 to 98.2%) utilization areas. Fish 2 received a similar proportion of protection for its location estimates (8.6%) and total utilization area (8.8%); however, Fish 2 did not receive core area protection due to the limited time (two location estimates) spent in Murphy Bay fish sanctuary (Figure 16). Fish 10 and Fish 19 received partial protection due to long-term location shifts between sanctuary and non-sanctuary areas (Figure 14). A large proportion of the total utilization area (67.0%) for Fish 10 was protected by Murphy Bay fish sanctuary because the location shift occurred near the end of the study (Figure 14a). The increase in core utilization area protection (98.2%) was due to the greater spread of locations in the new location (larger radial displacement; Appendix A) that limited the establishment of a significant core area. On the other hand, the mid-study location shift of Fish 19 resulted in two similarly sized core areas: one inside and one outside Murphy Bay fish sanctuary (Figure 14b). Fish 18 was the only largemouth bass to receive greater protection of its total utilization area (42%) relative to the proportion of protected location estimates (27%; Table 7). This occurred because Fish 18 received protection near the beginning of the study when its daily radial displacement was greatest (Appendix A). This early utilization of Murphy Bay fish sanctuary was followed by a location shift beyond spatial protection (Figure 13b), where lower
daily radial displacements were observed for Fish 18. The utilization of a more localized area outside Murphy Bay fish sanctuary explains the limited protection of its core utilization area (16.4%; Figure 13b). Only 53.5% of the total utilization area for Fish 12 received protection, whereas the core area received nearly full protection (96%). This occurred because Fish 12 consistently occupied a core within Murphy Bay fish sanctuary, but also made many short-term movements to areas outside of its protection (Figure 13a).

Fish 18 did not receive any open season protection, despite having 42.0% protection of its total utilization area. Fish 2 received no open season protection because occupation of the sanctuary only occurred for two location estimates prior to returning to unprotected areas. Fish 12 was not given a percentage of open season protection because all movements between sanctuary and non-sanctuary areas were short-term and could not be extrapolated to days the fish was not tracked.
Table 3. A summary of all potential sources of variation in log_{10} directional minimum displacement per hour (MDPH; m/hr) for the minimal model of all fish (N = 529), low-structure (L-S; N = 253) and high-structure (H-S; N = 276). Minimal model descriptive statistics and the relationship between the source of variation and directional log_{10} MDPH (%) are also shown. Asterisk (*) indicates a significant predictor of variation (p ≤ 0.05).

<table>
<thead>
<tr>
<th>Model</th>
<th>Source of Variation</th>
<th>R² explanation (%)</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDPH, All</td>
<td>Water Depth</td>
<td>9.4</td>
<td>&lt; 0.001*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water Temperature</td>
<td>1.1</td>
<td>0.018*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Temperature</td>
<td>3.0</td>
<td>&lt; 0.001*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air pressure</td>
<td>&lt;1</td>
<td>0.452</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Solar Radiation</td>
<td>&lt;1</td>
<td>0.041*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind Direction</td>
<td>&lt;1</td>
<td>0.083</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Whole Model</td>
<td>16.5</td>
<td>17.166</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>MDPH, L-S</td>
<td>Water Temperature</td>
<td>&lt;1</td>
<td>0.165</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Temperature</td>
<td>2.5</td>
<td>0.013*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Solar Radiation</td>
<td>2.4</td>
<td>0.014*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind Speed</td>
<td>&lt;1</td>
<td>0.632</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind Direction</td>
<td>1.4</td>
<td>0.065</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Whole Model</td>
<td>10.8</td>
<td>5.989</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>MDPH, H-S</td>
<td>Water Temperature</td>
<td>&lt;1</td>
<td>0.117</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Temperature</td>
<td>3.2</td>
<td>0.003*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Pressure</td>
<td>&lt;1</td>
<td>0.208</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Solar Radiation</td>
<td>&lt;1</td>
<td>0.558</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind Direction</td>
<td>&lt;1</td>
<td>0.299</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Whole Model</td>
<td>7.0</td>
<td>4.077</td>
<td>0.001*</td>
</tr>
</tbody>
</table>
Table 4. The linear fit of total length (TL; mm) regressed against the log_{10} variable and p-value (p) of the linear fit for all telemetered largemouth bass in Lake Opinicon.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Linear Fit (TL vs. Log_{10} variable)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home Range (MCP)</td>
<td>2.1779924 + 0.005643*TL</td>
<td>0.341</td>
</tr>
<tr>
<td>Total Utilization Area (95% KUD)</td>
<td>3.1501386 + 0.0029526*TL</td>
<td>0.330</td>
</tr>
<tr>
<td>Core Utilization Area (50% KUD)</td>
<td>2.1296835 + 0.0036583*TL</td>
<td>0.248</td>
</tr>
<tr>
<td>Directional Displacement Rate</td>
<td>-0.683237 + 0.0037852*TL</td>
<td>0.160</td>
</tr>
<tr>
<td>Daily Displacement Rate</td>
<td>-0.873846 + 0.0047982*TL</td>
<td>0.126</td>
</tr>
<tr>
<td>Daily Radial Displacement</td>
<td>-0.098943 + 0.0047476*TL</td>
<td>0.139</td>
</tr>
</tbody>
</table>
Figure 2. Mean (± SEM) log₁₀ area (m²) of the minimum convex polygon (MCP) home ranges of largemouth bass (N = 11 for each group) compared between high-structure and low-structure habitats in Lake Opinicon.
Figure 3. Mean (± SEM) log<sub>10</sub> area (m<sup>2</sup>) of the 95% kernel utilization distributions (KUD) of largemouth bass (N = 11 for each group) compared between high-structure and low-structure habitats in Lake Opinicon. Asterisk (*) indicates a significant difference (p ≤ 0.05) between habitat types.
Figure 4. Mean (± SEM) log₁₀ area (m²) of the 50% kernel utilization distributions (KUD) of largemouth bass (N = 11 for each group) compared between high-structure and low-structure habitats in Lake Opinicon. Asterisk (*) indicates a significant difference (p ≤ 0.05) between habitat types.
Figure 5. Mean (mean of individual means ± SEM) log_{10} directional minimum displacement per hour (MDPH; m/hr) of largemouth bass (N = 11 for each group) compared between high-structure and low-structure habitats in Lake Opinicon. Asterisk (*) indicates a significant difference (p ≤ 0.05) between habitat types.
Figure 6. Mean (mean of individual means ± SEM) log$_{10}$ minimum displacement per hour (MDPH; m/hr) of largemouth bass (N = 11 for each group) compared between diel periods (night-dawn, day, dusk-night). Different letters indicate a significant difference (p ≤ 0.05) between diel periods.
Figure 7. Mean (mean of individual means ± SEM) $\log_{10}$ daily minimum displacement per hour (MDPH; m/hr) of largemouth bass (N = 11 for each group) compared between high-structure and low-structure habitats in Lake Opinicon. Asterisk (*) indicates a significant difference (p ≤ 0.05) between habitat types.
Figure 8. Mean (mean of individual means ± SEM) $\log_{10}$ radial displacement (m) of largemouth bass ($N = 11$ for each group) compared between high-structure and low-structure habitats in Lake Opinicon. Asterisk (*) indicates a significant difference ($p \leq 0.05$) between habitat types.
Table 5. The descriptive statistics for all analyses between locations (sanctuary and non-sanctuary), including degrees of freedom (DF), test statistic (independent t-test = t; mixed-model ANOVA = F). All variables were log\(_{10}\) transformed prior to analyses. Asterisk (*) denotes a significant difference for that analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Analysis</th>
<th>DF</th>
<th>Test statistic</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home Range (MCP)</td>
<td>Independent t-test</td>
<td>20</td>
<td>1.505</td>
<td>0.148</td>
</tr>
<tr>
<td>Total Utilization Area (95% KUD)</td>
<td>Independent t-test</td>
<td>20</td>
<td>0.775</td>
<td>0.447</td>
</tr>
<tr>
<td>Core Utilization Area (50% KUD)</td>
<td>Independent t-test</td>
<td>20</td>
<td>0.163</td>
<td>0.872</td>
</tr>
<tr>
<td>Directional Displacement Rate</td>
<td>Mixed-model ANOVA</td>
<td>1.20</td>
<td>0.160</td>
<td>0.693</td>
</tr>
<tr>
<td>Diel Directional Displacement Rate</td>
<td>Mixed-model ANOVA</td>
<td>2.40</td>
<td>7.097</td>
<td>0.002*</td>
</tr>
<tr>
<td>Interaction (Diel*Location)</td>
<td>Mixed-model ANOVA</td>
<td>2.40</td>
<td>0.118</td>
<td>0.889</td>
</tr>
<tr>
<td>Daily Displacement Rate</td>
<td>Independent t-test</td>
<td>20</td>
<td>-1.054</td>
<td>0.304</td>
</tr>
<tr>
<td>Daily Radial Displacement</td>
<td>Independent t-test</td>
<td>20</td>
<td>-0.441</td>
<td>0.664</td>
</tr>
</tbody>
</table>
Table 6. The habitat use behaviour (HB), its specific description and the number of days it was observed (HB/Total days) are described with respect to the predominantly occupied habitat type of telemetered largemouth bass in Lake Opinicon. For example, Fish 10 utilized a high-structure habitat for 3.5 of 5 total tracking days.

<table>
<thead>
<tr>
<th>FISH</th>
<th>Habitat Type</th>
<th>Habitat Use Behaviour</th>
<th>Specific Description</th>
<th>HB/Total Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High-structure</td>
<td>Exclusive</td>
<td>Diel Location Shift</td>
<td>3/6</td>
</tr>
<tr>
<td>2</td>
<td>Low-structure</td>
<td>Exclusive</td>
<td>Pre-tracking Shift</td>
<td>5/5</td>
</tr>
<tr>
<td>3</td>
<td>High-structure</td>
<td>Exclusive</td>
<td></td>
<td>6/6</td>
</tr>
<tr>
<td>4</td>
<td>High-structure</td>
<td>Exclusive</td>
<td></td>
<td>6/6</td>
</tr>
<tr>
<td>5</td>
<td>Low-structure</td>
<td>Exclusive</td>
<td>Pre-tracking Shift</td>
<td>6/6</td>
</tr>
<tr>
<td>6</td>
<td>Low-structure</td>
<td>Exclusive</td>
<td>Pre-tracking Shift</td>
<td>6/6</td>
</tr>
<tr>
<td>8</td>
<td>High-structure</td>
<td>Flexible: Diel</td>
<td>Diel Habitat Shift</td>
<td>4/6</td>
</tr>
<tr>
<td>9</td>
<td>Low-structure</td>
<td>Exclusive</td>
<td>Pre-tracking Shift</td>
<td>6/6</td>
</tr>
<tr>
<td>10</td>
<td>High-structure</td>
<td>Flexible: Long-term</td>
<td>Habitat Shift</td>
<td>3.5/5</td>
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<tr>
<td>11</td>
<td>High-structure</td>
<td>Exclusive</td>
<td>Spring Low-structure</td>
<td>5/6</td>
</tr>
<tr>
<td>12</td>
<td>Low-structure</td>
<td>Exclusive</td>
<td>Spring Shift</td>
<td>6/6</td>
</tr>
<tr>
<td>13</td>
<td>Low-structure</td>
<td>Exclusive</td>
<td>Pre-tracking Shift</td>
<td>5/5</td>
</tr>
<tr>
<td>14</td>
<td>High-structure</td>
<td>Exclusive</td>
<td></td>
<td>6/6</td>
</tr>
<tr>
<td>15</td>
<td>High-structure</td>
<td>Exclusive</td>
<td></td>
<td>6/6</td>
</tr>
<tr>
<td>16</td>
<td>High-structure</td>
<td>Exclusive</td>
<td>Spring Low-structure</td>
<td>5/6</td>
</tr>
<tr>
<td>17</td>
<td>High-structure</td>
<td>Exclusive</td>
<td></td>
<td>6/6</td>
</tr>
<tr>
<td>18</td>
<td>Low-structure</td>
<td>Exclusive</td>
<td>Spring Shift</td>
<td>5/5</td>
</tr>
<tr>
<td>19</td>
<td>High-structure</td>
<td>Flexible: Long-term</td>
<td>Pre-tracking Shift &amp; Habitat Shift</td>
<td>3.5/6</td>
</tr>
<tr>
<td>20</td>
<td>Low-structure</td>
<td>Exclusive</td>
<td>Pre-tracking Shift</td>
<td>6/6</td>
</tr>
<tr>
<td>21</td>
<td>Low-structure</td>
<td>Exclusive</td>
<td>Pre-tracking Shift</td>
<td>6/6</td>
</tr>
<tr>
<td>22</td>
<td>Low-structure</td>
<td>Exclusive</td>
<td>Pre-tracking Shift</td>
<td>6/6</td>
</tr>
<tr>
<td>23</td>
<td>Low-structure</td>
<td>Exclusive</td>
<td>Pre-tracking Shift</td>
<td>6/6</td>
</tr>
</tbody>
</table>
Figure 9. A map showing the location estimates, minimum convex polygon (MCP), kernel density estimate (95% KDE), 95% and 50% kernel utilization distribution (95% and 50% contours) for two largemouth bass (a) Fish 4 and (b) Fish 14 that remained exclusively in high-
structure habitats of Lake Opinicon. Dashed line represents the Murphy Bay fish sanctuary boundary.

**Figure 10.** A map showing the location estimates, minimum convex polygon (MCP), kernel density estimate (95% KDE), 95% kernel utilization distribution (95% contour) and 50% kernel utilization distribution (50% contour) for Fish 1 in Lake Opinicon. Dashed line represents the Murphy Bay fish sanctuary boundary.
Figure 11. A map showing the location estimates, minimum convex polygon (MCP), kernel density estimate (95% KDE), 95% kernel utilization distribution (95% contour) and 50% kernel utilization distribution (50% contour) for two largemouth bass (a) Fish 5 and (b) Fish 13 that remained exclusively in low-structure habitats of Lake Opinicon.
Figure 12. A map showing the location estimates, minimum convex polygon (MCP), kernel density estimate (95% KDE), 95% and 50% kernel utilization distribution (95% and 50% contours) for two largemouth bass (a) Fish 11 and (b) Fish 16 that made late spring habitat shifts in Lake Opinicon. Dashed line represents the Murphy Bay fish sanctuary boundary.
Figure 13. A map showing the location estimates, minimum convex polygon (MCP), kernel density estimate (95% KDE), 95% and 50% kernel utilization distribution (95% and 50% contours) for two largemouth bass (a) Fish 12 and (b) Fish 18 that made late spring location shifts in Lake Opinicon. Dashed line represents the Murphy Bay fish sanctuary boundary.
Figure 14. A map showing the location estimates, minimum convex polygon (MCP), kernel density estimate (95% KDE), 95% and 50% kernel utilization distribution (95% and 50% contours) for two largemouth bass (a) Fish 10 and (b) Fish 19 that made long-term habitat shifts in Lake Opinicon. Dashed line represents the Murphy Bay fish sanctuary boundary.
Figure 15. A map showing the (a) location estimates, minimum convex polygon (MCP), kernel density estimate (95% KDE), 95% kernel utilization distribution (95% contour) and 50% kernel utilization distribution (50% contour) and (b) diel-specific locations for Fish 8 in Lake Opinicon.
Table 7. The percentage of location estimates, total areas (95% KUD), core areas (50% KUD) and open season days within the boundaries of Murphy Bay fish sanctuary. Only largemouth bass originally captured within the Murphy Bay fish sanctuary are shown.

<table>
<thead>
<tr>
<th>Fish</th>
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<th>95% KUD</th>
<th>50% KUD</th>
<th>Open Season</th>
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</tr>
<tr>
<td>2</td>
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</tr>
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</tr>
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<td>-</td>
</tr>
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<td>100%</td>
</tr>
<tr>
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<td>High-structure</td>
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<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>18</td>
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<td>16.4%</td>
<td>0%</td>
</tr>
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<td>19</td>
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<td>45.5%</td>
<td>76.5%</td>
</tr>
<tr>
<td>21</td>
<td>Low-structure</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

| High-structure Mean | 90.9% | 87.6% | 91.9% | 93.0% |
| Low-structure Mean  | 21.8% | 20.9% | 22.5% | 0%    |
| All Fish Mean       | 62.1% | 59.8% | 63.0% | 59.2% |
Figure 16. A map showing the location estimates, minimum convex polygon (MCP), kernel density estimate (95% KDE), 95% kernel utilization distribution (95% contour) and 50% kernel utilization distribution (50% contour) for Fish 2 in Lake Opinicon. Dashed line represents the Murphy Bay fish sanctuary boundary.
Chapter 5

Discussion

In Lake Opinicon, largemouth bass behaviour was correlated with the structural complexity of the habitats they occupied. The utilization areas, displacement rates and radial displacements were all greater for individuals using low-structure habitats compared to those using high-structure habitats. This behaviour suggests that habitat distribution and availability within a sanctuary will play a role in the dispersal of largemouth bass between protected and unprotected areas.

The evaluation of year-round bass sanctuaries involves two primary questions: do sanctuaries protect bass and what role does this protection have on the bass fishery? However, the evaluation of year-round sanctuaries has the additional challenge of evaluating two discrete forms of protection that are offered by a single regulation. In other words, a year-round bass sanctuary must be designated in a physical space that provides angling protection for nest-guarding males during the reproductive period (closed season) and harvest protection for adults during the open season. Therefore, the overall effectiveness of year-round bass sanctuaries will be a function of the success of these two forms of protection. This approach will help to determine the overall effectiveness of year-round sanctuaries, as well as the role of each type of protection. If the current regulations are not effective, this method of evaluation will help to determine the appropriate re-designation.

Previous literature indicates that sanctuary protection during the closed season can offer individual (greater reproductive success) and fishery (catch rates) benefits for bass (Sztramko
1985; Suski et al. 2002). On the other hand, there is limited knowledge of the protection offered during the open season and how it will impact the fishery.

5.1 Largemouth Bass Behaviour: Protection in a Physical Space

5.1.1 Largemouth Bass Behaviour: The Role of Sanctuary Boundaries

The designated boundaries of a fish sanctuary are not likely to restrict the behaviour of largemouth bass unless they follow a physical or biophysical barrier. Therefore, we can assume that largemouth bass are able to move freely across sanctuary boundaries that are not associated with these barriers. Alternatively, the designated boundaries do help determine the location, size and shape of fish sanctuaries and subsequently the availability and distribution of resources that often influence how a fish will use space (Bartholomew et al. 2008; Pelletier et al. 2008). The relationship between APAs and resource availability has been suggested to influence protection potential (Babcock et al. 2005). In this study, Murphy Bay fish sanctuary provided 87.6% protection of total utilization areas for largemouth bass using high-structure areas and only 20.9% for those using low-structure areas.

There are two primary factors that likely contribute to the habitat-specific protection offered by Murphy Bay fish sanctuary. Firstly, the fish sanctuary is located in Murphy Bay, which is in an area of ‘drowned land’ in Lake Opinicon that has a large number of submerged and emergent stumps. The shape of Murphy Bay and the presence of an island near its mouth result in a large proportion of the sanctuary to be in shallow nearshore areas with high vegetation densities and coarse woody structure. Alternatively, low-structure habitats are limited to the mouth of Murphy Bay and these locations are mostly located immediately adjacent to the sanctuary boundary.
The proximity of habitats to a sanctuary boundary will influence the likelihood of a fish moving between protected and unprotected areas. In Lake Opinicon, the proximity of low-structure habitats to the sanctuary boundary is further compounded by the behaviour of largemouth bass in those habitats. In low-structure areas, largemouth bass tend to have larger utilization areas and greater displacements resulting in an increased likelihood of spillover into a fishery (Zeller and Russ 1998; Kramer and Chapman 1999). Spillover, or dispersal of individuals into a fishery, is considered to be an integral component of successful resource-based APAs because of the potential to replenish harvested fish (Halpern 2003; Sale et al. 2005).

The shape and size of an APA is often evaluated using an edge: area ratio that measures the proportion of sanctuary perimeter (directly adjacent to the fishery) relative to the total sanctuary area (Kramer and Chapman 1999). In the case of Murphy Bay fish sanctuary, the location is also important because the three land-locked edges result in a limited interface with the fishery (i.e. low edge: area ratio). Therefore, the limited perimeter exposure to a fishery likely reduces the potential of movement between protected and unprotected areas, but may help to simplify management, enforcement and boundary identification by anglers. The land-locked location of Murphy Bay fish sanctuary also limits the possibility of increasing its edge: area ratio because any potential increase in exposed perimeter would result in an equal or greater increase in area (i.e. reducing the edge: area ratio further).

5.1.2 Largemouth Bass Behaviour: Open Season Sanctuary Protection

We have demonstrated that the open season sanctuary protection is dependent on the behavioural tendencies of largemouth bass within different habitat types. In addition, the level of open season protection is also dependent on the timing (during the open or closed season) and duration (short- or long-term) of these habitat use behaviours, as well as whether they occur
internally, externally or across sanctuary boundaries. There were many different individual habitat-use behaviours observed for largemouth bass in Lake Opinicon and were responsible for the level of protection that an individual received from Murphy Bay fish sanctuary.

All largemouth bass were captured and released in high-structure areas of Lake Opinicon. More than half (12 of 23) of these individuals made spring (closed fishing season) relocations to low-structure areas where almost all (11 of 12) remained for the duration of the study. Many largemouth bass made long-term and short-term location and habitat use changes throughout the open and closed fishing seasons. For example, Fish 1 made routine diel-dependent movements between two locations with similar habitat types. Fish 8 made diel-dependent movements between a high-structure area (near a fallen tree) along the shoreline during the day and deeper areas with lower structural complexity during low light levels (night and dawn).

Twelve individuals began the study in the high-structure habitats of Lake Opinicon’s Murphy Bay fish sanctuary. Five of these fish remained in high-structure habitats, four individuals moved to low-structure areas outside of Murphy Bay fish sanctuary during the spring where they remained throughout the study and two largemouth bass made open season changes in habitat use. Fish 19 returned (July 9) during the open season to receive partial sanctuary protection. Fish 10 remained in high-structure habitats of Murphy Bay fish sanctuary and relocated to a low-structure unprotected area near the end of the study (August 5). Despite the difference in timing and direction of movement, Fish 10 and Fish 19 each received the same partial protection (~13 days) during the open season.

Largemouth bass also made short-term location and habitat use changes that resulted in partial protection. Fish 2 made a temporary (two location estimates) return to Murphy Bay fish sanctuary during the open season following a long-term spring relocation. On the other hand, Fish
12 received a high level of core area protection from Murphy Bay fish sanctuary despite numerous short-term forays into non-sanctuary areas. This is due to the fact that Fish 12 routinely returned to a protected core area inside the boundaries of Murphy Bay sanctuary. The proximity of Fish 12’s core area to the sanctuary boundary illustrates the greater potential of moving into unprotected areas, especially because Fish 12 predominantly occupied low-structure habitats.

The variability in protection offered by Murphy Bay fish sanctuary illustrates the importance of the timing and duration of behaviours for the evaluation of sanctuary regulations. Understanding when behaviours occur and how long they are likely to last is a critical consideration. The underlying causes of largemouth bass behaviour can also be an essential component for determining the usefulness of sanctuary protection in bass management. Determining the specific causes of largemouth bass behaviour was beyond the scope of this study, although we present a number of potential biotic and abiotic factors that are known to influence largemouth bass movement and use of space.

5.1.3 Largemouth Bass Behaviour: Potential Causes

Habitat influences the availability and distribution of prey resources (Crowder and Cooper 1982), as well as the foraging behaviours typically used by largemouth bass (Savino and Stein 1982; Ahrenstorff et al. 2009). In low-structure areas, largemouth bass use a cruising foraging method that involves active hunting for specific prey species (Savino and Stein 1982). Hunting for specific prey could result in the need for a greater foraging arena. Due to the visual nature of largemouth bass predation, an increase in habitat structure reduces the efficiency of selective hunting. Higher structural density provides more potential hiding locations for prey (Gotceitas and Colgan 1987; Gotceitas and Colgan 1989), as well as reduces the distance at which they can be visually located (Crowl 1989). Therefore, despite the greater prey densities often
found in high-structure habitats, the reduction in prey vulnerability limits active foraging efficiency (Gotceitas and Colgan 1989; Savino and Stein 1989; Bettoli et al. 1992). In these areas, largemouth bass minimize energetically inefficient search and pursuit behaviours by using structure as a place to ambush prey (Selch and Chipps 2007). Also known as sit-and-wait foraging, ambush predation tends to occur in a more localized area with dense vegetation or coarse woody structure (Savino and Stein 1982). Although largemouth bass are generally piscivorous, they have been known to use a more generalist foraging strategy in nearshore high-structured environments that offer a wider range of prey species, including benthic invertebrates and amphibians (Anderson 1984). The opportunistic consumption of a diverse range of prey may enable largemouth bass to have greater foraging opportunities within a localized area. Therefore, it is possible that typical habitat-specific foraging tactics used by largemouth bass may explain the behaviours observed in Lake Opinicon. Furthermore, Lake Opinicon largemouth bass had greater activity during crepuscular and nocturnal periods. The greater activity of largemouth bass has been suggested to be a result of greater foraging success in low light levels due to a reduced ability of some prey species to detect predators in these conditions (Howick and O'Brien 1983). This behaviour may provide additional support for a prey-based interpretation of largemouth bass behaviour.

Environmental factors, as well as reproductive activities (Hanson et al. 2008a), vegetation densities and prey distributions (Gotceitas and Colgan 1989; Savino and Stein 1989; Bettoli et al. 1992) all result in seasonal changes that can influence largemouth bass behaviour and may explain the spring relocation of many individuals from high-structure to low-structure habitats. These seasonal changes specifically refer to those that occur in the spring because it is the most relevant to bass sanctuary protection.
In addition to spring changes in the environment, there are many variables such as water temperature, dissolved oxygen and water clarity that can influence largemouth bass behaviour (Hanson et al. 2007a; Hasler et al. 2009a). These environmental characteristics are important to consider; however, annual variations in many of these factors can cause unpredictable changes that make them difficult to use for management purposes (Diana 1995). Due to these limitations, environmental factors will not be discussed any further.

5.1.4 Largemouth Bass Behaviour: Translation into Fishery Benefits

A resource-based APA is built on the assumption that protection will result in a build-up of individuals within its boundaries and eventually spillover into the fishery (Abesamis et al. 2006). Therefore, sanctuary protection that results in greater spillover of individuals into the fishery would be the most effective. This underlying assumption of APAs is an example of density-dependent spillover, but there are also many density-independent factors that may result in the movement of fish into the fishery.

Resource availability (i.e. prey) is an example of a potential cause of density-dependent spillover. Largemouth bass individuals may alter their behaviour when conspecific competition for resources within the sanctuary becomes too great (Schindler et al. 1997). In a resource-based scenario, the greater densities of largemouth bass would build up within a sanctuary because of open season protection (from harvest) or closed season protection (from the incidental angling of nesting males). An increase in density relies on greater reproductive success and subsequent recruitment that occurs as a result of reduced angling of nesting males in previous years.

Understanding the causes of behaviour is important because it helps determine the importance of sanctuary protection to the fishery. Density-dependent spillover suggests that there is a build up of individuals in the sanctuary and that this protection ultimately benefits the fishery.
For example, largemouth bass only using Murphy Bay fish sanctuary during the spring may always be exposed to the open season fishery and spillover of these individuals would not be relevant to a discussion of how sanctuary protection translates into fishery benefits. This also emphasizes the importance of observing behaviours over multiple years to determine if annual trends exist. If there is greater spring use of Murphy Bay fish sanctuary, then it may indicate that open season protection is not necessary and a re-designation of the current regulations is required.

5.2 Impact of Potential Sanctuary Regulation Changes

5.2.1 Closed Season Sanctuary Protection: Incidental Angling of Nesting Males

Although traditional season regulations limit the targeting of nesting bass, seasonal sanctuaries have the greatest potential to eliminate incidental angling that occurs when other game species are targeted. Suski et al. (2002) demonstrated greater reproductive success for nesting bass, but this was done for voluntary (non-designated) sanctuaries that were only temporarily in place. Sztramko (1985) observed greater catch rates of smallmouth bass in years when a seasonal sanctuary was used. This study emphasizes the potential for fishery benefits due to a seasonal sanctuary, but it does focus on smallmouth bass in Lake Erie (large lake). Although these studies indicate the potential of closed season sanctuary protection, it is necessary to investigate a designated bass sanctuary that focuses on the protection of largemouth bass.

Closed season sanctuary protection was not specifically investigated during this study, although a shoreline snorkel survey was done in Lake Opinicon during the spring of 2008. The survey focused on Murphy Bay fish sanctuary, as well as a sample of non-sanctuary reference sites. There was an estimated 11 successful (presence of swim-up fry) largemouth bass nests per hectare in Murphy Bay fish sanctuary compared to eight nests per hectare for a random sample of sites in non-sanctuary areas. It is important to note that a shoreline survey of Murphy Bay fish
sanctuary may have underestimated the density of successful largemouth bass nests due to its relatively shallow depth profile. In many cases, nest-guarding males were observed in the offshore areas of Murphy Bay fish sanctuary that were not included in the survey. This was not the case in many of the non-sanctuary reference sites, where areas away from the shoreline did not provide suitable nesting habitats. Due to the greater observed densities and potential of underestimation, this survey suggests that Murphy Bay fish sanctuary may have greater densities of successful largemouth bass nests. These preliminary results do not provide definitive conclusions on overall densities in Lake Opinicon or that the observed differences were a result of incidental angling. A more thorough investigation of closed season sanctuary protection needs to account for unsuccessful nests (to incorporate angling), as well as survey the entire area of Murphy Bay fish sanctuary with suitable spawning habitats.

The success of a closed season sanctuary would also depend on a number of biological and environmental factors that act as pre- and post-nesting recruitment bottlenecks (Rogers and Allen 2009), as well as the lake-to-lake level of incidental closed-season angling pressure (Philipp et al. 1997). To determine the full potential of seasonal bass sanctuary protection, further research will need to determine how the greater individual reproductive success shown by Suski et al. (2002) can influence population-level recruitment and overall fishery productivity (Siepker et al. 2007).

5.2.2 Open Season Sanctuary Protection: Angler Harvest

Although many individuals relocated to low-structure areas during the spring, there were also a number of largemouth bass remaining in high-structure habitats throughout the study. Therefore, the removal of open season sanctuary protection would expose a number of individuals to the fishery. To determine the level of fishery benefit it is necessary to understand
the relationship between angler harvest mortality and the population demographic changes that result from open season protection.

Monitoring the locations of largemouth bass produced an indirect measure of harvest mortality in Lake Opinicon. Of the 18 individuals that were exposed to the fishery, two individuals were removed as a result of angler harvest and it is possible that the unknown cause of another removal was due to angler harvest as well. It should be noted that posters were distributed to local cottagers, residents, marinas and businesses to encourage the live-release of any fish with transmitters and therefore it is not clear whether this influenced the level of angler harvest. Assuming that the posters had no effect on the harvest mortality rate and the unknown removal was due to angler harvest, there were three (of 18) largemouth bass removed during a 55 day period of the open season. Two individuals were only exposed to the fishery for 13 days each and therefore had a more limited time when they would be susceptible to harvest. Although more information would be required to calculate accurate angler harvest rates, these results emphasize the importance of considering harvest mortality during the evaluation of open season sanctuary protection.

5.2.3 Year-round Sanctuary Protection: Modification of Existing Boundaries

If we assume the individuals used in this study are representative of the Lake Opinicon largemouth bass population, low-structure and high-structure habitats appear to be used relatively equally during the open fishing season. This suggests that a similar proportion of habitat area should be included within a sanctuary to ensure maximum protection of bass. A size increase would result in a greater potential to protect bass in the low-structure habitats during the open season; however, to provide equal protection of low-structure areas, the size increase would need to reflect the almost twofold increase in area utilization of these fish. An increase in the size of
the sanctuary is important to consider because the majority of opposition to APAs is usually related to a loss of fishing opportunities resulting from a reduction in fishery area (Sant 1996).

5.3 Non-biological Considerations: Socioeconomic Importance

The final consideration for the importance of Murphy Bay fish sanctuary focuses on the benefits to local communities. The waterbody-specific nature of spatial regulations can result in a unique socioeconomic connection with nearby communities. Like other bass sanctuaries along the Rideau Canal, the longstanding presence and historic tradition of Murphy Bay fish sanctuary has been deeply engrained into local communities. The sense of social attachment is evident through the strong local support, which includes the maintenance of boundary signage and a form of ‘neighbourhood watch’ that assures no fishing occurs inside the sanctuary. The presence of year-round sanctuaries often invokes a community stewardship for local resource conservation that may be otherwise absent. In many cases the sanctuaries can have a local economic impact by providing a marketing booster for fishing guides, campgrounds, cottage rentals and other local tourism activities.

5.4 The Future of Bass Sanctuaries: Management Implications

This study has demonstrated the importance of understanding largemouth bass behaviour for the evaluation of sanctuary performance. The behaviour of largemouth bass in Lake Opinicon may suggest that there is a need to modify current bass sanctuary regulations. This study presents a behavioural perspective of the potential for a fish sanctuary to provide protection of largemouth bass in physical space. To determine whether a high level of closed season protection and low level of open season protection are enough to maintain or alter the current designation of year-round bass sanctuaries, further research will need to investigate the specific causes of the
largemouth bass behaviours observed in Lake Opinicon. This will provide a greater understanding of how sanctuary designations will impact the fishery.

Based on this behavioural perspective and previous research we have outlined a number of potential scenarios for the future of Ontario’s bass sanctuaries, but also recognize this is only one in a series of studies that will be necessary to provide a sound biological evaluation. Further research should identify the role of closed and open season sanctuary protection in providing overall fishery benefits. Therefore, we recommend the maintenance of current year-round sanctuary protection until there is enough research to make definitive conclusions on the future of Ontario’s bass sanctuaries.
Chapter 6

Conclusions and Summary

Year-round bass sanctuaries are designated areas where all fishing is prohibited throughout the entire year. In these simple terms, year-round bass sanctuaries may seem like a relatively straightforward fisheries management regulation; however, they attempt to provide two discrete seasonal forms of protection using a single regulation. On the other hand, traditional bass management often uses multiple regulatory measures to provide protection during the open and closed fishing seasons. Specifically, year-round sanctuary protection during the closed season aims to prevent targeted (illegal) or incidental angling of nest-guarding largemouth bass, as well as prevent angler harvest during the open fishing season. The underlying complexity of these regulations may be a contributing factor in the lack of biological research evaluating their effectiveness.

The results of this study demonstrate that Murphy Bay fish sanctuary provides open season protection for largemouth bass in Lake Opinicon. There was a full range of sanctuary protection offered by Murphy Bay fish sanctuary that was dependent on the timing, duration, and location (internal, external or transboundary) of habitat use behaviours. The observed behaviour of largemouth bass in Lake Opinicon appears to be correlated with the structural complexity of the habitats they occupy. Area utilization, displacement rates and radial displacement were all greater in low-structure habitats relative to high-structure habitats. In Lake Opinicon, many largemouth bass made spring relocations from high-structure to low-structure areas. This resulted in open season protection that was limited to largemouth bass remaining in high-structure areas.
In this study, largemouth bass behaviour in Lake Opinicon was examined to provide a general understanding of the potential for open season sanctuary protection. It will be necessary to build on the results of this study to determine how the relationship between sanctuary protection and largemouth bass behaviour is able to translate into fishery benefits. Therefore, we recognize that physical protection is only the first stage in the evaluation of bass sanctuaries.

Based on the behaviour of largemouth bass in Lake Opinicon, it appears that open season sanctuary protection is limited and it will be important to determine how limited open season protection benefits overall bass management. Although a behavioural interpretation may suggest that its usefulness is questionable, it will be necessary to estimate largemouth bass harvest mortality, as well as evaluate how a reduction in harvest mortality (due to sanctuary protection) will result in greater adult densities within a sanctuary.

Determining the cause of a reserve effect such as an increase in the density of largemouth bass may be challenging in a long-established bass sanctuary. Firstly, the presence of year-round sanctuary protection during the past seven decades results in a lack of baseline knowledge for comparison that make it difficult to determine if measured reserve effects are the result of sanctuary protection or merely due to a location effect (i.e. the sanctuary is placed in a more productive area). In addition, year-round sanctuaries provide open and closed season protection that will ultimately have similar measured reserve effects. For example, greater densities of largemouth bass inside a year-round sanctuary may be due to increased protection of adults from angler harvest, but may also be the result of angling protection of nest-guarding males in previous years. Sanctuary protection has been known to result in greater reproductive success of bass (Suski et al. 2002). Although it still remains unclear whether an increase in reproductive success has an impact on the overall recruitment of largemouth bass, there is the potential for it to result
in greater densities of adult largemouth bass. It will be important to determine the specific contribution of both closed and open season sanctuary protection.

Density-dependent spillover of reserve effects (i.e. greater densities) would be an obvious indication that sanctuary protection is important for a bass fishery. Regardless of their specific cause, reserve effects are only beneficial to the fishery if significant spillover occurs. It will be necessary to determine the causes of observed behaviours to understand whether spillover is due to the protection offered by Murphy Bay fish sanctuary or some other factors.

There are three potential scenarios for the future of bass sanctuary regulations in Ontario. Year-round bass sanctuaries should be maintained if protection during the open and closed fishing seasons contributes significantly to the fishery. If closed season protection offers the only significant contributions to the bass fishery, then seasonal bass sanctuaries may be sufficient regulations. If open or closed season sanctuary protection does not significantly improve the overall bass fishery, then no sanctuaries should be used. The abovementioned scenarios are theoretical and therefore require further examination. Based on the need for additional research, we recommend that the current year-round designation of bass sanctuaries should be maintained until there is sufficient empirical rationale for the basis of sound management decisions.

There are still many questions that need to be answered before definitive conclusions can be made on the fate of Ontario’s bass sanctuaries. The specific focus of this research makes it difficult to generalize about the overall performance of year-round bass sanctuaries, but it does provide an important biological perspective of bass sanctuary protection that will be important in future management decisions. To our knowledge, this is the first empirical evidence related to an OMNR designated year-round bass sanctuary in more than 60 years. This study does not solve the
ongoing debate regarding the usefulness of bass sanctuaries; however, it does represent a progressive step towards the making of a biologically sound management decision.

6.1 Summary

1. In Lake Opinicon, largemouth bass behaviour is correlated with the structural complexity of the habitats they occupy.

2. Largemouth bass exhibited variable individual habitat use behaviours including habitat specificity, as well as long-term and short-term habitat shifts.

3. Murphy Bay fish sanctuary provided open season protection from angler harvest for largemouth bass.

4. The level of protection (from none to full) depended on the timing, duration and location of habitat use behaviours.

5. Future bass sanctuary research should include multi-year behavioural studies, examine the role of closed season sanctuary protection and the fishery benefits of open season sanctuary protection.

6. The current year-round designation of bass sanctuaries should be maintained until there is sufficient empirical rationale for the basis of sound management decisions.
Literature Cited


biotelemetry studies and laboratory experiments. Physiological and Biochemical Zoology 82(2):143-152.


Appendix A  
Data Summary Tables

Table 8. The habitat type, minimum convex polygon (MCP; m²), total area (95% KUD; m²), core area (50% KUD; m²), and aspect ratio (AR) for telemetered largemouth bass in Lake Opinicon.

<table>
<thead>
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<th>Fish</th>
<th>Habitat Type</th>
<th>MCP</th>
<th>95%</th>
<th>50%</th>
<th>AR</th>
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Table 9. The mean total, night-dawn, day and dusk-night minimum displacement per hour (MDPH; m/hr) for telemetered largemouth bass in Lake Opinicon.

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|                |                  |      |            |      |            |
| High-structure Mean | 11.5 | 13.6 | 7.6        | 16.7 |
| Low-structure Mean   | 22.9 | 34.3 | 16.9       | 23.9 |
| All Fish Mean        | 17.2 | 24.0 | 12.3       | 20.3 |
Table 10. The mean daily minimum displacement per hour (MDPH; m/hr) for telemetered largemouth bass in Lake Opinicon. Missing values are due to nesting males (Nesting), long-term location shift (Shift), angler harvest (Harvest) or insufficient location estimates (-). The days represent 24-hour tracking periods by location (i.e. not all fish were tracked on the same day; Sanctuary Day 1 = June 11 and Non-sanctuary Day 1 = June 16).

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**High-structure Total Mean** 11.1  
**Low-structure Total Mean** 20.9  
**All Fish Total Mean** 16.0
Table 11. The daily radial displacements (m) for telemetered largemouth bass in Lake Opinicon. Missing values are due to nesting males (Nesting), long-term location shift (Shift), angler harvest (Harvest) or insufficient location estimates (-). The days represent 24-hour tracking periods by location (i.e. not all fish were tracked on the same day; Sanctuary Day 1 = June 11 and Non-sanctuary Day 1 = June 16).

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<td>63.2</td>
</tr>
<tr>
<td>Low-structure</td>
<td>119.2</td>
</tr>
<tr>
<td>All Fish</td>
<td>91.2</td>
</tr>
</tbody>
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